APPENDIX A

QUESTIONNAIRES FOR SURVEY OF HIGHWAY AGENCIES

Version 1 -- for state highway agencies that use AASHTO ISD policy without modification

Version 2 -- for state highway agencies that have modified AASHTO ISD policy

Version 3 -- for local highway agencies (in both urban and rural areas)

SURVEY ON CURRENT POLICIES FOR INTERSECTION SIGHT DISTANCE DESIGN

The following survey on intersection sight distance (ISD) is being conducted as part of the National Cooperative Highway Research Program (NCHRP), which is sponsored by the American Association of State Highway and Transportation Officials (AASHTO) in cooperation with the Federal Highway Administration (FHWA). Your responses to a few questions concerning your agency's geometric design policies for ISD would be appreciated.

1. The AASHTO Green Book presents ISD policies for six cases identified below. Please indicate what policy your agency uses for each case (use codes 1 through 5 given below):

   Case I (No Control) __________
   Case II (YIELD Control) __________
   Case IIIA (STOP Control--Crossing Maneuver) __________
   Case IIIB (STOP Control--Left-Turn Maneuver) __________
   Case IIIC (STOP Control--Right-Turn Maneuver) __________
   Case IV (Signal Control) __________

   1 = Use policy in 1990 AASHTO Green Book
   2 = Use policy in 1984 AASHTO Green Book
   3 = Use State policy which differs from AASHTO
   4 = Do not consider this case
   5 = Other (specify)

   We would appreciate receiving a copy of your state's ISD design policy, if it differs from AASHTO.

2. What is your agency's assessment of the suitability of the current AASHTO ISD criteria for each case (use codes 1 through 4 given below):

   Case I (No Control) __________
   Case II (YIELD Control) __________
   Case IIIA (STOP Control--Crossing Maneuver) __________
   Case IIIB (STOP Control--Left-Turn Maneuver) __________
   Case IIIC (STOP Control--Right-Turn Maneuver) __________
   Case IV (Signal Control) __________

   1 = Sight distance required by AASHTO is longer than should be required for safe completion of the intended maneuver
   2 = Sight distance required by AASHTO is shorter than should be required for safe completion of the intended maneuver
   3 = Sight distance required by AASHTO is about right
   4 = No opinion or don't know

3. If your agency has established ISD criteria that differ from the AASHTO Green Book, do your agency's criteria apply to (check appropriate response):

_____ State-funded projects only
_____ Both Federal and State-funded projects
_____ Not applicable

4. Does your agency consider all six cases to be necessary for ISD design. _____ YES _____ NO

Please identify any of the six cases that, in your opinion could be dropped or combined with other cases. Your comments about why these cases could be dropped would be appreciated.

5. Does your agency have a separate ISD design policy for rehabilitation (RRR) projects that differs from the design policy for new construction/reconstruction projects? _____ YES _____ NO

If YES, we would appreciate receiving a copy of that design policy.

6. Do your agency's ISD criteria vary by functional class? In other words, do you have different ISD values that apply to different functional classes of road (arterials, collectors, local streets, etc.)? _____YES _____ NO

7. Does your agency request or utilize design exceptions for ISD when it is impractical to provide the full ISD required by the AASHTO Green Book or your agency's design policy? _____ YES _____ NO

What geometric design or traffic control modifications are considered by your agency at intersections where the full ISD required by AASHTO or State policies cannot be provided (please describe):

8. Some highway agencies have suggested the need to modify some or all of the six ISD cases using alternative concepts that differ from the current AASHTO model. For example, several State highway agencies have adopted ISD criteria for Cases IIIB and IIIC based on gap acceptance rather than on the current AASHTO model. Please identify any cases for which, in your opinion, an alternative to the current AASHTO model may be appropriate and any alternative models or assumptions that you think should be considered:

9. The AASHTO Green Book includes a procedure for ISD at at-grade ramp terminals. This procedure is a special case of ISD Cases IIIB and IIIC.

   Does your agency use the AASHTO ramp terminal procedure for ISD? _____ YES _____ NO

   If NO, does your agency have its own ramp terminal procedure for ISD? _____ YES _____ NO

   Do you think that a separate at-grade ramp terminal ISD procedure should be retained in the AASHTO Green Book?

   _____ YES, retain a separate procedure for ramp terminal ISD.

   _____ NO, eliminate the ramp terminal ISD procedure and simply state that ISD for Cases IIIB and IIIC should be provided at ramp terminals.

10. The AASHTO Green Book does not address the sight distance requirements for left turns off a major roadway onto a minor roadway. Does your agency have a policy concerning ISD for this maneuver?
    _____ YES _____ NO

    In your opinion, should sight distance requirements for left turns off a major roadway onto a minor roadway be added to the AASHTO Green Book? _____ YES _____ NO

11. Does your agency policy for ISD Case III apply to driveways as well as intersections?
    _____ YES _____ NO

    If YES, does the policy apply to commercial driveways, residential driveways, or both (check one):

    _____ Commercial driveways only
    _____ Residential driveways only
    _____ Both commercial and residential driveways

    If NO, does your agency have any other sight distance policy applicable to driveways?
    _____ YES _____ NO

12. Are there any other aspects of current ISD policy for which, in your opinion, changes should be considered?
_____ YES _____ NO

If YES, please explain:

13. May we have the name of an engineer in your agency that we may contact to obtain follow-up information?

Name ______________________________
Title ______________________________
Agency ______________________________
Mailing Address: ______________________________
____
____
____
____

Telephone No.: ______________________________

Please mail the questionnaire to:

Mr. Douglas W. Harwood
Principal Traffic Engineer
Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

A postage-paid envelope has been provided for your response. If you have any questions or comments, please feel free to call Mr. Harwood at (816) 753-7600, Ext. 571.

THANK YOU FOR YOUR ASSISTANCE.

SURVEY ON CURRENT POLICIES FOR INTERSECTION SIGHT DISTANCE DESIGN

The following survey on intersection sight distance (ISD) is being conducted as part of the National Cooperative Highway Research Program (NCHRP), which is sponsored by the American Association of State Highway and Transportation Officials (AASHTO) in cooperation with the Federal Highway Administration (FHWA). Your responses to a few questions concerning your agency's geometric design policies for ISD would be appreciated.

1. The AASHTO Green Book presents ISD policies for six cases identified below. Please indicate what policy your agency uses for each case (use codes 1 through 5 given below):

   Case I (No Control) ____________
   Case II (YIELD Control) ____________
   Case IIIA (STOP Control--Crossing Maneuver) ____________
   Case IIIB (STOP Control--Left-Turn Maneuver) ____________
   Case IIIC (STOP Control--Right-Turn Maneuver) ____________
   Case IV (Signal Control) ____________

   1 = Use policy in 1990 AASHTO Green Book
   2 = Use policy in 1984 AASHTO Green Book
   3 = Use State policy which differs from AASHTO
   4 = Do not consider this case
   5 = Other (specify)

2. What is your agency's assessment of the suitability of the current AASHTO ISD criteria for each case (use codes 1 through 4 given below):

   Case I (No Control) ____________
   Case II (YIELD Control) ____________
   Case IIIA (STOP Control--Crossing Maneuver) ____________
   Case IIIB (STOP Control--Left-Turn Maneuver) ____________
   Case IIIC (STOP Control--Right-Turn Maneuver) ____________
   Case IV (Signal Control) ____________

   1 = Sight distance required by AASHTO is longer than should be required for safe completion of the intended maneuver
   2 = Sight distance required by AASHTO is shorter than should be required for safe completion of the intended maneuver
   3 = Sight distance required by AASHTO is about right
   4 = No opinion or don't know

3. If your agency has established ISD criteria that differ from the AASHTO Green Book, do your agency's criteria apply to (check appropriate response):

3. If your agency has established ISD criteria that differ from the AASHTO Green Book, do your agency's criteria apply to (check appropriate response):

_____ State-funded projects only
_____ Both Federal and State-funded projects
_____ Not applicable

4. Does your agency consider all six cases to be necessary for ISD design. _____YES _____NO

Please identify any of the six cases that, in your opinion could be dropped or combined with other cases. Your comments about why these cases could be dropped would be appreciated.

5. Does your agency have a separate ISD design policy for rehabilitation (RRR) projects that differs from the design policy for new construction/reconstruction projects? _____ YES _____NO

If YES, we would appreciate receiving a copy of that design policy.

6. Do your agency's ISD criteria vary by functional class? In other words, do you have different ISD values that apply to different functional classes of road (arterials, collectors, local streets, etc.)? _____ YES _____ NO

7. Does your agency request or utilize design exceptions for ISD when it is impractical to provide the full ISD required by the AASHTO Green Book or your agency's design policy? _____ YES _____ NO

What geometric design or traffic control modifications are considered by your agency at intersections where the full ISD required by AASHTO or State policies cannot be provided (please describe):

8. Some highway agencies have suggested the need to modify some or all of the six ISD cases using alternative concepts that differ from the current AASHTO model. For example, several State highway agencies have adopted ISD criteria for Cases IIIB and IIIC based on gap acceptance rather than on the current AASHTO model. Please identify any cases for which, in your opinion, an alternative to the current AASHTO model may be appropriate and any alternative models or assumptions that you think should be considered:

9. From an initial review of ISD policies provided by your agency, it appears that your agency has a policy for ISD Case(s) ____________________ that differs from the policy in the AASHTO Green Book. Please explain the rationale used by your agency in adopting these differing policies:

10. Is your agency satisfied with your own current policy for the Case(s) identified in Question 8 or are further changes being contemplated?

11. From an initial review of ISD policies provided by your agency, it appears that your agency has omitted ISD Case(s) ____________________ from your design policy or manual. Please explain the rationale used by your agency in deciding to omit these cases. Is it your agency's view that these cases could be omitted from the AASHTO Green Book without compromising safety?

12. The AASHTO Green Book includes a procedure for ISD at at-grade ramp terminals. This procedure is a special case of ISD Cases IIIB and IIIC.

    Does your agency use the AASHTO ramp terminal procedure for ISD? _____ YES _____ NO

    If NO, does your agency have its own ramp terminal procedure for ISD? _____ YES _____ NO

    Do you think that a separate at-grade ramp terminal ISD procedure should be retained in the AASHTO Green Book?

    _____ YES, retain a separate procedure for ramp terminal ISD.
    _____ NO, eliminate the ramp terminal ISD procedure and simply state that ISD for Cases IIIB and IIIC should be provided at ramp terminals.

13. The AASHTO Green Book does not address the sight distance requirements for left turns off a major roadway onto a minor roadway. Does your agency have a policy concerning ISD for this maneuver?
_____ YES _____ NO

In your opinion, should sight distance requirements for left turns off a major roadway onto a minor roadway be added to the AASHTO Green Book? _____ YES _____ NO

14. Does your agency policy for ISD Case III apply to driveways as well as intersections?
_____ YES _____ NO

If YES, does the policy apply to commercial driveways, residential driveways, or both (check one):

_____ Commercial driveways only
_____ Residential driveways only
_____ Both commercial and residential driveways

If NO, does your agency have any other sight distance policy applicable to driveways?
_____ YES _____ NO

15. Are there any other aspects of current ISD policy for which, in your opinion, changes should be considered?
_____ YES _____ NO

If YES, please explain:

16. May we have the name of an engineer in your agency that we may contact to obtain follow-up information?

Name ______________________________
Title ______________________________
Agency ______________________________
Mailing Address: ______________________________
____
____
____
____

Telephone No.: ______________________________

Please mail the questionnaire to:

Mr. Douglas W. Harwood
Principal Traffic Engineer
Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

A postage-paid envelope has been provided for your response. If you have any questions or comments, please feel free to call Mr. Harwood at (816) 753-7600, Ext. 571.

THANK YOU FOR YOUR ASSISTANCE.

MRI-M\QUEST2

SURVEY ON CURRENT POLICIES FOR INTERSECTION SIGHT DISTANCE DESIGN

The following survey on intersection sight distance (ISD) is being conducted as part of the National Cooperative Highway Research Program (NCHRP), which is sponsored by the American Association of State Highway and Transportation Officials (AASHTO) in cooperation with the Federal Highway Administration (FHWA). Your responses to a few questions concerning your agency's geometric design policies for ISD would be appreciated.

1. Does your agency have a formal intersection sight distance (ISD) policy (please check appropriate response)?

YES, our agency has adopted its own ISD policy	_____
YES, our agency follows the 1990 AASHTO Green Book	_____
YES, our agency follows the 1984 AASHTO Green Book	_____
YES, our agency follows the ISD policy of State highway agency in our State	_____
NO, our agency does not have a formal ISD policy	_____

If your agency has an ISD policy that differs from AASHTO and State policies, we would appreciate it if you would attach a copy to this response.

2. The AASHTO Green Book presents ISD policies for six cases identified below. Please indicate what policy your agency uses for each case (use codes 1 through 5 given below):

Case I (No Control)	__________
Case II (YIELD Control)	__________
Case IIIA (STOP Control--Crossing Maneuver)	__________
Case IIIB (STOP Control--Left-Turn Maneuver)	__________
Case IIIC (STOP Control--Right-Turn Maneuver)	__________
Case IV (Signal Control)	__________

1 = Use policy in 1990 AASHTO Green Book
2 = Use policy in 1984 AASHTO Green Book
3 = Use State policy which differs from AASHTO
4 = Use local policy which differs from AASHTO
5 = Do not consider this case
6 = Other (specify)

3. What is your agency's assessment of the suitability of the current AASHTO ISD criteria for each case (use codes 1 through 4 given below):

Case I (No Control)	________
Case II (YIELD Control)	________
Case IIIA (STOP Control--Crossing Maneuver)	________
Case IIIB (STOP Control--Left-Turn Maneuver)	________
Case IIIC (STOP Control--Right-Turn Maneuver)	________
Case IV (Signal Control)	________

1 = Sight distance required by AASHTO is longer than should be required for safe completion of the intended maneuver
2 = Sight distance required by AASHTO is shorter than should be required for safe completion of the intended maneuver
3 = Sight distance required by AASHTO is about right
4 = No opinion or don't know

4. Does your agency consider all six cases to be necessary for ISD design. _____ YES _____ NO

Please identify any of the six cases that, in your opinion could be dropped or combined with other cases. Your comments about why these cases could be dropped would be appreciated.

5. Does your agency have a separate design policy for rehabilitation (RRR) projects that differs from the design policy for new construction/reconstruction projects? _____ YES _____ NO

If YES, we would appreciate receiving a copy of that design policy.

6. Do your agency's ISD criteria vary by functional class? In other words, do you have different ISD values that apply to different functional classes of road (arterials, collectors, local streets, etc.)? _____ YES _____ NO

7. Does your agency request or utilize design exceptions for ISD when it is impractical to provide the full ISD required by the AASHTO Green Book or your agency's design policy? _____ YES _____ NO

What geometric design or traffic control modifications are considered by your agency at intersections where the full ISD required by AASHTO or State policies cannot be provided (please describe):

8. Some highway agencies have suggested the need to modify some or all of the six ISD cases using alternative concepts that differ from the current AASHTO model. For example, several State highway agencies have adopted ISD criteria for Cases IIIB and IIIC based on gap acceptance rather than on the current AASHTO model. Please identify any cases for which, in your opinion, an alternative to the current AASHTO model may be appropriate and any alternative models or assumptions that you think should be considered:

9. ISD Case I addresses intersections with no traffic control (i.e., no traffic signals, no STOP signs, and no YIELD signs) on any approach. Does your agency operate intersections with no control on any approach (e.g., on low-volume residential streets or low-volume rural roads)? _____ YES _____ NO

   If YES, in your opinion, do current AASHTO criteria for ISD Case I adequately address the sight distance needs at the uncontrolled intersections operated by your agency? _____ YES _____ NO

   What specific changes to the AASHTO policy for ISD Case I do you think should be considered (please describe):

10. ISD Case II addresses intersections with YIELD signs on the minor approach(es). Does your agency operate intersections with YIELD signs on the minor road? _____ YES _____ NO

    If YES, in your opinion, do the current AASHTO criteria for ISD Case II adequately address the sight distance needs at the YIELD-controlled intersections operated by your agency? _____ YES _____ NO

    What specific changes, if any, to the AASHTO policy for ISD Case II do you think should be considered (please describe):

11. The AASHTO Green Book does not address the sight distance requirements for left turns off a major roadway onto a minor roadway. Does your agency have a policy concerning ISD for this maneuver?
_____ YES _____ NO

In your opinion, should sight distance requirements for left turns off a major roadway onto a minor roadway be added to the AASHTO Green Book? _____ YES _____ NO

12. Does your agency policy for ISD Case III apply to driveways as well as intersections?
_____ YES _____ NO

If YES, does the policy apply to commercial driveways, residential driveways, or both (check one):

_____ Commercial driveways only
_____ Residential driveways only
_____ Both commercial and residential driveways

If NO, does your agency have any other sight distance policy applicable to driveways?
_____ YES _____ NO

13. Are there any other aspects of current ISD policy for which, in your opinion, changes should be considered?
_____ YES _____ NO

If YES, please explain:

14. May we have the name of an engineer in your agency that we may contact to obtain follow-up information?

Name ______________________________
Title ______________________________
Agency ______________________________
Mailing Address: ______________________________
____
____
____
____

Telephone No.: ______________________________

Please mail the questionnaire to:

Mr. Douglas W. Harwood
Principal Traffic Engineer
Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

A postage-paid envelope has been provided for your response. If you have any questions or comments, please feel free to call Mr. Harwood at (816) 753-7600, Ext. 571.

THANK YOU FOR YOUR ASSISTANCE.

MRI-M\QUEST3

APPENDIX B

SUMMARY OF QUESTIONNAIRE RESPONSES FROM STATE AND LOCAL HIGHWAY AGENCIES

This appendix presents a summary of the responses to the survey questionnaire sent to state and local highway agencies concerning their ISD design policies. Copies of the questionnaire have been presented in Appendix A. Responses were received from 45 of the 50 state highway agencies (i.e., a 90% response rate). Two additional state highway agencies that did not respond to the questionnaire have provided copies of their ISD policies in response to a previous request. Therefore, whenever possible, the summary in this appendix is based on data from 47 of the 50 state highway agencies (94%).

Responses to the questionnaire have been received from 37 out of 80 local highway agencies in urban areas (46%) and 23 out of 55 local highway agencies in rural areas (42%). The local agencies in urban areas that responded included 30 cites and 6 urban counties. All of the local agencies in rural areas are counties.

Separate discussions of the responses received from state and local agencies are presented below because state and local agencies are organized differently and operate different types of intersections.

ISD POLICIES USED BY STATE HIGHWAY AGENCIES

Summary of Policies

Table B-1 summarizes the ISD design policies used by state highway agencies. The table shows that the majority of highway agencies follow the ISD policies in the AASHTO Green Book. A significant minority of Green Book users still use the 1984 Green Book, presumably because the 1990 Green Book had not yet been approved by FHWA. It should be noted that this survey was conducted in 1992, prior to the publication of the 1994 Green Book, which is now the current edition. The following discussion addresses the policies followed by state highway agencies for each of the AASHTO cases.

Of the states which responded to the questionnaire and have an ISD policy for uncontrolled intersections, all but three use the AASHTO Green Book policy for Case I, which is unchanged between the 1984 and 1990 editions of the Green Book. However, 22 state highway agencies do not consider ISD Case I, generally because they do not permit intersections on their highway system to be operated with no control.

Table B-1. DESIGN POLICIES USED BY STATE HIGHWAY AGENCIES FOR EACH ISD CASE

	Number (percentage) of states					
Design policy	Case I	Case II	Case IIIA	Case IIIB	Case IIIC	Case IV
1990 AASHTO Green Book	15 (31.9)	18 (38.3)	27 (57.4)	23 (48.9)	22 (46.8)	21 (44.7)
1984 AASHTO Green Book	8 (17.0)	8 (17.0)	13 (27.7)	12 (25.5)	12 (25.5)	6 (12.8)
Own state policy	2 (4.3)	4 (8.5)	3 (6.4)	12 (25.5)	12 (25.5)	10 (21.3)
Don't consider this case	22 (46.8)	17 (36.2)	4 (8.5)	0 (0.0)	1 (2.1)	10 (21.3)
	47	47	47	47	47	47

ISD Case II is similar to Case I in that many state highway agencies do not permit the use of YIELD signs at at-grade intersections, except to establish the right-of-way for separate right-turn roadways. Those agencies that have a policy for ISD Case II overwhelmingly use the AASHTO Green Book. However, four state highway agencies have adopted their own policies for ISD Case II.

More than 85% of state highway agencies use the AASHTO Green Book policy for ISD Case IIIA. However, two agencies have adopted their own policy that differs from AASHTO. Five agencies do not consider Case IIIA on the grounds that Cases IIIB and IIIC are always more critical.

More than 70% of state highway agencies use the AASHTO Green Book policy for ISD Cases IIIB and IIIC. However, 12 agencies have adopted their own policy for Cases IIIB and Case IIIC. All state highway agencies have a policy for Case IIIB, although a number of agencies have policies that differ from AASHTO; one state does consider Case IIIB, but does not consider Case IIIC.

About 50% of highway agencies use the AASHTO Green Book policy for ISD Case IV. However, 10 agencies have adopted their own policies. These policies typically limit consideration of ISD at signalized intersections to providing the ISD equivalent to Case IIIC where right turn on red is permitted. Eleven state highway agencies do not require consideration of ISD at signalized intersections.

Each of the state highway agencies that have adopted their own ISD criteria, which differ from AASHTO, stated that these criteria apply to both Federal-aid projects and state-funded projects.

Assessment of Current AASHTO ISD Policy

Respondents to the questionnaire survey were asked to state their agency's assessment of the current AASHTO ISD criteria. In particular, respondents were asked whether the sight distance specified by AASHTO for each case was (1) longer than should be required for safe completion of the intended maneuver; (2) shorter than should be required for safe completion of the intended maneuver; or (3) about right. The responses to this question are summarized in Table B-2. This table, and the remaining tables of state responses, include only the 45 state agencies that actually responded to the questionnaire.

Most of the state highway agencies that offered an assessment consider the current AASHTO policy for ISD Cases I and II to be about right. However, for the most part, the agencies that do not use Cases I and II understandably declined to assess them.

Table B-2. STATE HIGHWAY AGENCY ASSESSMENTS OF CURRENT AASHTO ISD POLICY

ISD Required by AASHTO is:	Number and Percentage of States					
	Case I	Case II	Case IIIA	Case IIIB	Case IIIC	Case IV
Too long	1 (2.2)	0 (0.0)	9 (20.0)	12 (37.8)	16 (35.6)	10 (22.2)
Too short	1 (2.2)	3 (6.7)	1 (2.2)	1 (2.2)	0 (0.0)	0 (0.0)
About right	18 (40.0)	19 (42.2)	30 (66.7)	17 (42.2)	21 (46.7)	22 (48.9)
No opinion or don't know	25 (55.6)	23 (51.1)	5 (11.1)	6 (17.8)	8 (17.8)	13 (28.9)
	45	45	45	45	45	45

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The majority of state highway agencies that expressed an opinion consider the current AASHTO ISD values for Cases III and IV to be about right. However, a significant minority of agencies consider the sight distance values specified by AASHTO to be longer than should be required. The greatest concern is for Cases IIIB and IIIC, which approximately 35% of agencies consider to be too long. On the other hand, very few agencies hold the view that the current AASHTO criteria are shorter than should be required.

Respondents were asked in several ways whether specific cases should be dropped, combined with other cases, or modified. Approximately 49% of state highway agencies stated that all six cases that appear in the current AASHTO policy are necessary. The remaining agencies thought that one or more of the cases could be dropped or combined with other cases. The responses also indicated a need to modify the criteria for one or more of the six cases in the current AASHTO policy. Table B-3 summarizes these responses.

Approximately 33% of agencies were of the opinion that ISD Case I could be dropped or combined with Case II. Of course, while agencies that do not use uncontrolled intersections may feel that Case I can be dropped, other agencies do need it. A smaller number of state highway agencies advocated dropping or combining ISD Case II than Case I.

As was the case for Table B-2, Table B-3 shows that a substantial minority of highway agencies see the need for changes to Cases III and IV.

Rehabilitation Policies and Design Exceptions

Table B-4 shows that slightly more than 30% of highway agencies have specific policies that address ISD requirements for rehabilitation (RRR) projects. Typically, these policies involve (1) specifying ISD as a desirable design policy with SSD as a minimum requirement; or (2) improving ISD only at intersections where a pattern of accidents indicates an ISD-related problem. The remaining state highway agencies address limited ISD in RRR projects by justifying and obtaining formal design exceptions when necessary.

Variation of ISD Policies by Functional Class

Table B-5 shows that most state ISD policies do not vary by functional class. In other words, highway agencies do not have different ISD policies for collectors or local roads than they do for arterials. The two agencies that claim to have ISD policies that vary by functional class stated that they typically use different design speeds for the different functional classes. This is not what was intended by the question.

Table B-3. STATE HIGHWAY ASSESSMENTS OF WHICH ISD CASES SHOULD BE DROPPED, COMBINED WITH ANOTHER CASE, OR MODIFIED

	Number (percentage) of states					
ISD case should be:	Case I	Case II	Case IIIA	Case IIIB	Case IIIC	Case IV
Dropped or combined with another case	15 (33.3)	9 (20.0)	3 (6.7)	4 (8.9)	6 (13.3)	4 (8.9)
Modified	1 (2.2)	4 (8.9)	12 (26.7)	20 (44.4)	18 (40.0)	15 (33.3)
No change suggested	29 (64.4)	32 (71.1)	30 (66.7)	21 (46.7)	21 (46.7)	26 (57.8)
	45	45	45	45	45	45

Table B-4. STATE HIGHWAY AGENCY RRR POLICIES RELATED TO ISD

Does your agency have a separate ISD policy for rehabilitation (RRR) projects?	Number (percentage) of states	
Yes	14	(31.1)
No	30	(66.7)
Not stated	1	(2.8)
	45	

Table B-5. STATE HIGHWAY AGENCIES WITH ISD POLICIES THAT VARY BY FUNCTIONAL CLASS

Do your agency's ISD criteria vary by functional class?	Number (percentage) of states	
Yes	2	(4.4)
No	43	(95.6)
Not stated	0	(0.0)
	45	

Use of the AASHTO ISD Procedure for Ramp Terminals

The AASHTO ISD procedure for ramp terminals is used by approximately 64% of state highway agencies, as shown in Table B-6. Of the remaining states, 40% use an ISD procedure of their own for ramp terminals and 60% simply apply the Case III criteria. When asked their assessment of how sight distance at ramp terminals should be addressed in the AASHTO Green Book, 53% of agencies favored retaining a separate procedure, as in the 1984 and 1990 Green Books, while 40% thought it would be sufficient to state that ISD Case III must be applied to ramp terminals. One agency emphasized that if the latter approach is taken, the discussion in the Green Book emphasizing the special problems of sight distance at ramp terminals (i.e., structures, bridge rails, and guardrails that may block the driver's view) should be retained.

SIGHT DISTANCE NEEDS FOR LEFT TURNS OFF OF THE MAJOR ROAD

Table B-7 shows that over 95% of state highway agencies stated that they do not have a policy concerning the sight distance requirements for left turns off of the major road. Approximately 47% of state highway agencies stated that sight distance requirements for left turns off a major roadway should be added to the AASHTO Green Book, while 49% stated that they should not. Several agencies stated that their policy for left turns off a major roadway was to provide stopping sight distance.

This question, as posed in the survey questionnaire, was misleading because it is based on the premise that there are no sight distance requirements in the Green Book for left turns off the major roadway. Shortly after the questionnaire was mailed, the research team realized that although sight distance requirements for left turns from the major road were not addressed in the 1984 Green Book, the last paragraph of the discussion concerning Case IIIB in the 1990 Green Book does set a sight distance requirement for left turns off of a major roadway. We regret this error, which makes it difficult to interpret the responses summarized in Table B-7. This sight distance criterion for left turns has been designated as Case V in the 1994 Green Book.

ISD REQUIREMENTS FOR DRIVEWAYS

State highway agency policies concerning ISD requirements at driveways are summarized in Table B-8. Approximately half of state highway agencies stated that their requirements for ISD Case III apply to driveways as well as intersections.

Table B-6. STATE HIGHWAY AGENCY USE OF THE AASHTO ISD PROCEDURE FOR RAMP TERMINALS

Does your agency use the AASHTO ISD procedure for ramp terminals?	Number	(percentage) of states
Yes	29	(64.4)
No	15	(33.3)
Not stated	1	(2.2)
	45	
If NO, does your agency have its own ramp terminal procedure?		
Yes	6	(13.3)
No	9	(20.0)
Not stated	0	(0.0)
	15	
Should a separate ramp terminal procedure be retained in the AASHTO Green Book?		
Yes	24	(53.3)
No	18	(40.0)
Not stated	3	(6.7)
	45	

Table B-7. STATE HIGHWAY AGENCY ISD POLICIES CONCERNING LEFT TURNS OFF THE MAJOR ROAD

Does your agency have a policy concerning ISD for left turns off the major road?	Number (percentage) of states	
Yes	2	(4.4)
No	43	(95.6)
Not stated	0	(0.0)
	45	
Should sight distance requirements for left turns off a major roadway be added to the AASHTO Green Book?		
Yes	21	(46.7)
No	22	(48.9)
Not stated	2	(4.4)
	45	

Table B-8. STATE HIGHWAY AGENCY ISD POLICIES FOR DRIVEWAYS

Does your agency's policy for ISD Case III apply to driveways as well as intersections?	Number	(percentage) of states
Yes	23	(51.1)
No	22	(48.9)
Not stated	0	(0.0)
	45	
If YES, does your policy apply to:		
Commercial driveways only	7	(15.6)
Residential driveways only	0	(0.0)
Both commercial and residential driveways	15	(33.3)
Not stated	1	(2.2)
	23	
If NO, does agency have any other sight distance policy applicable to driveways?		
Yes	11	(24.4)
No	10	(22.2)
Not stated	1	(2.2)
	22	

However, the remaining agencies generally have no policy concerning the sight distance at driveways except for the provision of stopping sight distance along the major road.

Of those state highway agencies that apply ISD Case III to driveways, 7 agencies stated that their policy applies to commercial driveways only and 15 agencies stated that their policy applies to both commercial and residential driveways.

ISD POLICIES USED BY LOCAL HIGHWAY AGENCIES

Summary of Policies

The ISD design policies used by local agencies in urban and rural areas are summarized in Table B-9 and B-10, respectively. Most local agencies use ISD policies from the 1990 or 1984 AASHTO Green Book. However, between 19% and 33% of local agencies in urban areas have adopted their own local policies for each ISD case. Rural agencies are less likely than urban agencies to have formulated their own local policies. The specific ISD policies used by local agencies for each ISD cases are discussed in the chapter of this report that deals with that case.

It should also be noted that for each ISD case, 11% and 573% of local agencies do not have an ISD policy. In both urban and rural areas, Case IV (signal control) is the case most frequently omitted from ISD policies.

Assessment of Current AASHTO ISD Policy

Respondents to the questionnaire survey from local agencies were asked their assessment of the current AASHTO ISD criteria. In particular, respondents were asked whether the sight distance specified for each case was (1) longer than should be required for safe completion of the intended maneuver; (2) shorter than should be required for safe completion of the intended maneuver; or (3) about right. The responses to this question are summarized in Table B-11 for local agencies in urban areas and in Table B-12 for local agencies in rural areas.

Between 30% and 50% of urban agencies and between 60% and 80% of rural agencies declined to express an opinion on the suitability of the current AASHTO policy.

Table B-9. DESIGN POLICIES USED BY LOCAL AGENCIES IN URBAN AREAS FOR EACH ISD CASE

	Number (percentage) of agencies											
Design policy	Case I		Case II		Case IIIA		Case IIIB		Case IIIC		Case IV	
1990 AASHTO Green Book	12	(32.4)	13	(35.1)	15	(40.5)	15	(40.5)	16	(43.2)	11	(29.7)
1984 AASHTO Green Book	5	(13.5)	6	(16.2)	6	(16.2)	6	(16.2)	5	(13.5)	7	(18.9)
State highway agency policy	0	(0.0)	0	(0.0)	1	(2.7)	1	(2.7)	1	(2.7)	1	(2.7)
Own local policy	12	(32.4)	9	(24.3)	9	(24.3)	11	(29.7)	10	(27.0)	7	(18.9)
Don't consider this case	8	(21.6)	9	(24.3)	6	(16.2)	4	(10.8)	5	(13.5)	11	(29.7)
	37		37		37		37		37		37	

Table B-10. DESIGN POLICIES USED BY LOCAL AGENCIES IN RURAL AREAS FOR EACH ISD CASE

Design policy	Number (percentage) of agencies					
	Case I	Case II	Case IIIA	Case IIIB	Case IIIC	Case IV
1990 AASHTO Green Book	6 (26.1)	6 (26.1)	6 (26.1)	5 (21.7)	5 (21.7)	5 (21.7)
1984 AASHTO Green Book	2 (8.7)	2 (8.7)	2 (8.7)	1 (4.3)	1 (4.3)	1 (4.3)
State highway agency policy	4 (17.4)	4 (17.4)	4 (17.4)	4 (17.4)	4 (17.4)	3 (13.0)
Own local policy	2 (8.7)	3 (13.0)	3 (13.0)	3 (13.0)	3 (13.0)	1 (4.3)
Don't consider this case	9 (39.1)	8 (34.8)	8 (34.8)	10 (43.5)	10 (43.5)	13 (56.5)
	23	23	23	23	23	23

Table B-11. ASSESSMENTS OF CURRENT AASHTO ISD POLICY BY LOCAL AGENCIES IN URBAN AREAS

ISD Required by AASHTO is:	Number and percentage of agencies					
	Case I	Case II	Case IIIA	Case IIIB	Case IIIC	Case IV
Too long	4 (10.8)	6 (16.2)	9 (24.3)	11 (29.7)	11 (29.7)	8 (21.6)
Too short	1 (2.7)	0 (0.0)	0 (0.0)	1 (2.7)	0 (0.0)	0 (0.0)
About right	16 (43.2)	12 (32.4)	16 (43.2)	13 (35.1)	13 (35.1)	13 (35.1)
No opinion or don't know	16 (43.2)	18 (48.6)	12 (32.4)	12 (32.4)	13 (35.1)	16 (43.2)
	37	37	37	37	37	37

Table B-12. ASSESSMENTS OF CURRENT AASHTO ISD POLICY BY LOCAL AGENCIES IN RURAL AREAS

ISD Required by AASHTO is:	Number and percentage of agencies					
	Case I	Case II	Case IIIA	Case IIIB	Case IIIC	Case IV
Too long	1 (4.3)	2 (8.7)	2 (8.7)	2 (8.7)	2 (8.7)	3 (13.0)
Too short	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
About right	5 (21.7)	6 (26.1)	5 (21.7)	5 (21.7)	5 (21.7)	4 (17.4)
No opinion or don't know	17 (73.9)	16 (69.6)	15 (65.2)	16 (69.6)	16 (69.6)	16 (69.6)
	23	23	23	23	23	23

Of those who did express an opinion, the majority felt that the AASHTO criteria for ISD Cases I and II are about right. Most local agencies also consider the AASHTO criteria for Cases III and IV to be about right. However, a substantial minority of agencies (particularly those in urban areas) consider the AASHTO sight distance requirements for Cases III and IV to be longer than necessary.

Respondents were asked in several ways whether specific cases should be dropped, combine with other cases, or modified. Approximately 30% of local agencies stated that all six cases that appear in the current AASHTO policy are necessary. The remaining agencies thought that one or more of the cases could be dropped, combined with other cases, or modified. Tables B-13 and B-14 summarize these responses for local agencies in urban and rural areas, respectively.

Local agencies were less likely than state highway agencies to advocate the elimination of ISD Case I or combining Cases I and II. However, as for state highway agencies, a substantial minority of local highway agencies are of the opinion that modifications to the criteria for ISD Case III are needed.

Rehabilitation Policies

Table B-15 shows that most local agencies to not have formal RRR policies for ISD. However, it is probable that most local agencies improve ISD only when an accident problem development or when a property owner violates a local sight obstruction ordinance.

Variation of ISD Policies by Functional Class

Table B-16 shows that most local agency ISD policies do not vary by functional class. Agencies that stated that their ISD policies do vary by functional class, generally stated that this occurred because they use different design speeds for different functional classes. This is not what was intended by the question.

ISD Policies for Uncontrolled Intersections

Table B-17 shows that most local agencies operate intersections with no control. In urban areas, these are typically intersections of local residential streets and in rural areas these are typically intersections of low-volume (often unpaved) roads. A majority of the agencies that operate uncontrolled intersections are of the opinion that the current AASHTO Case I criteria are adequate for their needs.

Table B-13. ASSESSMENTS BY LOCAL AGENCIES IN URBAN AREAS OF WHICH ISD CASES SHOULD BE DROPPED, COMBINED WITH ANOTHER CASE, OR MODIFIED

	Number (percentage) of agencies											
ISD case should be:	Case I		Case II		Case IIIA		Case IIIB		Case IIIC		Case IV	
Dropped or combined with another case	6	(16.2)	6	(16.2)	3	(8.1)	3	(8.1)	5	(13.5)	7	(18.9)
Modified	5	(13.5)	5	(13.5)	10	(27.0)	14	(37.8)	12	(32.4)	6	(16.2)
No change suggested	26	(70.3)	26	(70.3)	24	(64.9)	20	(54.1)	20	(54.1)	24	(64.9)
	37		37		37		37		37		37	

Table B-14. ASSESSMENTS BY LOCAL AGENCIES IN URBAN AREAS OF WHICH ISD CASES SHOULD BE DROPPED, COMBINED WITH ANOTHER CASE, OR MODIFIED

	Number (percentage) of agencies											
ISD case should be:	Case I		Case II		Case IIIA		Case IIIB		Case IIIC		Case IV	
Dropped or combined with another case	1	(4.3)	1	(4.3)	1	(4.3)	4	(17.4)	4	(17.4)	5	(21.7)
Modified	1	(4.3)	2	(8.7)	2	(8.7)	2	(8.7)	2	(8.7)	2	(8.7)
No change suggested	21	(91.3)	20	(87.0)	20	(87.0)	17	(73.9)	17	(73.9)	16	(69.6)
	23		23		23		23		23		23	

Table B-15. LOCAL AGENCY RRR POLICIES RELATED TO ISD

Does your agency have a separate ISD policy for rehabilitation (RRR) projects?	Number (percentage) agencies			
	Urban		Rural	
Yes	4	(10.8)	0	(0.0)
No	32	(86.5)	20	(87.0)
Not stated	1	(2.7)	3	(13.0)
	37		23	

Table B-16. LOCAL AGENCY WITH ISD POLICIES THAT VARY BY FUNCTIONAL CLASS

Do your agency's ISD criteria vary by functional class?	Number (percentage) agencies			
	Urban		Rural	
Yes	10	(27.0)	2	(8.7)
No	25	(67.6)	15	(65.2)
Not stated	2	(5.4)	5	(21.7)
	37		23	

Table B-17. LOCAL AGENCY ASSESSMENTS OF ISD CASE I

Does your agency operate intersections with no control?	Number (percentage) of agencies			
	Urban		Rural	
Yes	30	(81.1)	11	(47.8)
No	6	(16.2)	8	(34.8)
Not stated	1	(2.7)	4	(17.4)
	37		23	

If YES, do the AASHTO criteria for ISD Case I adequately address sight distance needs at uncontrolled intersections operated by your agency?	Urban		Rural	
Yes	19	(51.4)	8	(34.8)
No	10	(27.0)	2	(8.7)
Not stated	1	(2.7)	1	(4.3)
	29		11	

ISD Policies for YIELD-Controlled Intersection

Table B-18 shows that most local agencies operate intersections with YIELD control and most agencies that do so are of the opinion that the current AASHTO Case II criteria are adequate for their needs.

Sight Distance Needs for Left Turns Off of the Major Road

Table B-19 shows that approximately 80% of local highway agencies do not have a formal policy concerning the sight distance requirements for left turns off of the major road. A majority of local agencies stated that they support addition to the AASHTO Green Book of sight distance requirements for left turns off of the major road. As explained in the discussion of state highway agency responses to the questionnaire, this question was misleading because it implied that there was no AASHTO policy on sight distance requirements for left turns off of the major road. Such a policy has, in fact, been added to the 1990 AASHTO Green Book.

ISD Requirements for Driveways

Local agency policies concerning ISD requirements at driveways are summarized in Table B-20. Only 30% to 40% of local agencies stated that their requirements for ISD Case III apply to driveways as well as intersections. The remaining 60% of local agencies generally have no policy conceming sight distance at driveways except for the provision of stopping sight distance along the major road.

Of those local agencies that apply ISD Case III to driveways, 7 agencies stated that their policy applies to commercial driveways only and 16 agencies stated that their policy applies to both commercial and residential driveways.

Table B-18. LOCAL AGENCY ASSESSMENTS OF ISD CASE II

Does your agency operate intersections with YIELD control?	Number (percentage) of agencies			
	Urban		Rural	
Yes	26	(70.3)	13	(56.5)
No	10	(27.0)	5	(21.7)
Not stated	1	(2.7)	5	(21.7)
	37		23	

If YES, do the AASHTO criteria for ISD Case II adequately address sight distance needs at YIELD-controlled intersections operated by your agency?	Urban		Rural	
Yes	16	(43.2)	10	(43.5)
No	8	(21.6)	2	(8.7)
Not stated	2	(5.4)	1	(4.3)
	26		13	

Table B-19. LOCAL AGENCY ISD POLICIES CONCERNING LEFT TURNS OFF THE MAJOR ROAD

Does your agency have a policy concerning ISD for left turns off the major road?	Number (percentage) of agencies			
	Urban		Rural	
Yes	5	(13.5)	2	(8.7)
No	31	(83.8)	18	(78.3)
Not stated	1	(2.7)	3	(13.0)
	36		14	

Should sight distance requirements for left turns off a major roadway be added to the AASHTO Green Book?				
Yes	21	(56.8)	9	(39.1)
No	13	(35.1)	6	(26.1)
Not stated	3	(8.1)	8	(34.8)
	37		23	

Table B-20. LOCAL AGENCY ISD POLICIES FOR DRIVEWAYS

Does your agency's policy for ISD Case III apply to driveways as well as intersections?	Number (percentage) of agencies			
	Urban		Rural	
Yes	16	(43.2)	7	(30.4)
No	20	(54.1)	13	(56.5)
Not stated	1	(2.7)	3	(13.0)
	36		14	
If YES, does your policy apply to?				
Commercial driveways only	6	(16.2)	1	(4.3)
Residential driveways only	0	(0.0)	0	(0.0)
Both commercial and residential driveways	10	(27.0)	6	(26.1)
	16		7	
If NO, does agency have any other sight distance policy applicable to driveways?				
Yes	8	(21.6)	2	(8.7)
No	11	(29.7)	8	(34.8)
Not stated	1	(2.7)	3	(13.0)
	20		13	

APPENDIX C

INTERSECTION SIGHT DISTANCE POLICIES OF HIGHWAY AGENCIES IN OTHER COUNTRIES

This appendix summarizes the ISD design policies used by highway agencies in Australia (25), Canada (26), France (27), Germany (28), the Netherlands (29), Sweden (30), and Switzerland (31) in comparison to those of the United States. The policies reviewed are generally national policies of the countries concerned. Provincial and local policies may differ. For some of these countries, the portion of the policy dealing with ISD was directly reviewed. For other counties, we reviewed a research report on guideline document that described the policy.

The French, German, and Swiss policies were partially translated into English by the research team. An English translation of the Swedish policy was already available.

CASE I

None of the countries whose policies were reviewed has a policy based on uncontrolled intersections, equivalent to AASHTO Case I. The German policy stated that intersections controlled by the right-of-way rule were not generally found on highways of the type addressed by the policy and, therefore, were not considered.

CASE II

Sight distance policies for intersections equivalent to AASHTO Case II (YIELD-controlled intersections where the minor-road vehicle may not need to stop) were found in the policies of Germany and Sweden.

In the German policy, the leg of the sight triangle along the minor road is extended from the 3 m (10 ft) length used for Case IIIB to 10 m (33 ft), measured from the edge of the traveled way to the drivers eye, for Case II. In rural areas, it is recommended that the length of the leg of the sight triangle along the major road be increased to 20 m (66 ft) for sites with high volumes of turning trucks. The leg of the sight triangle along the major road is exactly the same in the German policy for Case II as that discussed below in the German policy for Case IIIB. Since AASHTO policy for Case II uses a leg of the sight triangle along the minor road equal to SSD, the sight distance requirement for this leg of the sight triangle is much longer in the United States than that required in Germany.

In the Swedish policy, the legs of the sight triangle along both the major and minor road are longer for Case II than for Case IIIB. The legs of the sight triangle used in Sweden for YIELD-controlled intersections are as follows:

	Leg of sight triangle, m (ft)	
Major-road design speed km/h (mph)	Along major road	Along minor road
50 (31)	-	-
70 (44)	195 (639)	20 (66)
90 (56)	275 (902)	20 (66)
110 (68)	355 (1,164)	20 (66)

The sight distances along the major road required for Case II by the Swedish policy are substantially longer than the AASHTO SSD values for the given design speeds. However, the leg of the sight triangle along the minor road, while twice as long as that used in Germany, is much shorter than AASHTO SSD.

CASE IIIA

Of the countries whose policies were reviewed, it appears that only Canada has a policy for the crossing maneuver equivalent to AASHTO Case IIIA. The design policies of the Transportation Association of Canada (TAC, formerly RTAC) are modeled on the AASHTO policies. The ISD values used in Canada for Case IIIA, presented in Tables G-1 and G-2, are essentially a metric version of the policies in the 1984 AASHTO Green Book.

It is unclear whether the Swiss policy is intended to address the crossing maneuver or the left- and right-turn maneuvers. The diagrams and equations presented appear to apply to the crossing maneuvers but the ISD values provided for design have specific values that apply to left and right turns.

CASES IIIB AND IIIC

Every country reviewed has an ISD design policy equivalent to AASHTO Cases IIIB and IIIC. The ISD values specified in these policies are presented in Table C-1, in comparison to the AASHTO policies used in the United States. For American readers, the comparison that is presented in metric units in Table C-1 is also presented in customary units in Table C-2.

Tables C-1 and C-2 show that the ISD requirements used in other countries are all shorter than those used in the United States. The only ISD criteria that approach those required by AASHTO are those used in Australia and Canada.

The Australian criteria known as Entering Sight Distances (ESD) are desirable design values, but are not mandatory; the minimum ISD values that are required in Australia, known as Safe Intersection Sight Distances (SISD), which are substantially shorter than the ESD, are also shown in Tables C-1 and C-2. The Canadian values are based on a metric equivalent of Curve B2-b & Cb in the 1984 AASHTO Green Book.

The ISD design policies of Australia, Canada, and Sweden are based on design speed. The policies of France, Germany, the Netherlands, and Switzerland are based on prevailing 85th percentile speed.

With a few exceptions, the international policies reviewed do not say much about how the ISD criteria were derived. However, the Australian policy does state that their ISD criteria are based on an enhanced SSD model. An interesting feature of the Australian policy is the specified maximum sight distance of 500 m (1,640 ft). The policy assumes that drivers are unlikely to seek gaps over 500 m, and therefore the ISD requirements have been reduced to 500 m for speeds of 100 km/h (62 mph) and greater, even when their ISD model indicates a higher value.

The French ISD criteria are based on a gap acceptance approach that results in sight distances equal to 6 to 9 sec travel time at the prevailing 85th percentile speed of the major road. The critical gap varies in the range from 6 to 9 sec based on the design vehicle selected and the designer's choice of minimum or desirable criteria.

Table C-3 compares the ISD measurement rules in the policies of other countries to those specified by AASHTO. The AASHTO specification of 6 m (20 ft) as the distance from the edge of the major road to the driver's eye is larger than the values used in the other countries reviewed, except for the Australian policy; the AASHTO value is midway between the Australian minimum and desirable values. The AASHTO value for driver eye height is in the mid-range of the international values for passenger car drivers. Two countries use a passenger car driver eye height of 1,000 mm (3.28 ft), which is slightly less than the AASHTO value of 1,070 mm (3.50 ft), while one country uses the slightly higher value of 1.15 m (3.77 ft). The AASHTO value for height of object is at least 150 mm (0.5 ft) higher than the object height used in any other country for which data are available. It should also be noted that, in each country other than the United States for which the table shows both driver eye height and an object height, these two values are the same.

Table C-1. INTERNATIONAL CRITERIA FOR ISD CASE III IN COMPARISON TO AASHTO POLICY (METRIC UNITS)

Country	Equivalent AASHTO Case	Design situation	Required intersection sight distance (m) Major-road design or prevailing 85th percentile speed (km/hr)									Remarks
			40	50	60	70	80	90	100	110	120	
Australia	IIIB & IIIC	minimum ISD – urban	60	80	105	130	165	--	--	--	--	known as Safe Intersection Sight Distance (SISD)
	IIIB & IIIC	minimum ISD – rural	70	90	115	140	175	210	250	290	330	known as Safe Intersection Sight Distance (SISD)
	IIIB & IIIC	desirable ISD	100	125	160	220	305	400	500	500	500	known as Entering Sight Distance (ESD)
Canada	IIIA	passenger car (Length = 6 m)	--	99	119	138	158	178	198	217	--	based on 1984 AASHTO Green Book
	IIIA	single-unit truck (Length = 9m)	--	129	155	181	207	233	258	284	--	based on 1984 AASHTO Green Book
	IIIA	WB15 truck (Length = 17m)	--	172	206	241	275	309	344	278	--	based on 1984 AASHTO Green Book
	IIIB & IIIC	similar to AASHTO B-1 Curve	--	115	135	160	180	200	215	235	--	based on 1984 AASHTO Green Book
	IIIB & IIIC	similar to AASTO B-2b curve	--	125	165	215	265	320	380	435	--	based on 1984 AASHTO Green Book
France	IIIB & IIIC	desirable – 3-lane or 2-lane divided road	100	125	150	175	200	225	250	275	300	based on travel time of 9 sec at 85th %ile speed
	IIIB & IIIC	desirable – 2-lane road	89	111	133	156	178	200	222	244	267	based on travel time of 8 sec at 85th %ile speed
	IIIB & IIIC	minimum – 3-lane or 2-lane divided road	78	97	117	136	156	175	194	214	233	based on travel time of 7 sec at 85th %ile speed
	IIIB & IIIC	minimum – 2-lane road	67	83	100	117	133	150	167	183	200	based on travel time of 6 sec at 85th %ile speed
Germany	IIIB & IIIC	rural hwys w/o access control – Pass. cars	--	70	85	110	135	170	200	--	--	
	IIIB & IIIC	rural hwys w/o access control – Trucks	--	--	--	175	210	250	300	--	--	
	IIIB & IIIC	urban and suburban, partial access control	--	70	85	110	--	--	--	--	--	
	IIIB & IIIC	urban arterials and collectors	50	70	--	--	--	--	--	--	--	
Netherlands	IIIB & IIIC		--	--	100	--	150	--	250	--	--	
Sweden	IIIB & IIIC	normal design	--	110	--	170	--	240	--	320	--	provides acceptable gaps for 85% of drivers
	IIIB & IIIC	extreme design	--	80	--	130	--	190	--	260	--	provides acceptable gaps for 50% of drivers
Switzerland	IIIB	left turns – passenger cars	60	80	115	140	170	210	240	--	--	
	IIIC	right turns – passenger cars	55	70	105	125	155	195	230	--	--	
	IIIB & IIIC	left & right turns – trucks	125	155	180	220	245	--	--	--	--	
United States	IIIA	1990 Green Book (2-lane road/pass. car)	77	95	112	130	148	166	183	201	219	
	IIIB & IIIC	1990 Green Book (Curve B-2b & Cb)	86	118	156	199	250	308	375	452	544	

Table C-2. INTERNATIONAL CRITERIA FOR ISD CASE III IN COMPARISON TO AASHTO POLICY (ENGLISH UNITS)

Country	Equivalent AASHTO Case	Design situtaion	Required intersection sight distance (ft) Major-road design or prevailing 85th percentile speed (mph)									Remarks
			25	31	37	44	50	56	62	68	75	
Australia	IIIB & IIIC	minimum ISD – urban	197	262	344	426	541	--	--	--	--	known as Safe Intersection Sight Distance (SISD)
	IIIB & IIIC	minimum ISD – rural	230	295	377	459	574	689	820	951	1082	known as Safe Intersection Sight Distance (SISD)
	IIIB & IIIC	desirable ISD	328	410	525	721	1000	1311	1639	1639	1639	known as Entering Sight Distance (ESD)
Canada	IIIA	passenger car (Length = 6 m)	--	325	390	452	518	584	649	711	--	based on 1984 AASHTO Green Book
	IIIA	single-unit truck (Length = 9m)	--	423	508	593	679	764	846	931	--	based on 1984 AASHTO Green Book
	IIIA	WB15 truck (Length = 17m)	--	564	675	790	902	1013	1128	911	--	based on 1984 AASHTO Green Book
	IIIB & IIIC	similar to AASHTO B-1 Curve	--	377	443	525	590	656	705	770	--	based on 1984 AASHTO Green Book
	IIIB & IIIC	similar to AASTO B-2b curve	--	410	541	705	869	1049	1246	1426	--	based on 1984 AASHTO Green Book
France	IIIB & IIIC	desirable – 3-lane or 2-lane divided road	328	410	492	574	656	738	820	902	984	based on travel time of 9 sec at 85th %ile speed
	IIIB & IIIC	desirable – 2-lane road	291	364	437	510	583	656	729	801	874	based on travel time of 8 sec at 85th %ile speed
	IIIB & IIIC	minimum – 3-lane or 2-lane divided road	255	319	383	446	510	574	638	701	765	based on travel time of 7 sec at 85th %ile speed
	IIIB & IIIC	minimum – 2-lane road	219	273	328	383	437	492	546	601	656	based on travel time of 6 sec at 85th %ile speed
Germany	IIIB & IIIC	rural hwys w/o access control – Pass. cars	--	230	279	361	443	557	656	--	--	
	IIIB & IIIC	rural hwys w/o access control – Trucks	--	--	--	574	689	820	984	--	--	
	IIIB & IIIC	urban and suburban, partial access control	--	230	279	361	--	--	--	--	--	
	IIIB & IIIC	urban arterials and collectors	164	230	--	--	--	--	--	--	--	
Netherlands	IIIB & IIIC		--	--	328	--	492	--	820	--	--	
Sweden	IIIB & IIIC	normal design	--	361	--	557	--	787	--	1049	--	provides acceptable gaps for 85% of drivers
	IIIB & IIIC	extreme design	--	262	--	426	--	623	--	852	--	provides acceptable gaps for 50% of drivers
Switzerland	IIIB	left turns – passenger cars	197	262	377	459	557	689	787	--	--	
	IIIC	right turns – passenger cars	180	230	344	410	508	639	754	--	--	
	IIIB & IIIC	left & right turns – trucks	410	508	590	721	803	--	--	--	--	
United States	IIIA	1990 Green Book (2-lane road/pass. car)	252	310	368	427	485	543	601	660	718	
	IIIB & IIIC	1990 Green Book (Curve B-2b & Cb)	284	387	510	653	819	1009	1228	1483	1785	

Table C-3. COMPARISON OF ISD MEASUREMENTS RULES USED IN OTHER COUNTRIES TO AASHTO POLICY

Country	Distance from edge of major road to driver's eye (m)	Height of driver's eye (m)	Height of object to be seen (passenger car) (m)	Distance from edge of major road to driver's eye (ft)	Height of driver's eye (ft)	Height of object to be seen (passenger car) (ft)
Australia	7.00 – desirable 5.00 – minimum	1.15	1.15	23 – desirable 17 – minimum	3.77	3.77
France	3.00	1.00	1.00	10	3.28	3.28
Germany	3.00 (see Note A)	1.00 for PC 2.00 for truck	1.00	10 (see Note A)	3.28 for PC 6.56 for truck	3.28
Netherlands	5.00	--	--	17	--	--
Sweden	5.00 – desirable 3.00 – minimum	--	--	17 – desirable 10 – minimum	--	--
Switzerland	2.50	--	--	9	--	--
United States	6.10	1.07	1.30	20	3.50	4.25

Note A: Increased to 4.50 to 5.00 m (15 or 17 ft) if there is a bicycle path along the major road

APPENDIX D

PROBABILITY OF VEHICLE-VEHICLE CONFLICTS AT UNCONTROLLED INTERSECTIONS

An evaluation of ISD Case I, which is applicable to intersections with uncontrolled approaches, indicates that the current AASHTO allowance of 3 sec for drivers to adjust speeds (2 sec for perception-reaction time and 1 sec to accelerate or decelerate) may not provide adequate sight distance for drivers to avoid collisions in all cases. The most critical situation appears to occur when two or more vehicles on intersecting approaches arrive simultaneously at locations which are 3 sec travel time from the intersection.

An important part of determining the need for changes in the sight distance criteria for uncontrolled intersections is estimation of the likelihood or probability that critical conflict situations will arise. It could be argued that the possibility of vehicle-vehicle conflicts leading to accidents might be tolerated if those conflicts occurred only rarely. On the other hand, frequent occurrence of critical conflict situations (e.g., numerous times per day) might indicate a need for changes in sight distance policy. Obviously, the likelihood or probability of vehicle-vehicle conflicts is a function of the traffic volumes on the intersecting approaches.

EXISTING MODEL

An existing model for estimating the frequency of vehicle-vehicle conflicts at uncontrolled intersections was formulated by Glennon (7) for NCHRP Report 214, "Design and Traffic Control Guidelines for Low-Volume Rural Roads." Glennon estimated conflict frequencies based on the following equation:

$$N_C = 4\ V_a\ N_{C/A} \qquad \text{(D-1)}$$

where: N_C = expected number of right-angle intersection conflicts per day
V_a = average daily traffic volume (for one direction of travel) on the analysis approach (veh/day)
$N_{C/A}$ = number of conflicting arrivals on an intersecting approach per arrival on the analysis approach

Glennon determined the value of $N_{C/A}$ as:

$$N_{C/A} = \frac{V_b}{32{,}400} \qquad \text{(D-2)}$$

where: V_b = average daily traffic volume (for one direction of travel) on the intersecting approach (veh/day)

Equations (D-1) and (D-2) can be combined as:

$$N_C = \frac{V_A V_B}{8100} \tag{D-3}$$

This model is based on the following assumptions:

- No intersection STOP control is provided.
- All vehicles arrive during an 18-hr period during the day (i.e., there is zero traffic volume during 6 nighttime hours; this is reasonable on most low-volume roads).
- Traffic volumes do not vary throughout the 18-hr day. (This assumption may be reasonable for low-volume rural roads, but some peaking should probably be assumed for local residential streets in urban areas.)
- A traffic conflict occurs when a maneuver of a vehicle on one intersection approach causes the driver of a vehicle on an intersecting approach to brake or change direction to avoid collision (i.e., a response by one vehicle to avoid collision is sufficient to classify a vehicle-vehicle interaction as a traffic conflict).
- Any two vehicles approaching an intersection from perpendicular directions are considered to be in conflict if one arrives within 2 sec after another.
- Only one arrival per approach is possible during one 2-sec interval. In other words, all approaches are single lanes, and all headways are greater than 2 sec.
- The possibility of vehicles arriving on three or four approaches within the same 2-sec interval is small enough to be ignored.

No assumption is made concerning the available ISD on the intersection approaches. On approaches with limited ISD, conflicts would seem more likely to result in accidents than on less restricted approaches. Glennon also states an assumption that the average speed is 40 mph on each approach to the intersection, but this assumption does not appear to be necessary to formulate the model.

Glennon's model can be generalized to evaluate conflict exposure intervals other than 2 sec in the following manner:

$$N_C = \frac{V_A V_B t}{16{,}200} \quad \text{(D-4)}$$

where: t = conflict exposure interval (sec)

POISSON MODEL

Glennon's model is based on the assumption that arriving traffic at the intersection follows a uniform distribution. A more common assumption is that traffic arrivals at an intersection follow a Poisson distribution. A Poisson model equivalent to Equation (D-3) can be formulated as:

$$m = \frac{V_b t}{T} \quad \text{(D-5)}$$

$$P_b = m e^{-m} \quad \text{(D-6)}$$

$$N_C = 4 V_a P_b \quad \text{(D-7)}$$

where: m = mean expected traffic volume (number of arrivals) during interval t
T = total time (sec) during an 18-hr day (18 x 60 x 60 = 64,800 sec)
e = base of natural logarithms
P_b = probability that a vehicle will arrive on Approach B during a specified conflict exposure interval

Sensitivity analyses show that Equations (D-4) and (D-7) provide equivalent numerical results (within round-off error). Thus, Glennon's use of the uniform distribution as a simplifying assumption for low-volume intersections is justified. However, the Poisson approach also allows evaluation of low-probability events that Glennon assumed would not occur, such as multiple arrivals during the same time interval.

The AASHTO Green Book recognizes that the existing criteria for ISD Case I do not provide for the possibility that a vehicle approaching an uncontrolled intersection will encounter a succession of vehicles (i.e., a platoon of two or more closely spaced vehicles) on an intersecting approach. The Poisson model, in its most general form, provides one method to estimate the expected number of such conflicts:

$$P_x = \frac{m^x e^{-m}}{x!} \tag{D-8}$$

where: P_x = probability that x vehicles will arrive on approach A during a specified conflict exposure interval
x = number of vehicles

However, the chosen value of x must be consistent with the selected conflict exposure interval, t. For example, it would be unreasonable to calculate the probability of 5 vehicles arriving in the same lane within a period of 2 sec, because this is physically impossible.

ESTIMATED CONFLICT FREQUENCIES

Table D-1 summarizes the expected number of conflicts per day between single vehicles at uncontrolled intersections based on the assumption that any vehicles that arrive within 2 sec of one another are potentially in conflict. Table D-1 focuses on low-volume intersections on roadways with ADT less than 400 veh/day. This is typical of the type of intersection that is operated with no control. Table D-1, equivalent to Glennon's Table H-1 in NCHRP Report 214, can be derived with either Equation (D-4) or (D-7). Please note that the two-way ADTs in the table must be divided in half to obtain one-way ADTs before applying the equations.

For higher-volume situations, the expected conflict frequencies are as follows:

ADT for Road A and Road B	Conflicts per Day
1,000-1,000	30
2,000-2,000	120
4,000-4,000	490

These higher conflict frequencies indicate why uncontrolled intersections are seldom used at higher volume levels.

The conflicts tabulated in Table D-1 do not necessarily represent accidents, only the possibility that accidents could occur. One approach to interpretation of the expected conflict frequencies is to translate them into expected accident rates. Based on traffic conflict evaluations in the literature, Glennon estimated a ratio of 0.00016 between annual accident frequency and annual conflict frequency. This small ratio implies that the accident rates at low-volume intersections should be very small. However, as is made clear by the basic assumptions of Glennon's model, this approach does not address the safety implications of restricted ISD.

Another approach to assessing the implications of restricted ISD is to vary the length of the conflict exposure interval (t) in Equations (D-4) and (D-5). The conflicts most likely to lead to accidents occur when vehicles arrive at the intersection at close to the same time. While such conflicts are included in the expected values presented in Table D-1, so are less serious conflicts when vehicles arrive as much as 2 sec apart.

The sensitivity analysis of the existing ISD Case I shows that when ISD equivalent to 3 sec of travel time at the design speed is provided, negative margins of safety as large as 0.6 sec can result. In other words, a collision would be likely unless (1) the second vehicle arrived at least 0.6 sec later than the first vehicle, (2) one or both vehicles used unusually large acceleration or deceleration rates, or (3) one or both vehicles made a major change in path to avoid a collision. In Table D-2, the Poisson model represented by Equations (D-5) through (D-7) is used to evaluate the probability of a conflict involving two vehicles arriving at the intersection within 0.6 sec of one another. These conflict rates are approximately 25% of the conflict rates shown in Table D-1.

Finally, the Poisson model represented by Equation (D-5) was applied to estimate the probability of a vehicle on one approach approaching the intersection within 2 sec of a platoon of two vehicles on an intersecting approach. The results of this evaluation are shown in Table D-3. The expected conflict frequencies in Table D-3 are small enough to suggest that it is reasonable to assume, as AASHTO does, that the risk of collisions involving platooned vehicles at low-volume intersections is low enough to be discounted.

Table D-1. EXPECTED NUMBER OF RIGHT-ANGLE INTERSECTION CONFLICTS PER DAY

Two-way ADT for Road A (veh/day)	Two-way ADT for Road B (veh/day)				
	50	100	200	300	400
50	0.08	0.15	0.31	0.46	0.62
100	0.15	0.31	0.62	0.92	1.23
200	0.31	0.62	1.23	1.84	2.46
300	0.46	0.92	1.84	2.76	3.68
400	0.62	1.23	2.46	3.68	4.91

Table D-2. EXPECTED NUMBER OF SEVERE RIGHT-ANGLE INTERSECTION CONFLICTS PER DAY

Two-way ADT for Road A (veh/day)	Two-way ADT for Road B (veh/day)				
	50	100	200	300	400
50	0.02	0.05	0.09	0.14	0.18
100	0.05	0.09	0.19	0.28	0.37
200	0.09	0.19	0.37	0.56	0.74
300	0.14	0.28	0.55	0.83	1.11
400	0.18	0.37	0.74	1.11	1.48

Table D-3. EXPECTED NUMBER OF RIGHT-ANGLE INTERSECTION CONFLICTS PER DAY INVOLVING A TWO-VEHICLE PLATOON

Two-way ADT for Road A (veh/day)	Two-way ADT for Road B (veh/day)				
	50	100	200	300	400
50	0.00003	0.00009	0.00030	0.00062	0.00107
100	0.00009	0.00024	0.00071	0.00142	0.00237
200	0.00030	0.00071	0.00190	0.00356	0.00569
300	0.00062	0.00142	0.00356	0.00640	0.00995
400	0.00107	0.00237	0.00569	0.00995	0.01515

APPENDIX E

ALTERNATIVE ISD MODELS CONSIDERED IN THE RESEARCH BUT NOT RECOMMENDED

This appendix provides documentation of some alternative ISD models for uncontrolled and STOP-controlled intersections that were considered in the research, but have not been recommended for inclusion in AASHTO policy. The purpose of this appendix is to document what these models are and why they were not recommended, so that readers who are familiar with previous literature will know the reasons these models were not recommended.

ALTERNATIVE ISD MODELS FOR UNCONTROLLED INTERSECTIONS

Three alternative ISD models for uncontrolled intersections that were proposed prior to this research were reviewed during the research. These include a model developed by McGee et al. (9), a model developed by Harwood et al. (10), and a model presented in the Traffic Control Devices Handbook (5). The following discussion explains each of the models and why they were not recommended for use in ISD policy.

Alternative ISD Model Developed by McGee et al.

An alternative model for ISD Case I has been proposed by McGee et al. (9). The McGee et al. model is one of several alternatives to the AASHTO model based on the explicit consideration of a deceleration rate, rather than an assumed value of time to adjust speed. The model recommended by McGee et al. is:

$$ISD_a = 1.47\ V_a t_{pr} + \frac{WV_a}{V_b} - \frac{a_r W^2}{2.93\ V_b^2} \qquad \textbf{(E-1)}$$

where:

ISD_a = d_a; minimum intersection sight distance for Vehicle A (ft); (see Figure 2)

V_a = design speed for Vehicle A (mph)

t_{pr} = perception-reaction time (sec) (assumed: t_{pr} = 2.0 sec)

W = width of roadway on which Vehicle A is traveling (ft)

V_b = design speed for Vehicle B (mph)

a_r = deceleration rate of Vehicle A (mph/sec) (Note: if the vehicle accelerates, a_r has a negative value)

The derivation of the model in Equation (E-1) appears only in an unpublished paper by Hooper and McGee (32). This model is based on the assumption that the existing AASHTO Case I model provides no time to adjust speed. In other words, they assumed that in Equations (1) and (2), t_{pr} = 3.0 sec and t_{adj} = 0.0 sec. Equation (E-1) was intended to remedy this problem.

The derivation of Equation (E-1) will be explained with reference to Figure E-1. McGee et al. assume that at the limit of the required sight distance Vehicle B is 3.0 sec travel time from the intersection, equal to the current AASHTO Case I ISD. In order for Vehicle A to avoid collision with Vehicle B, it is assumed that Vehicle A must have a leg of the sight triangle that is longer than that of Vehicle B, including both the distance traveled during perception-reaction time (d_{pr}) and the distance traveled during braking (d_{dec}). McGee et al. chose to measure all distances for Vehicle A from the front of the vehicle all and distances for Vehicle B from the rear of the vehicle; this avoids the need for a vehicle length term in the model.

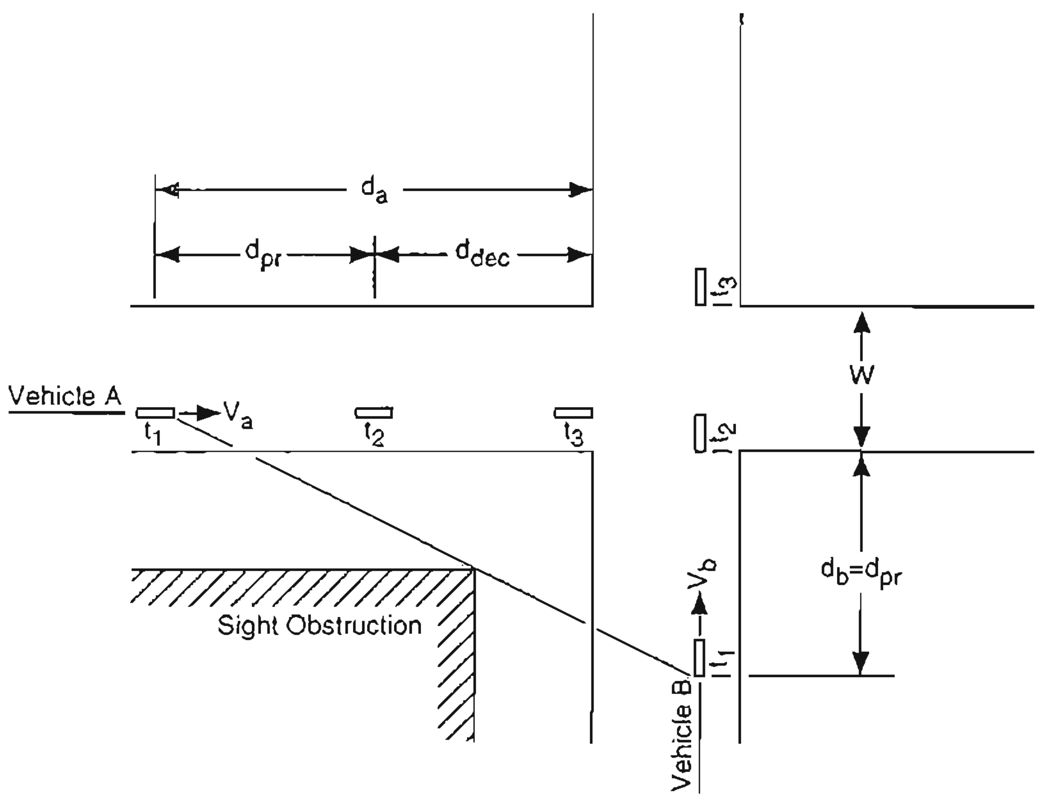


Figure E-1. Distances and vehicle positions assumed in McGee et al. model for ISD Case I (9,32).

At time t_1, it is assumed that both vehicles are at the vertices of the sight triangle. Vehicle A is at a distance $d_{pr} + d_{dec}$ from the intersection, and Vehicle B is at a distance d_{pr} from the intersection. Therefore, in the time interval from t_1 to t_2 before braking begins, Vehicles A and B both travel a distance equal to d_{pr} at the design speeds of their respective highways and the rear of Vehicle B is just about to enter the intersection. It is then assumed that during the time interval from t_2 to t_3, Vehicle A must decelerate so that it does not enter the intersection until Vehicle B has cleared the intersection. These relationships can be expressed as follows:

$$d_a = d_{pr} + d_{dec} \qquad \text{(E-2)}$$

$$d_{pr} = 1.47\, V_a\, t_{pr} \qquad \text{(E-3)}$$

$$d_{dec} = 1.47 \left(\frac{V_a - a_r (t_3 - t_2)}{2.93} \right) (t_3 - t_2) \qquad \text{(E-4)}$$

$$t_3 - t_2 = \frac{W}{1.47\, V_b} \qquad \text{(E-5)}$$

where the speed, distance, and time variables are defined in Figure E-1. The deceleration rate (a_r) is expressed in units of mph/sec. Equation (E-1) is obtained by substituting Equation (E-5) into Equation (E-4) and then substituting Equations (E-3) and (E-4) into Equation (E-2).

A sensitivity analysis of Equation (E-1) conducted during the research found that the required ISD was very sensitive to both the speed of Vehicle A and the perception-reaction time. ISD was much less sensitive to the speed of Vehicle B and the width of the intersection. And, finally, there was almost no sensitivity of ISD to deceleration rate. This is unfortunate, because one of the most attractive features of the McGee et al. model is that it incorporates an explicit term for deceleration rate. It is also a concern that the sight distance required for Vehicle A decreases as the speed of Vehicle B increases, which seems counterintuitive.

It should be noted that, using the same input parameter values, the McGee et al. model actually requires less sight distance than the current AASHTO Case I model. This feature of the McGee et al. model makes it undesirable because our sensitivity analysis has found that the current Case I model does not provide sufficient time for drivers to adjust speeds.

There is also a conceptual concern in the use of Equation (E-1) as an ISD model. While most ISD models assume that both vehicles first sight each other at the same distance from the intersection (at least if the design speeds of the two roadways are the same), Equation (E-1) is based on the assumption that Vehicle B begins closer to the intersection than Vehicle A. This could lead to a problem; if Vehicle B were actually the same distance from the intersection as Vehicle A at time t_1, Vehicle A might not see Vehicle B in time to be able to decelerate sufficiently to avoid a collision.

Based on the problems noted and the lack of sensitivity to deceleration rate, the use of the McGee et al. model as a basis for ISD policy is not recommended.

Alternative ISD Model Developed by Harwood et al.

Harwood et al. (10) developed an alternative to the McGee et al. model as part of a recent FHWA study of the effects of truck characteristics on geometric design.

The ISD model in Equation (E-1) contains a deceleration term for which a truck deceleration rate could be used, but the equation does not explicitly consider vehicle length (which would also be needed to determine ISD Case I for trucks). Therefore, in 1990, Harwood et al. proposed a further modification of the McGee equation to incorporate both the length of the vehicle that has the right-of-way (L_b) and the deceleration rate of the vehicle that does not have the right-of-way (d_r):

$$ISD_a = 1.47\ V_a\ t_{pr} + \left(W + L_b\right)\frac{V_a}{V_b} - \frac{a_r\left(W + L_b\right)^2}{2.93\ V_b^2} \qquad \textbf{(E-6)}$$

where:

ISD_a = d_a; minimum intersection sight distance for Vehicle A (ft); (see Figure 2)

V_a = design speed for Vehicle A (mph)

V_b = design speed for Vehicle B (mph)

t_{pr} = perception-reaction time (sec) (assumed: t_{pr} = 2.0 sec)

W = width of roadway on which Vehicle A is traveling (ft)

L_b = length of Vehicle B (ft)

a_r = deceleration rate of Vehicle A (mph/sec) (Note: if the vehicle accelerates, a_r has a negative value.)

Hooper and McGee (32) indicated that a modification of this type to their model would be necessary if all of Vehicle B in Figure E-1 were not visible to Vehicle A at the beginning of the maneuver. Harwood et al. concluded that the same type of modification could be used to assure that the entire length of Vehicle B could clear the intersection.

A sensitivity analysis of the Harwood et al. model provides results very similar to those for the McGee et al. model from which it is derived. ISD in the Harwood et al. model is most sensitive to the speed of Vehicle A and the perception-reaction time. There is much less sensitivity to the speed of Vehicle B, the width of the intersection, and the length of Vehicle B. As in the McGee et al. model, there is almost no sensitivity of ISD to deceleration rate.

Our evaluation has concluded that the Harwood et al. model in Equation (E-6) has many of the same potential problems as the McGee et al. model in Equation (E-3). Therefore, the Harwood et al. model has not been recommended as a basis for ISD policy.

Alternative Model Based on Safe Approach Speed

Existing criteria for the installation of traffic control devices at intersections have incorporated the concept of "safe approach speed" or "critical approach speed." The MUTCD (23) uses the term "safe approach speed" and the Traffic Control Devices Handbook (TCDH) (5) uses the term "critical approach speed." These two terms are essentially equivalent. For convenience, the following discussion will use the term "safe approach speed" exclusively, since this is the term used in the MUTCD.

The safe approach speed is the threshold speed above which a vehicle approaching an intersection would not be able to react in time to avoid a possible accident. The safe approach speed is a measure of the available sight distance to which the prevailing vehicle speed on an intersection approach can be compared.

The STOP sign warrants in MUTCD Section 2B-5 do not contain any specific criteria for safe approach speed. However, the YIELD sign warrants in MUTCD Section 2B-8 state that YIELD signs may be warranted on an intersection approach where it is necessary to assign the right-of-way and where the safe approach speed exceeds 16 km/h (10 mph).

The TCDH provides more specific guidance on the installation of STOP and YIELD signs. The TCDH states that a roadway with a safe approach speed between 16 and 24 km/h (10 and 15 mph) would normally be controlled with a YIELD sign and a roadway with a safe approach speed of 16 km/h (10 mph) or less would normally be controlled with a STOP sign. Other considerations discussed in the MUTCD and TCDH can also warrant the use of STOP and YIELD signs. By implication, no control is permissible when the safe approach speed exceeds 24 km/h (15 mph), because a YIELD sign is not warranted.

The TCDH guidelines are, in effect, an ISD policy that is used widely by local agencies. These agencies assume that if the available sight distance on an intersection approach provides a safe approach speed greater than 24 km/h (15 mph), then that sight distance is adequate for uncontrolled operation of the intersection.

Research in 1981 by Stockton et al. (33) for FHWA endorsed the 16-km/h (10-mph) safe approach speed criterion to distinguish between locations for STOP and YIELD signs and suggested that a reduction to 8 km/h (5 mph) might be justified at low-volume intersections. Stockton et al. also concluded that further research was needed on the minimum safe approach speed to distinguish YIELD from uncontrolled operation.

The TCDH provides a chart for determining the safe approach speed of an intersection approach. Figure E-2 presents this chart and an accompanying intersection diagram that defines the distances used in the chart. The chart is entered by plotting a point on the horizontal axis representing the prevailing speed on the major road. Two points are then plotted representing (a,b), and (c,d), the location of the sight obstructions in the left and right quadrants of the approach, respectively. Lines are drawn connecting the plotted points and safe approach speeds for the sight distance available in the left and right quadrants are read from the vertical scale. The lower of the two values is the safe approach speed for the approach.

This TCDH chart was originally developed at the University of California—Berkeley. It has also appeared in the 1965 Traffic Engineering Handbook (34), in a textbook by Kennedy, Homburger, and Kell (35) and in the FHWA report by Stockton et al. (33).

Figure E-2 presents the assumptions on which this chart is based. There appear to be some potential problems with these assumptions. In particular, the assumed perception-reaction time is 1 sec, in contrast to 2 sec which is used in the AASHTO ISD policy. In addition, the assumed deceleration rate is 4.9 m/sec^2 (16 ft/sec^2). This is an extremely high deceleration rate for consideration in geometric design criteria, larger than those used in the AASHTO SSD policy. This deceleration rate represents an emergency maneuver, and it may not be achievable on a wet pavement because the vehicle will skid instead.

The authors have been unable to derive the results indicated by the chart in Figure E-2 from the assumptions presented there. In a telephone conversation with one of the authors, Dr. Wolfgang Homburger indicated that he had found the same problem. This chart, therefore, had been replaced in the 1980 edition of the textbook by Homburger and Kell (36), which is an update of the Kennedy, Homburger, and Kell textbook.

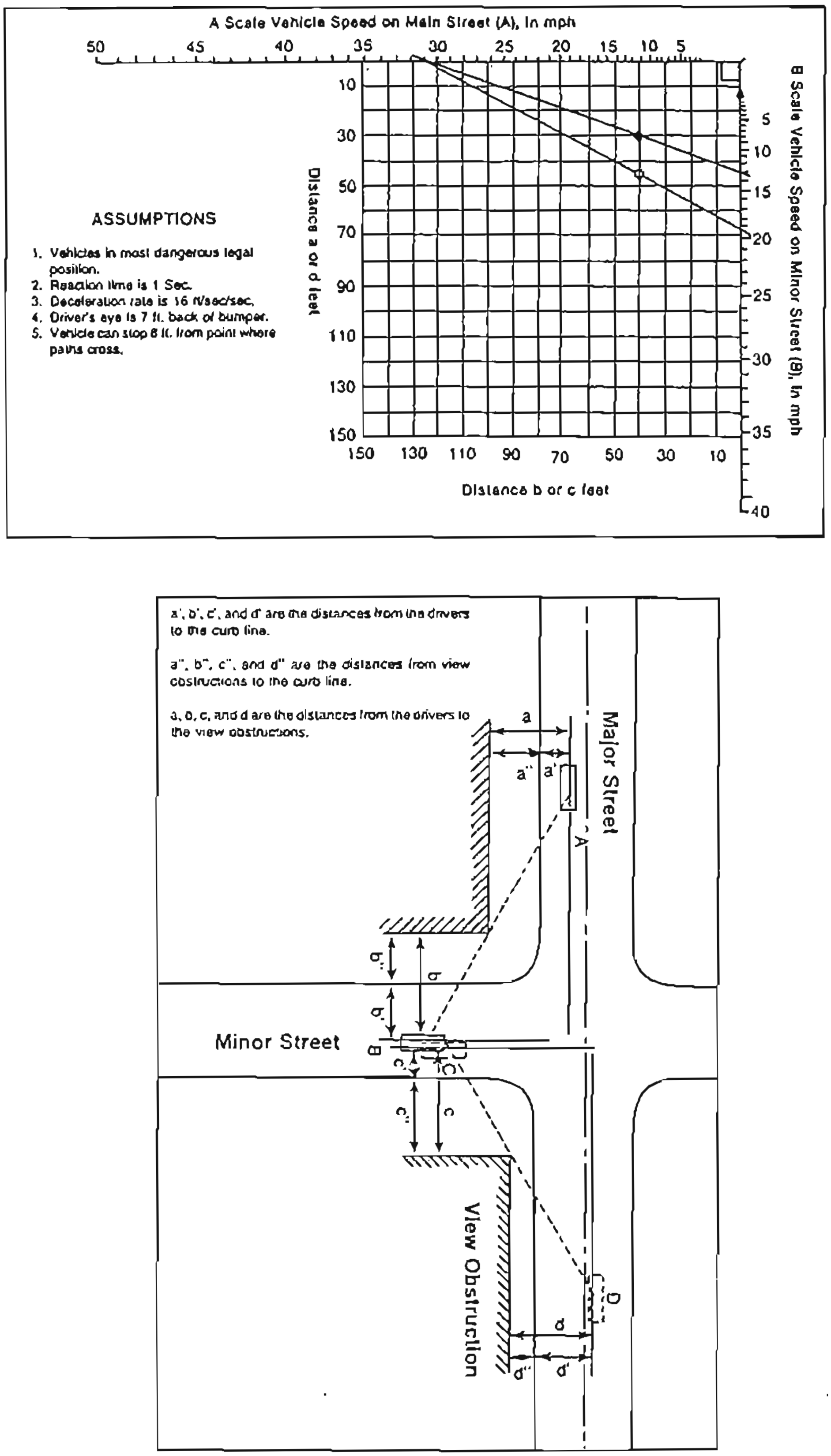


Figure E-2. **Safe approach speed method for intersection approaches presented in the Traffic Control Devices Handbook (5).**

The Homburger and Kell model (36) is based on analysis of a minor-road vehicle at the location closest to the intersection from which this vehicle can stop with a clearance margin of X_c before colliding with a major road vehicle. The following discussion shows how the Homburger and Kell model can be used to determine ISD as well as safe approach speed.

The leg of the sight triangle along the minor road is computed as:

$$ISD_a = 1.47\ V_a\ t_{pr} + \frac{(1.47\ V_a)^2}{2\ a_r} + X_c \tag{E-7}$$

where:

where:	ISD_a	=	leg of sight triangle along the minor road measured from the point at which the major- and minor-road vehicle paths cross (ft)
	V_a	=	speed of minor-road vehicle (mph)
	t_{pr}	=	perception-reaction time of minor-road driver (sec)
	a_r	=	maximum comfortable deceleration rate of the minor-road vehicle (ft/sec^2)
	X_c	=	clearance margin between stopped minor-road vehicle and the point at which the major- and minor-road vehicle paths cross (ft)

Because ISD in Equation (E-7) is computed from the point at which the vehicle paths cross rather than the curb line, ISD_a should technically be reduced by the value of a′ in Figure E-2. However, the value of a′ [typically 2 m (6 ft)] is trivial compared to the value of ISD_a.

The leg of the sight triangle along the major road required for the driver of the minor-road vehicle to stop before reaching the intersection is computed as:

$$t_s = t_{pr} + \frac{1.47\ V_a}{a_r} \tag{E-8}$$

$$ISD_b = 1.47\ V_b\ t_s \tag{E-9}$$

where:	t_s	=	maneuver time for minor-road vehicle (sec)
	V_b	=	speed of major-road vehicle (mph)
	ISD_b	=	leg of sight triangle along major road (ft); equivalent to the distance traveled by the major-road vehicle during t_s

The ISD model in Equations (E-8) and (E-9) provides enough sight distance to allow the minor-road drivers to avoid an accident as long as they make the decision to stop in time to complete the stopping maneuver before reaching the intersection.

The leg of the sight triangle along the major road required for the driver of the minor-road vehicle to continue at constant speed and cross the major road before a potentially conflicting major-road vehicle reaches the intersection is computed as:

$$t_s = \frac{(ISD_a + L_r)}{1.47\ V_a} + t_c \qquad \text{(E-10)}$$

$$ISD_b = 1.47\ V_b\ t_s \qquad \text{(E-11)}$$

where: L_r = remaining length of minor-road vehicle behind the location of the driver's eye (ft)

t_c = clearance margin between departure of minor-road vehicle from potential collision point and arrival of major-road vehicle (sec)

The ISD model is Equations (E-10) and (E-11) provides enough sight distance to allow minor-road drivers to avoid an accident provided that they makes the decision to proceed through the intersection without slowing down. If the larger of the two sight distance values that have been computed above is used, then there is enough sight distance to avoid an accident if the minor-road river decides either to stop or to continue through the intersection at constant speed. The only potential for an accident would arise from indecision on the part of the minor-road driver, e.g., slowing and then deciding to continue through the intersection.

Homburger and Kell assume the following values for these parameters in their model:

t_{pr}	1.0 sec
a_r	3.1 m/sec^2 (10 ft/sec^2)
X_c	4.6 m (15 ft)
L_r	4.6 m (15 ft)
t_c	3.0 sec

The authors of the current report have two concerns about these assumptions. First, the perception-reaction time (t_{pr}) of 1.0 sec seems too short, given that 2.0 sec is used by AASHTO for ISD applications and that our evaluation has recommended even greater perception-reaction time for uncontrolled intersections. Second, the clearance margin (t_c) of 3.0 sec between the major-road vehicles seems too long; a clearance margin of 1.0 sec may be adequate for safety.

Homburger and Kell extend these sight distance models to the computation of safe approach speed by determining the major-road leg of the available sight triangle when the minor-road vehicle is at a distance equivalent to ISD_a from the potential collision point. The major-road legs of the available sight triangles to the left and to the right are determined as:

$$d_L = \frac{ISD_a\ b}{ISD_a - a} \tag{E-12}$$

$$d_R = \frac{ISD_a\ d}{ISD_a - c} \tag{E-13}$$

where: d_L = distance along the major road to the left that can be seen by the minor-road driver (ft)

d_R = distance along the major road to the right that can be seen by the minor-road driver (ft)

a = a′ + a″, distance to view obstruction as defined in Figure E-2

b = b′ + b″, distance to view obstruction as defined in Figure E-2

c = c′ + c″, distance to view obstruction as defined in Figure E-2

d = d′ + d″, distance to view obstruction as defined in Figure E-2

The safe approach speed for the minor-road with respect to a vehicle approaching from the left on the major road can be determined by setting d_L equal to ISD_b and solving the resulting equation for V_a. The safe approach speed with respect to a vehicle approaching from the right can be determined in a analogous manner by setting d_R equal to ISD_b and solving for V_a.

A sensitivity analysis of the application of the Homburger and Kell safe approach speed model to ISD was conducted. A sensitivity analysis of Equation (E-7) found that ISD_a is most sensitive to the speed of Vehicle A and to the deceleration rate of Vehicle A. ISD_a is much less sensitive to perception-reaction time and is not at all sensitive to the clearance distance margin.

A sensitivity analysis of the sight distance along the major road required to accommodate stopping by the minor-road vehicle based on Equations (E-8) and (E-9) found that ISD_b is very sensitive to the speed of Vehicle A, the speed of

Vehicle B, and the deceleration rate of Vehicle A. However, ISD_b is not very sensitive to perception-reaction time.

A sensitivity analysis of the leg of the sight distance along the major road required to accommodate a crossing maneuver by the minor-road vehicle based on Equations (E-10) and (E-11) found that ISD_b is very sensitive to the speed of Vehicle B and is also moderately sensitive to the deceleration rate of Vehicle A. ISB_b is less sensitive to the time clearance margin for the crossing maneuver, perception-reaction time, and the speed of Vehicle A, while ISD_b is nearly insensitive to the distance clearance margin for the stopping maneuver and the remaining length of the Vehicle A behind the driver's eye.

The sight distance methodology in Equations (E-7) through (E-11), with the exceptions noted above, appears to represent traffic operations at uncontrolled intersections quite reasonably and might have been used in deriving ISD criteria, except that it does not incorporate the field observations that drivers on approaches to uncontrolled intersections normally slow down to 50% of their midblock running speed. Therefore, an alternative ISD model for uncontrolled intersections that incorporates this observation was formulated and has been recommended in Chapter Two.

ALTERNATIVE ISD MODELS FOR STOP-CONTROLLED INTERSECTIONS

Four alternative ISD models for STOP-controlled intersections that were proposed or in use prior to this research were reviewed during the research. These include the current AASHTO model with a variable speed reduction, a model developed by Fitzpatrick et al. (12), a model developed by the Arizona DOT, and a model developed by the Connecticut DOT. The following discussion documents each of these models and the reasons they were not recommended for use in ISD policy.

Current AASHTO Model With Variable Speed Reduction (Alternative 1)

Several state highway agencies have formulated models for Case IIIB based on speed reductions by the major-road vehicle to speeds other than 85% of the design speed. Such models have the general form:

$$Q = 1.47(SR*V)\ (J + t_a) \qquad \textbf{(E-14)}$$

where: SR = average speed reduction of major-road vehicle (expressed as a percentage of design speed on the major road)

The term SR*V in Equation (E-14) represents the average speed of the major-road vehicle during the deceleration maneuver. However, the term t_a, whether determined from Green Book Table IX-8 or from truck data, should be determined from the final speed to which the major-road vehicle decelerates (V_r), not the average speed of the major road vehicle (SR*V). Similarly the value of h should be determined as:

$$h = P - D - 1.5\,w_t - \frac{\pi R}{2} + 2R - 1.47\ V_r\,t_{vg} - L_a \qquad \text{(E-15)}$$

where: V_r = final speed reached by deceleration of major-road vehicle (mph); also speed to which minor-road vehicle must accelerate.

Equation (E-15) is identical to Equation (26) in Chapter Two. The conceptual problem with using Equation (E-15) in the variable speed model is that V_r in Equation (E-15) cannot be evaluated without knowing the relationship between the average speed (SR*V) and the final speed (V_r) of the major-road vehicle. For example, the AASHTO Case IIIB policy assumes that the average speed of the major-road vehicle is 95% of the design speed and the final speed is 85% of the design speed.

The variable speed model represented by Equation (E-14) and (E-15) cannot be used unless the relationship between the average speed and the final speed of the major-road vehicle is specified for various initial speeds. This could be done, but the modified AASHTO model presented in Equations (34) through (39) provides a better approach to evaluating variable speed reductions. Therefore, the use of Equations (E-14) and (E-15) is not recommended.

Alternative Model Developed by Fitzpatrick et al.

A model formulated by Fitzpatrick et al. (12), presented in Table E-1, was developed to reproduce the ISD Case IIIB model from the 1990 Green Book. This model successfully reproduces the 1990 values for Case IIIB within 3 to 10%. This model was originally formulated because the 1990 Green Book did not fully explain the AASHTO model for ISD Cases IIIB and IIIC. However, this model is not recommended because it sets both SR*V in Equation (E-14) and V_r in Equation (E-15) equal to 85% of the major-road design speed. Again, the modified AASHTO model presented in Equations (34) to (39) appears to provide a better approach to Case IIIB.

Alternative Model Developed by the Arizona DOT

The model used by the Arizona DOT for Case IIIB is an equation for sight distance that is meant to prevent rear-end collisions between turning vehicles and following major-road vehicles. This equation is intended to provide enough ISD to ensure that the major-road vehicle can stop if necessary.

The ISD is calculated as distance traveled by the major-road vehicle while minor-road vehicle enters the highway plus the braking distance for major-road vehicle (equal to second term of the AASHTO SSD equation) minus the distance traveled by minor-road vehicle during the major-road vehicle's braking maneuver plus the length of the minor-road vehicle. The Arizona DOT model for ISD is:

$$ISD = 1.47V_a(t_x + 1) + \frac{V_a^2}{30(f \pm G)} - \left[1 + \frac{(V_a)^2}{30(f \pm G)} * \frac{2}{1.47\ V_a}\right] A_f\ G_f + L \tag{E-16}$$

where:

ISD = required intersection sight distance (ft)

V_a = speed of major-road vehicle (mph)

t_x = time required for stopped vehicle to accelerate and travel a distance X (sec) (note: the 1.0 sec added to t_x in Equation (E-16) represents perception-reaction time)

f = coefficient of braking friction

G = percent grade in decimal form

A_f = acceleration factor for stopped vehicle (equal to 26 for passenger cars and 15 for truck and buses)

G_f = adjustment factor for grade effect

L = length of turning vehicle (ft)

The distance X is equal to:

$$X = D + Z \tag{E-17}$$

where:

X = distance which stopped vehicle must travel to make the turn-in-front movement apparent to the approaching vehicle

D = distance traversed from the stopping position of the minor-road vehicle to edge of the traveled way (ft) (assumed minimum: D = 6 ft)

Z = length of pavement along turning path of entering vehicle, measured from the edge of the traveled way to the front end location of the vehicle when it reaches the center of the intended lane of travel (ft)

Equation (E-16) makes intuitive sense. The inclusion of the first term of the equation representing the distance traveled by the major-road vehicle during the entering vehicle's initial maneuver is essentially equivalent to perception-reaction time for the major-road vehicle. At the end of this time, the minor-road vehicle has entered the roadway and is beginning to accelerate to speed. The addition of the second term of the AASHTO SSD model stopping sight distance accounts for the braking of the major-road vehicle. The third term of the equation accounts for the distance traveled by the minor-road vehicle during the time that the major-road vehicle is braking. Since the minor-road vehicle is in the roadway and beginning to accelerate away from the decelerating major-road vehicle, this term has a negative sign. Finally, the required ISD is increased by the length of the minor-road vehicle. This accounts for the fact that the front-end of the minor-road vehicle was the reference point for the first two terms of the equation, whereas the potential collision point between the major- and minor-road vehicles would be at the rear end of the minor-road vehicle.

The weakness of the Arizona model is that it is based on stopping by the major-road vehicle. This contradicts the normal right-of-way rule and assumes that the major-road vehicle should be prepared to stop to accommodate a turning maneuver by the minor-road vehicle, rather than the other way around. Furthermore, a complete stop by Vehicle B should not be necessary except in an emergency situation involving a misjudgment by one or more of the involved drivers; Vehicle B needs only to slow to the speed of Vehicle A, which is accelerating. The Arizona DOT model was not pursued further in the research because the modified AASHTO model presented in Equations (34) to (39) appeared to be a superior method for evaluating ISD requirements at STOP-controlled intersections.

Alternative Model Developed by the Connecticut DOT

The Connecticut Department of Transportation (ConnDOT) conducted a research study in 1985 to develop a modified formulation for the AASHTO Case IIIB model. Specifically, ConnDOT was concerned that pertinent factors in the Case IIIB situation were not accounted for by the AASHTO model. These included perception-reaction times for both the minor-road and major-road vehicles. Additionally, concerns were raised by ConnDOT regarding the validity of the vehicle acceleration rates used by AASHTO (which were subsequently updated for the 1990 Green Book). Finally, concerns were raised regarding the lack of a specified value for the vehicle gap or tailgate distance in the 1984 Green Book and the use of average running speed as the final speed of the major-road vehicle. This vehicle gap value has now been specified in the 1990 Green Book as a distance equivalent to 2.0 sec of travel time at 85% of the major-road design speed.

The alternative model that resulted from the ConnDOT research is:

$$ISD = 1.47\left[(DS*J1) + \frac{(DS^2 - RS^2)}{2XD} + (RS*TR)\right] - (X_a - 35 - TG) \qquad \textbf{(E-18)}$$

where:

DS = design speed (mph)

RS = reduced speed of major-road vehicle (mph) (assumed: RS = 0.9 DS)

X = width of opposing lanes (ft)

D = deceleration rate (mph/sec) (assumed: D decreases from 1 mph/sec at 30 mph to 1.55 mph/sec at 70 mph)

J1 = perception-reaction time of major-road vehicle (sec)

TR = time at reduced speed (sec)

X_a = distance accelerating vehicle travels (ft)

TG = tailgate distance (ft) (assumed: TG equal to one car length for every 10 mph)

Based on their research, ConnDOT provided tables for the parameters X, J1 and D. TR, the time at the reduced speed, can be computed as:

$$TR = TA + J2 - J1 - TD \qquad \textbf{(E-19)}$$

where:

TA = time required for minor-road vehicle to accelerate to speed RS (sec)

J2 = perception-reaction time of minor-road vehicle (sec assumed J2 = 1.0 sec)

TD = time for major-road vehicle to decelerate from design speed (DS) to reduced speed (RS)

The ConnDOT model appears to be a promising approach to Case IIIB. However, the modified AASHTO model presented in Equations (34) to (39) incorporates several of the key concepts included in the ConnDOT model, including consideration of the perception-reaction time for both the major-road and minor-road vehicles. Therefore, the ConnDOT model was not pursued further as a basis for ISD at STOP-controlled intersections.

APPENDIX F

FIELD STUDIES OF DRIVER GAP ACCEPTANCE BEHAVIOR AND ACCELERATION/DECELERATION RATES IN TURNING MANEUVERS AT STOP-CONTROLLED INTERSECTIONS

This appendix describes the field observational studies that were conducted at selected intersections to evaluate alternative models for ISD for right and left turns from the minor road at STOP-controlled intersections. The primary purpose of these field studies was to provide data to assess the appropriate values of the parameters of the alternative models for this ISD case presented in Chapter 3 of this report: a gap acceptance model and a modified AASHTO model based on the acceleration rates, deceleration rates, and perception-reaction times of major- and minor-road vehicles. The field studies were performed by videotaping traffic operations at each of the study intersections, typically during both peak and off-peak conditions. During the same time periods, traffic data recorders placed on the roadway in the lanes of the major roadway in the intersection area recorded the speed, length, and arrival time of each vehicle on the major road both upstream and downstream of the intersection. These data were reduced and analyzed to quantify the parameters of the gap acceptance and acceleration/deceleration models. The remainder of this appendix describes the data collection, reduction, and analysis activities.

FIELD STUDY INTERSECTIONS

Field observational data for STOP-controlled intersections were collected at a total of 13 intersections located in Illinois, Missouri, and Pennsylvania. A total of 229.5 hr of traffic observational data were collected at STOP-controlled intersections, representing a total of 44 days of field data collection. In addition to the gap acceptance and acceleration/deceleration studies, studies of vehicle stopping positions on the STOP-controlled minor-road leg were performed at each of these intersections; at 1 of the 13 intersections, only stopping position studies were performed. The collection, reduction, and analysis of the stopping position data is discussed in Appendix H.

The 13 field study intersections were located in two major geographic regions of the United States: the Northeast and Midwest. Table F-1 summarizes the characteristics of the field study intersections. Of the 13 field study intersections, two were located in Illinois, four in Missouri, and seven in Pennsylvania.

Table F-1. CHARACTERISTICS OF STOP-CONTROLLED INTERSECTIONS INCLUDED IN FIELD STUDIES

Site number	Area type	Number of legs	Orientation of approach legs studied		Estimated ADT (veh/day)		Available ISD for minor-road driver, m (ft)[a]				Posted speed limit on major-road approach, km/h (mph)		Remarks
							NB/EB approach		SB/WB approach				
			Major road	Minor road	Major road	Minor road	to left	to right	to left	to right	NB/EB	SB/WB	
IL01	Fringe	3	EB/WB	NB	10,600	2,000	Unlimited[b]	Unlimited	-	-	80 (50)[c]	80 (50)[c]	
IL02	Rural	3	EB/WB	SB	9,700	4,700	-	-	370 (1,200)	340 (1,100)	88 (55)[d]	88 (55)[d]	
MO01	Fringe	3	NB/SB	WB	11,200	2,000	-	-	410 (1,330)	440 (1,420)	80 (50)	72 (45)	
MO02	Suburban	4	EB/WB	SB	11,000	-	-	-	310 (1,000)	320 (1,050)	88 (55)	88 (55)	
MO03	Suburban	4	EB/WB	SB	8,000	3,500	-	-	330 (1,060)	450 (1,470)	72 (45)	72 (45)	Flashing beacon
MO04	Suburban	3	EB/WB	SB	10,200	6,600	-	-	180 (600)	Unlimited	56 (35)	56 (35)	
PA01	Rural	3	NB/SB	EB	-	-	270 (880)	80 (250)	-	-	72 (45)	72 (45)	
PA02	Rural	3	NB/SB	WB	-	-	-	-	320 (1,030)	270 (880)	72 (45)	72 (45)	
PA03	Rural	4	NB/SB	WB	13,500	3,900	-	-	140 (440)	90 (280)	72 (45)	72 (45)	
PA04	Rural	4	NB/SB	EB	5,100	3,200	210 (670)	260 (830)	-	-	72 (45)	72 (45)	Flashing beacon
PA05	Suburban	4	NB/SB	EB/WB	3,600	4,800	420 (1,350)	240 (760)	170 (530)	420 (1,350)	72 (45)	72 (45)	
PA06	Rural	4	EB/WB	SB	1,750	3,200	-	-	30 (80)	250 (800)	72 (45)	72 (45)	
PA07	Rural	4	NB/SB	EB/WB	-	-	Unlimited	150 (460)	190 (600)	Unlimited	72 (45)	72 (45)	

[a] Measured from a position on the minor-road approach 6 m (20 ft) from the edge of the major-road traveled way, as prescribed in the current AASHTO policy for ISD Cases IIIB and IIIC.
[b] Unlimited sight distance means at least 600 m (2,000 ft).
[c] Advisory speed of 72 km/h (45 mph) on major road.
[d] Advisory speed of 64 km/h (40 mph) on major road.

As shown in Table F-2, a total of 229.5 hr of data collection were performed at these 13 intersections. As shown in the table, 8.0 hr of data collection were performed over 3 days at the two Illinois intersections, 81.0 hr over 16 days at the four Missouri intersections, and 140.5 hr over 25 days at the seven Pennsylvania intersections.

Of the 13 field study intersections, six had three legs, while the remaining seven were four-way intersections. A total of 97.5 hr over 20 days were conducted at three-leg intersections, with the remaining 132.0 hr over 24 days of data collection were performed at four-leg intersections.

Field observational studies of both left- and right-turn maneuvers were conducted at many of the study intersections. A total of 121.0 hr of data collection over 24 days were performed for left-turn maneuvers, while 102.5 hr of data collection over 19 days were performed for right-turn maneuvers. The specific intersection approaches and turning maneuvers selected for data collection were based on the traffic volumes and turning movement patterns observed in the field for various times of the day. Naturally, at three-leg STOP-controlled intersections, all of the data collection involved turns from the single minor-road approach. In several cases, at four-leg intersections, data for left- and right-turn maneuvers were collected for both minor-road approaches.

Several of the study intersections had relatively high volumes of trucks turning onto the major road. Site MO02, in particular, was selected because it provided access to a state highway from a major warehouse and storage facility served by many large trucks.

Table F-3 summarizes the accident experience at each of the study intersections for periods of three to five calendar years. The table is limited to accidents that involved vehicles making the specific turning maneuvers studied in the field from the specific intersection approaches studied. None of the study intersections experienced more than 0.7 accidents per year associated with the turning movement of interest, and many of the intersections experienced no accidents associated with that particular turning movement. Thus, it can be documented that the intersections on which the research recommendations are based operate safely.

FIELD DATA COLLECTION PROCEDURES

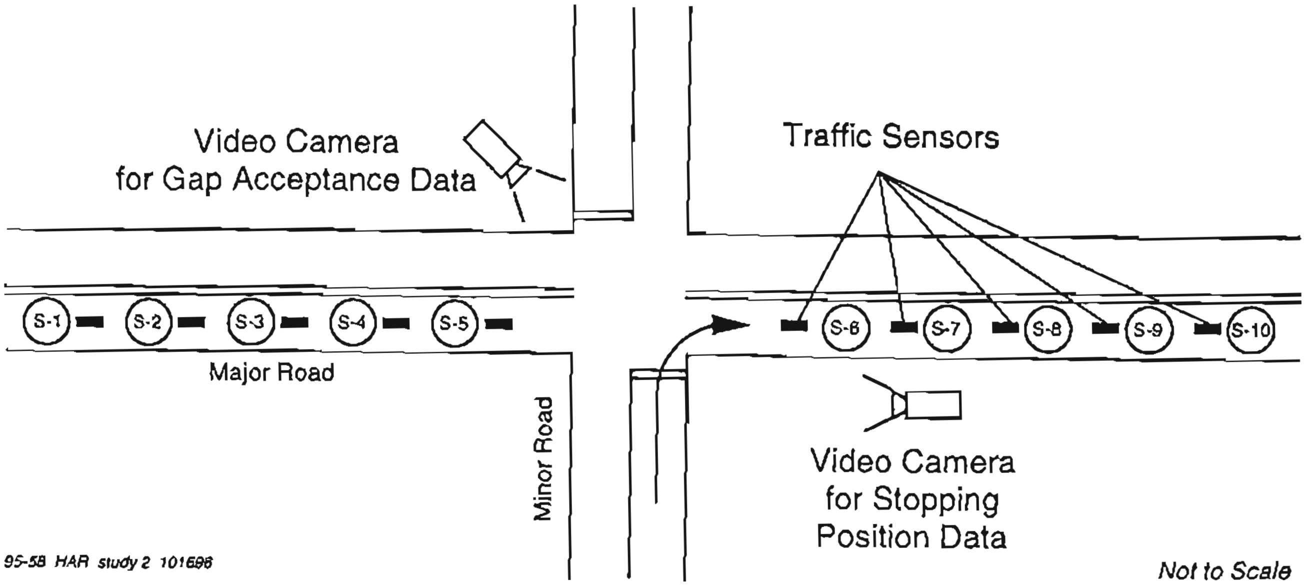
Figure F-1 illustrates typical data collection setups for field studies of left- and right-turn maneuvers. The video cameras were used to visually record the traffic operations at the intersection proper. At most intersections, only one video camera was necessary to obtain the data needed for the gap acceptance

Table F-2. SUMMARY OF DATA COLLECTION PERIODS FOR FIELD STUDIES AT STOP-CONTROLLED INTERSECTIONS

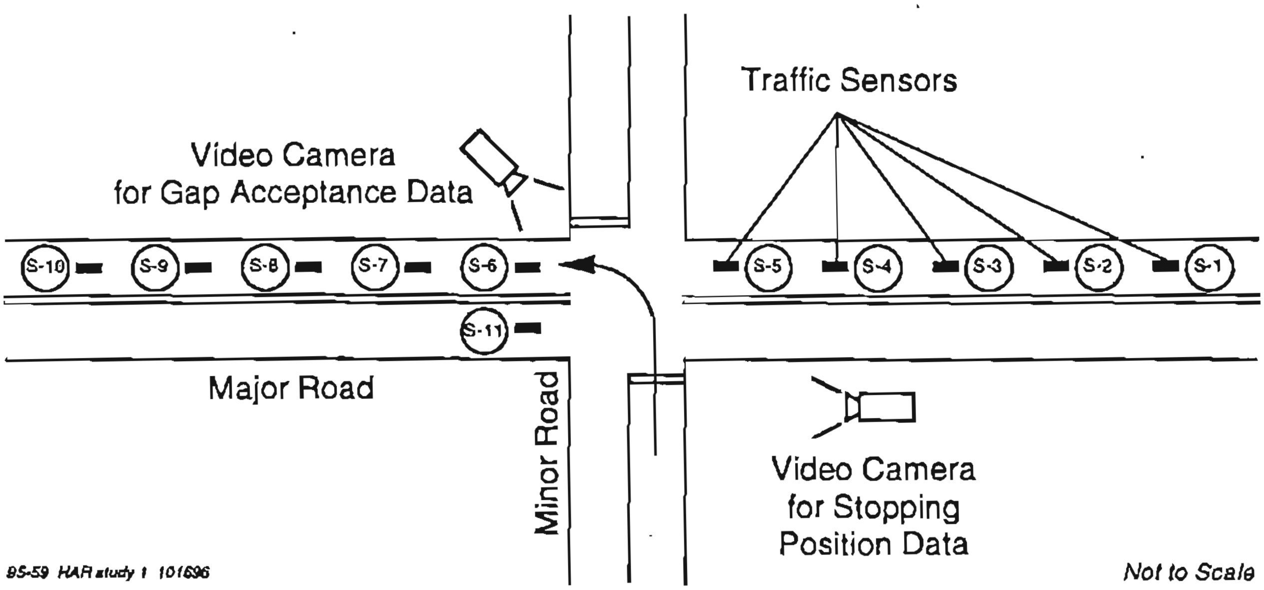
Site number	Minor-road approach studied	Turning maneuver studied	Total duration of study (hr)	Study date	Time of day/conditions
IL01	NB	Right turn	2.0	4/13/94	AM peak
IL01	NB	Left turn	4.0	4/13/94	Off peak
IL02	SB	Left turn	2.0	4/14/94	AM peak
MO01	WB	Right turn	4.0	3/9/94	PM peak, off peak
MO01	WB	Left turn	4.0	3/10/94	PM peak, off peak
MO02	SB	Right turn	16.0	3/15/94, 6/24/94, 6/27/94	Off peak, heavy truck volumes
MO02	SB	Left turn	10.0	3/16/94, 6/28/94	Off peak, heavy truck volumes
MO03	SB	Right turn	9.0	3/14/95, 11/2/94	PM peak, off peak
MO03	SB	Left turn	15.0	3/17/94, 3/18/94, 11/3/94	PM peak, off peak
MO04	SB	Right turn	11.0	10/25/94, 10/28/94	PM peak, off peak
MO04	SB	Left turn	12.0	10/26/94, 10/27/94	PM peak, off peak
PA01	EB	Right turn	12.0	5/20/94, 10/14/94	PM peak, off peak
PA01	EB	Left turn	23.5	12/3/93, 5/27/94, 8/23/94, 10/11/94, 10/12/94	PM peak, off peak
PA02	WB	Right turn	11.5	6/8/94, 9/2/94	PM peak, off peak
PA02	WB	Left turn	11.5	6/7/94, 9/23/94	PM peak, off peak
PA03	WB	Left turn	8.0	9/7/94, 9/8/94	Off peak
PA04	EB	Right turn	6.0	9/16/94	Off peak
PA04	EB	Left turn	7.0	9/15/94	Off peak
PA05	EB	Right turn	7.0	9/22/94	Off peak
PA05	EB	Left turn	6.0	9/21/94	Off peak
PA05	WB	Right turn	6.0	9/18/94	Off peak
PA05	WB	Left turn	6.0	9/19/94	AM peak, off peak
PA06	SB	Right turn	6.0	9/28/94	Stopping position data only
PA07	EB	Right turn	12.0	9/39/94, 10/7/94	PM peak, off peak
PA07	EB	Left turn	6.0	10/4/94	Off peak
PA07	WB	Right turn	6.0	10/6/94	AM peak, off peak
PA07	WB	Left turn	6.0	10/5/94	Off peak
		TOTAL	229.5		

Table F-3. SUMMARY OF ACCIDENT HISTORY OF STOP-CONTROLLED FIELD STUDY INTERSECTIONS

Site number	Minor-road approach studied	Turning maneuver studied	Number of reported accidents					Accidents per year
			1990	1991	1992	1993	1994	
IL01	NB	Right turn	0	0	0	-	-	0.0
IL01	NB	Left turn	1	0	0	-	-	0.3
IL02	SB	Left turn	0	0	0	-	-	0.0
MO01	WB	Right turn	0	0	0	-	-	0.0
MO01	WB	Left turn	0	0	0	-	-	0.0
MO02	SB	Right turn	0	0	0	-	-	0.0
MO02	SB	Left turn	0	0	0	-	-	0.0
MO03	SB	Right turn	0	0	0	-	-	0.0
MO03	SB	Left turn	0	1	1	-	-	0.7
MO04	SB	Right turn	0	0	0	-	-	0.0
MO04	SB	Left turn	0	0	0	-	-	0.0
PA01	EB	Right turn	0	1	0	0	0	0.2
PA01	EB	Left turn	0	0	0	0	0	0.0
PA02	WB	Right turn	0	0	0	0	0	0.0
PA02	WB	Left turn	0	0	0	0	0	0.0
PA03	WB	Left turn	1	0	0	0	0	0.2
PA04	EB	Right turn	0	0	0	0	0	0.0
PA04	EB	Left turn	0	0	0	0	0	0.0
PA05	EB	Right turn	0	0	0	0	0	0.0
PA05	EB	Left turn	0	0	2	0	0	0.4
PA05	WB	Right turn	0	0	0	0	0	0.0
PA05	WB	Left turn	1	0	0	2	0	0.6
PA06	SB	Right turn	0	0	0	0	0	0.0
PA07	EB	Right turn	0	0	0	0	0	0.0
PA07	EB	Left turn	0	0	0	0	0	0.0
PA07	WB	Right turn	0	0	0	0	0	0.0
PA07	WB	Left turn	0	0	0	0	0	0.0



Field Studies of Right-turn Maneuvers



Field Studies of Left-turn Maneuvers

Figure F-1. Typical data collection setups for field studies at STOP-controlled intersections.

studies. The second camera provided a backup for the gap acceptance studies and was also used for the stopping position studies described in Appendix H. The gap acceptance camera provided a view of a minor-road vehicle as it approached the intersection, stopped at the STOP sign, and then proceeded to turn left or right into the major-road traffic stream. This camera also provided a view of each major-road vehicle as it passed through the intersection.

The field studies used HI-STAR NC-90 sensors placed on the pavement surface along the major road upstream and downstream of the intersection to record the speed, length, and arrival time of each individual vehicle that passed over the sensor. The sensors were placed at intervals of 60 to 120 m (200 to 400 ft). The sensor locations and spacings were determined for each site to avoid driveways where vehicles might turn on the intersection legs. The farthest upstream sensor was typically placed at a location before the intersection or any advance signing came into view, so that vehicle speeds beyond the influence area of the intersection could be determined. In a left- or right-turn maneuver, the sensors downstream of the intersection recorded the speeds of the minor-road vehicle at each sensor as it accelerated to complete its turning maneuver. The speeds of the next following major-road vehicle were recorded by the sensors both upstream and downstream of the intersection. These data were used to determine how the speed profile of the major-road vehicle was influenced by the minor-road vehicle's turning maneuver. Each sensor was approximately 330 mm (13 in) thick, 150 mm (6 in) wide, and 6 mm (0.25 in) thick. The sensors were attached to the roadway surface with gray duct tape in the center of the appropriate travel lane of the major road. The size and color of the sensors and the tape was such that they were relatively inconspicuous to oncoming motorists.

During the field studies, each video camera was set up at the location that provided the best vantage point to record the traffic operations at the intersection. In most cases, as shown in Figure F-1, the video camera recording the gap acceptance data was placed on the opposite side of the intersection from the study approach, while the camera recording the vehicle stopping position was on the same side of the intersection as the study approach. At other intersections, if a better view could be obtained, both cameras were placed on the same side of the intersection. The camera locations depended primarily on the local terrain, using elevated positions whenever possible to obtain a better view.

Field observers were present at each site during the videotaping to make sure that the equipment was operating properly and to identify any unusual traffic events so that they could be excluded from the study periods. The observers remained in a concealed location during as much of the study period as possible.

Since data from two video cameras and up to 11 traffic data recorders were used together in the data analysis, all of these devices had to be synchronized. Therefore, a procedure was developed to convert the times recorded by each device to a common time base.

Each video camera was connected to an external character generator that superimposed on the videotape the elapsed time from the beginning of the study period to the nearest tenth of a second. Each traffic data recorder was programmed for a specific start time using a laptop computer; the internal clock of the data recorder was set based on the time from the internal time clock of the laptop computer. Thus, the laptop computer provided the common time base for all of the traffic data recorders. A program developed for this research displayed the internal clock of the laptop in large characters filling the entire screen display, so that the numbers were several inches high. With this program running, the laptop computer was held in view of each video camera at the beginning of the 2-hr videotape and at periodic intervals during the study. This allowed the data from the two video cameras to be placed on the common time base that was also by the traffic data recorders. Thus, the laptop computer served as the master time for the entire study.

DATA REDUCTION ACTIVITIES

Once the data collection activities were performed, efforts focused on reducing the data to a usable format. The first step in reducing the data was to extract data from the videotapes on the gap acceptance behavior of drivers turning left and right from the minor road. Then, a set of maneuvers with relatively short gaps was identified and the speed profile of the minor-road vehicle and the next following major-road vehicle were determined from the data recorded by the traffic sensors.

Gap Acceptance

The objective of the first data reduction effort was to determine the gap acceptance/rejection behavior of each minor-road driver as he/she waited to enter the major-road traffic stream. These data were determined from review of one of the videotapes recorded in the field.

An initial review or screening of each gap acceptance/rejection videotape was performed to select those tapes that were the best candidates for complete data reduction. Six of the 118 videotapes were excluded because the video camera was misaimed during all or part of the study. Other videotapes were excluded because traffic volumes were lower than desired, so there would be few potential conflicts between major-road vehicles and turning vehicles from the minor road. Based on this screening process, 63 videotapes (or approximately 53% of the entire data set) were selected as the highest priority for data reduction. These high-priority videotapes were then reduced and analyzed.

The field data set includes observations of driver acceptance and rejection of gaps and lags of various lengths. A gap is the time headway between two vehicles on the major road into which a minor-road vehicle may choose to turn. A lag is the portion of a gap that remains when the minor-road vehicle first arrives at the stop line or first begins to move onto the major road. Gap lengths were measured in the study by the elapsed time from the crossing of the centerline of the intersection by one vehicle until the crossing of the centerline of the intersection by the next.

To perform the data reduction, each 2-hr tape was watched in real time. As each event of interest occurred, the videotape was slowed or freeze-framed to find the precise video frame on which that event was observed. The following data were recorded for each vehicle on the minor-road approach:

- Vehicle type (passenger car/single-unit truck/combination truck).
- Vehicle color (or other identifying characteristic).
- Time of arrival at the STOP sign or stop line (i.e., the first complete stop by the minor-road vehicle, or, if a queue was present on the minor road, the time at which the vehicle of interest became the first in the queue).
- Time of departure from the STOP sign or stop line to enter the major road.
- Maneuver executed (e.g., left turn, right turn, straight through).

The arrival and departure times were determined from the elapsed time (to the nearest tenth of a second) that was superimposed on each video frame by the video camera.

The minor-road vehicle was not necessarily stopped for the entire interval between the recorded arrival and departure times. During this interval, the minor-road driver often crept forward to get a better view or to start from a position closer to the major road. In many instances, the minor-road vehicle never completely stopped, but executed a maneuver often called a "rolling stop," i.e., the vehicle slowed gradually as it approached the intersection, and then accelerated into the major-road traffic stream without coming to a complete stop. In these situations, the departure time was taken from the video frame in which the vehicle began to accelerate markedly and continuously onto the major road. This was often seen on the videotape as a release of the brake lights or a sudden increase in the vehicle's speed. When this occurred, the arrival time was coded as 0.1 sec less than the departure time as a flag that the minor-road vehicle never completely stopped.

Arrival times were also recorded for each major-road vehicle that passed through the intersection while the minor-road vehicle was present at the intersection, as well as for the immediately preceding and following major-road vehicles. The process was intended to determine the arrival times of the major-road vehicles that bounded each gap in minor-road traffic considered by the driver of each minor-road vehicle. For a right-turn study, data were recorded only for vehicles in the near lane of the major road. For a left-turn study, data were recorded for major-road vehicles in both the near and far lanes.

The data recorded for major-road vehicles was similar to the data recorded for minor-road vehicles. Specifically, the following data were recorded for each major-road vehicle:

- Vehicle type (passenger car/single-unit truck/combination truck).
- Vehicle color (or other identifying characteristic).
- Arrival time (time at which the major-road vehicle crossed the centerline of the intersection).

The centerline of the intersection used to record major-road vehicle arrival times was defined as the extension of the centerline of the minor-road approach across the intersection.

Careful quality assurance procedures were implemented for each videotape that was reduced. After the data reduction for each videotape was completed, the videotape and the recorded data were given to another reduction team member who checked several entries (two or three per page) at random. This procedure assured that any systematic errors in data reduction were detected. In addition, a simple visual scan of the entire recorded data set also served to catch any errors that might not be caught in a random check, such as two minor-road vehicles having the same arrival time was recorded.

Upon completion of the quality assurance procedures, the data were keyed for subsequent analysis. All of the keyed data were reviewed to identify and correct keying errors.

The analysis of these data to determine the gap acceptance/rejection behavior of drivers on the minor-road approach is discussed below.

Acceleration/Deceleration Study

The objective of the second data reduction activity was to determine the acceleration rates used by minor-road vehicles in turning maneuvers and the speed reductions and deceleration rates used by the following major-road vehicles. These acceleration and deceleration rates and speed reductions were of interest only for situations in which the following major-road vehicle was close enough to the turning minor-road vehicle that its speed choice was influenced by the turning vehicle. Therefore, the data reduction for the acceleration/deceleration study was limited to turning maneuvers for which the accepted gap or lag was 10 sec or less. Turning maneuvers that met this criterion were identified in the data from the gap acceptance study.

It was originally hoped that the identification and tracking of vehicles through the HI-STAR sensor data could be automated so that vehicles from the gap acceptance data could be identified in the HI-STAR data and traced from sensor to sensor by a computer program. The commercially available HI-STAR Model NC-90 sensors record vehicle arrival times only to the nearest second. Greater precision was needed for tracking vehicles, so it was arranged with the manufacturer of the HI-STAR sensors to make an engineering modification, involving hardware and software changes, so that vehicle arrival times were recorded to the nearest tenth of a second. However, even with modification, it was found that the vehicle tracing could not be automated because the HI-STAR sensors did not always begin data collection at their preprogrammed times; variations up to several minutes were not unusual. Therefore, it was determined that the vehicle tracing had to be performed manually. A long vehicle, such as a large combination truck, traveling along the major road could usually be found in the data recorded by each major-road sensor and could, therefore, be used to determine the approximate time offsets between the sensors. The fact that the time offsets between the sensors were known only approximately did not limit our ability to compute acceleration and deceleration rates because the locations of the sensors and, the distances between them, were known exactly.

The vehicle tracing was performed by obtaining printouts of the sequence of vehicles passing over each major-road sensor during the entire study period. These printouts were typically placed on a long table in the same sequence as the sensors on the road.

Next, a particular turning maneuver was identified for tracing. This involved finding in the gap acceptance data a particular turning maneuver for which the accepted gap or lag was 10 sec or less. The duration of the accepted gap or lag, the vehicle types of the minor- and major-road vehicles, and the clock times at which they passed through the intersection were noted.

A logical starting point for tracing a particular vehicle along the major road was in the data for the major-road sensor immediately upstream of the intersection. This sensor was typically about 38 m (125 ft) upstream of the centerline of the intersection. The major-road vehicle was identified on the printed output from the HI-STAR sensor by looking for a vehicle of the appropriate length, with a headway approximately equal to the accepted gap, at approximately the correct clock time.

Once the major-road vehicle was identified at the first upstream sensor, it was manually traced backwards in time through the remaining upstream sensors and forwards in time through the downstream sensors. When this tracing was complete, the speed of the major-road vehicle as it crossed each sensor was noted and these speeds were entered on a data form. This process was then repeated for the minor-road vehicle, which was the vehicle immediately preceding the major-road vehicle in the data for each of the sensors downstream of the intersection. The vehicle length and headway of the minor-road vehicle were checked in the data for each downstream sensor to assure that the correct vehicle was being traced. The speed of the minor-road vehicle as it crossed each downstream sensor was then entered on the same data form described above.

In a few cases, where there were driveways or other access points between sensors, vehicles entering the roadway and interfering with a particular maneuver of interest were noted. These cases were extremely rare, but could be easily recognized by the reduction in vehicle headways and speeds downstream of the driveway. Where such events were found, those data points were dropped from further consideration.

In summary, the following data were obtained from the vehicle tracing process:

- The vehicle number of the minor-road vehicle from the gap acceptance data.
- The vehicle number of the major-road vehicle from the gap acceptance data.
- The time at which the minor-road vehicle crossed the first sensor downstream of the intersection.
- The time at which the major-road vehicle crossed the first sensor downstream of the intersection.
- The speed of the minor-road vehicle at each sensor location downstream of the intersection.
- The speed of the major road vehicle at each sensor location both upstream and downstream of the intersection.

DATA ANALYSIS ACTIVITIES

The data analysis activities for the gap acceptance and acceleration/ deceleration studies are briefly described below. The analysis results are presented in Chapter Three of the report.

Gap Acceptance Study

Acceptance and rejection of gaps and lags are evaluated as follows. When the minor-road vehicle first arrives at the stop line, the driver evaluates the lag represented by remaining portion of the current gap in traffic on the major road in the lane the minor-road driver plans to enter (the near lane for right turns and the far lane for left turns). If the minor-road driver accepts the initial lag and enters the major road, the length of the accepted lag was noted and the consideration of that minor-road vehicle ended. If the minor-road driver rejects the initial lag, then the length of the rejected lag was noted, and the driver then considered each subsequent gap, in turn. If the driver rejects a particular gap, the length of the rejected gap was noted by the program and the driver then considered the next gap. If the driver accepts a gap, the length of the accepted gap was noted and the next minor-road vehicle was then considered. Whenever a gap is accepted, the length of both the accepted gap and the accepted lag (to the next major-road vehicle) were recorded.

The only maneuvers considered were those for which there was no interference from other vehicles that could have affected the gap acceptance behavior of the minor-road vehicle. For example, gaps accepted by right-turning vehicles were excluded if the following major road turned right or left at the intersection rather than continuing straight ahead; gaps accepted by left-turning vehicles were excluded if the following vehicle in the far lane of the major road made a right or left turn or if a near-lane vehicle was present on the major road within the current AASHTO ISD for the major-road approach plus 2 sec. These criteria for interference by other vehicles were purposely made quite conservative to assure that no interference is present in any of the observations that are included in the analysis.

A total of 4,277 minor-road vehicles were observed turning right onto the major road in the full data set. Of these 4,277 vehicles, a total of 2,758 right-turning vehicles accepted the initial lag that was in progress when they arrived at the stop line on the minor road, and 1,519 minor-road vehicles rejected the initial lag. Of the subsequent minor-road gaps that were considered by the right-turning drivers, 1,758 gaps were rejected and 1,519 were accepted; in other words, sooner or later, each of the 1,519 turning vehicles accepts some particular gap. In summary, a total of 7,554 acceptance/rejection decisions were evaluated by right-turning drivers, resulting in 4,277 acceptances and 3,277 rejections. A total of

1,311 of the acceptance/rejection decisions (or 17% of the total decisions) were excluded from consideration because of potential interference from other vehicles with the gap acceptance/rejection decision. However, a total of 6,243 decisions (3,341 acceptances and 2,902 rejections) provided usable data. These 6,243 usable right-turn decisions included 5,356 right-turn decisions by passenger cars (86%), 363 right-turn decisions by single-unit trucks (6%), and 524 right-turn decisions by combination trucks (8%).

A total of 2,388 minor-road vehicles were observed turning left in the gap acceptance data set. Of these 2,388 vehicles, 1,104 accepted the initial lag that was in progress when they first arrived at the stop line, and 1,284 rejected the initial lag. The 1,284 drivers who rejected the initial lag evaluated a total of 5,576 subsequent gaps; 4,292 of these subsequent gaps were rejected and, eventually, 1,284 gaps (one per vehicle) were accepted. However, in 556 of the 1,284 accepted gaps, the minor-road driver had to wait for one or more near-lane vehicles to clear before accepting the remaining lag. A total of 7,964 acceptance/rejection decisions were observed, including gaps in the far-lane traffic that were "rejected" because a near-lane vehicle was present and lags in the far lane traffic that were accepted or rejected after a near-lane vehicle cleared. There were usable data (without interference from other vehicles) for a total of 3,256 acceptance/rejection decisions in left-turn maneuvers including 3,311 left-turn decisions by passenger cars (94%), 108 left-turn decisions by single-unit trucks (3%), and 107 left-turn decisions by combination trucks (3%).

An analysis of the accepted and rejected gaps and lags was completed using two methods that have been used in previous work for FHWA (10). These are the Raff method (19) and the logit method (also known as logistic regression) (20). These methods are explained in Chapter Three of this report. The logistic regression (for individual sites and for all sites combined) and the results from the Raff method are presented in Tables F-4 through F-6 for right turns and Tables F-7 through F-9 for left turns. These tables present separate analysis results for three vehicle types (passenger cars, single-unit trucks, and combination trucks). These results are summarized and interpreted in Chapter Three.

Acceleration/Deceleration Study

Each maneuver for which the vehicle speed profiles were traced was evaluated by determining several kinematic parameters of interest. All of the computations assume that each vehicle has a constant acceleration or deceleration rate over the 60 to 120 m (200 to 400 ft) interval between each pair of adjacent sensors. The following parameters were determined in the analysis:

- The acceleration or deceleration rate used by each vehicle between each pair of sensors.

Table F-4. CRITICAL GAPS FOR RIGHT TURNS ONTO THE MAJOR ROAD BY PASSENGER CARS

Site	Number of observed gaps and lags		Logistic regression coefficients		Critical gap (sec) for specified probability of acceptance			
	Accepted	Rejected	Intercept	Slope	50%	60%	75%	85%
IL01	36	156	-5.495	0.821	6.69	7.19	8.03	8.81
MO01	81	55	-6.867	1.089	6.30	6.68	7.31	7.90
MO02	722	591	-6.791	1.007	6.74	7.15	7.83	8.47
MO03	124	65	-6.804	0.997	6.83	7.23	7.93	8.57
MO04	415	329	-5.649	0.867	6.51	6.98	7.78	8.51
PA01	384	334	-4.502	0.640	7.04	7.67	8.76	9.75
PA02	431	298	-3.225	0.495	6.52	7.34	8.74	10.03
PA04	49	17	--	--	--	--	--	--
PA05	684	535	-4.389	0.750	5.86	6.40	7.32	8.17
PA07	22	12	--	--	--	--	--	--
Combined	2948	2392	-4.753	0.730	6.51	7.07	8.02	8.89
				Site Averages	6.56	7.08	7.96	8.77

NOTE: Comparable critical gap from Raff method is 6.3 sec.

Table F-5. CRITICAL GAPS FOR RIGHT TURNS ONTO THE MAJOR ROAD BY SINGLE-UNIT TRUCKS

Site	Number of observed gaps and lags		Logistic regression coefficients		Critical gap (sec) for specified probability of acceptance			
	Accepted	Rejected	Intercept	Slope	50%	60%	75%	85%
MO02	68	85	-8.266	0.828	9.98	10.47	11.30	12.07
MO03	2	2	--	--	--	--	--	--
MO04	27	34	-2.135	0.186	11.50	13.68	17.41	20.84
PA01	14	11	-3.861	0.492	7.84	8.67	10.08	11.37
PA02	15	14	-6.643	0.724	9.18	9.74	10.69	11.57
PA04	7	3	--	--	--	--	--	--
PA05	43	29	-5.685	0.839	6.78	7.26	8.09	8.85
PA07	1	8	--	--	--	--	--	--
Combined	177	186	-4.130	0.436	9.48	10.41	12.00	13.46
				Site Averages	9.06	9.96	11.52	12.94

NOTE: Comparable critical gap from Raff method is 8.4 sec.

Table F-6. CRITICAL GAPS FOR RIGHT TURNS ONTO THE MAJOR ROAD BY COMBINATION TRUCKS

Site	Number of observed gaps and lags		Logistic regression coefficients		Critical gap (sec) for specified probability of acceptance			
	Accepted	Rejected	Intercept	Slope	50%	60%	75%	85%
MO02	168	251	-8.66	0.610	11.26	11.92	13.06	14.10
MO04	1	1	--	--	--	--	--	--
PA01	33	39	-6.798	0.582	11.68	12.37	13.56	14.66
PA02	11	20	-5.698	0.531	10.73	11.50	12.80	14.00
Combined	213	311	-6.769	0.600	11.28	11.95	13.11	14.17
				Site Averages	11.22	11.93	13.14	14.25

NOTE: Comparable critical gap from Raff method is 10.7 sec.

Table F-7. CRITICAL GAPS FOR LEFT TURNS ONTO THE MAJOR ROAD BY PASSENGER CARS

	Number of observed gaps and lags		Logistic regression coefficients		Critical gap (sec) for specified probability of acceptance			
Site	Accepted	Rejected	Intercept	Slope	50%	60%	75%	85%
IL01	102	163	-8.209	1.064	7.71	8.10	8.75	9.34
MO01	100	254	-7.775	1.037	7.50	7.89	8.56	9.17
MO02	102	318	-5.617	0.744	7.55	8.09	9.02	9.88
MO03	155	89	-6.647	0.809	8.22	8.72	9.58	10.37
MO04	63	103	-9.162	1.298	7.06	7.37	7.91	8.40
PA01	287	282	-5.082	0.532	9.55	10.31	11.61	12.81
PA02	350	263	-1.412	0.143	9.87	12.71	17.55	22.00
PA03	31	39	-5.884	0.713	8.25	8.82	9.79	10.68
PA04	20	8	--	--	--	--	--	--
PA05	301	252	-3.341	0.358	9.32	10.45	12.39	14.16
PA07	19	6	-2.570	0.357	7.20	8.34	10.28	12.06
Combined	1530	1777	-3.442	0.375	9.17	10.25	12.10	13.79
				Site Averages	8.22	9.08	10.54	11.89

NOTE: Comparable critical gap from Raff method is 8.0 sec.

Table F-8. CRITICAL GAPS FOR LEFT TURNS ONTO THE MAJOR ROAD BY SINGLE-UNIT TRUCKS

	Number of observed gaps and lags		Logistic regression coefficients		Critical gap (sec) for specified probability of acceptance			
Site	Accepted	Rejected	Intercept	Slope	50%	60%	75%	85%
IL01	6	11	--	--	--	--	--	--
MO01	2	9	-10.723	1.101	9.74	10.11	10.74	11.32
MO02	5	12	-4.531	0.383	11.83	12.89	14.70	16.36
MO03	7	8	--	--	--	--	--	--
MO04	1	1	--	--	--	--	--	--
PA01	13	1	--	--	--	--	--	--
PA02	9	3	--	--	--	--	--	--
PA04	5	3	--	--	--	--	--	--
PA05	4	5	--	--	--	--	--	--
PA07	2	1	--	--	--	--	--	--
Combined	54	54	-5.768	0.568	10.15	10.86	12.08	13.20
				Site Averages	10.79	11.50	12.72	13.84

NOTE: Comparable critical gap from Raff method is 9.8 sec.

Table F-9. CRITICAL GAPS FOR LEFT TURNS ONTO THE MAJOR ROAD BY COMBINATION TRUCKS

Site	Number of observed gaps and lags		Logistic regression coefficients		Critical gap (sec) for specified probability of acceptance			
	Accepted	Rejected	Intercept	Slope	50%	60%	75%	85%
IL01	1	4	--	--	--	--	--	--
MO02	7	31	--	--	--	--	--	--
PA01	17	28	-8.351	0.686	12.18	12.77	13.78	14.71
PA02	4	8	--	--	--	--	--	--
PA03	1	6	--	--	--	--	--	--
Combined	30	77	-10.718	0.924	11.60	12.04	12.79	13.48
				Site Averages	12.18	12.77	13.78	14.71

NOTE: Comparable critical gap from Raff method is 10.0 sec.

- The headway between the major- and minor-road vehicles at each sensor downstream of the intersection, and the minimum headway at any point during the maneuver.

- The location of the major-road vehicle (distance from the intersection) at the instant the minor-road vehicle begins its turning maneuver.

- The maximum speed of the major-road vehicle during the minor-road vehicle's turning maneuver (usually the speed of the major-road vehicle at the instant when the minor-road vehicle begins to turn, but a higher speed may occur in some cases between that point and the intersection).

- The minimum speed reached by the major-road vehicle during the maneuver. Typically, this occurs downstream of the intersection, as the major-road vehicle catches up to the minor-road vehicle. In determining the minimum speed, the speed of the major-road vehicle at each sensor is considered until a point is reached at which the speed of the minor-road vehicle exceeds the speed of the major-road vehicle.

- The speed reduction by the major-road vehicle (the difference between its maximum and minimum speeds, as defined above).

- The speed reduction by the major-road vehicle, expressed as a percentage of its maximum speed.

- The average and maximum acceleration rates of the minor-road vehicle as it completes its turn (the acceleration of the minor-road vehicle to speeds of 40 and 64 km/h (25 and 40 mph) is also being determined).

- The average and maximum deceleration rates of the major-road vehicle during the maneuver.

- The separation distance between the major- and minor-road vehicles at each sensor location, and the minimum separation distance during the entire maneuver.

The results from the analysis of these data are presented in Chapter Three of this report.

APPENDIX G

FIELD STUDIES OF DRIVER SPEED SELECTION ON APPROACHES TO UNCONTROLLED AND YIELD-CONTROLLED INTERSECTIONS

This appendix presents the results of a field study that was conducted to help in formulating ISD policy for approaches to uncontrolled and YIELD-controlled intersections (ISD Cases I and II). The appendix presents the field study objective, field study sites, data collection, and data reduction and analysis. The field study results have been utilized in the evaluation of ISD requirements for approaches to uncontrolled and YIELD-controlled intersections in Chapters Two and Four of this report.

FIELD STUDY OBJECTIVE

The objective of the field study reported in this appendix was conducted to document driver speed selection on approaches to uncontrolled and YIELD-controlled intersections. While the AASHTO Green Book does not explicitly state this, it is generally understood that the assumed vehicle speed for an approach to an uncontrolled or YIELD-controlled intersection is the design speed of the roadway on which that approach is located. Thus, AASHTO policy for ISD Cases I and II appears to presume that drivers approach uncontrolled and YIELD-controlled intersections at their full midblock running speed. However, even casual observation of uncontrolled and YIELD-controlled approaches shows that many drivers do slow on approaching the intersection, even if there are no conflicting vehicles present to whom the approaching driver must yield the right of way. Therefore, field studies were conducted to quantify the speed-reduction behavior of drivers on approaches to uncontrolled and YIELD-controlled intersections.

FIELD STUDY SITES

The field study sites included seven uncontrolled intersections located in the City of Phoenix, Arizona, and four YIELD-controlled intersections located in the City of Kansas City, Missouri. Each study site was a four-leg intersection. The uncontrolled intersections had no traffic control present on any of the four approaches. The YIELD-controlled intersections each had YIELD control on two approaches and no control on the other two approaches.

All of the intersections were located on relatively low-volume streets in urban and suburban residential subdivisions. The intersecting streets would all be classified functionally as local streets or minor collectors. Higher volume intersections could not be studied because, if an intersections intersection had higher traffic volumes, it would be more likely to have STOP control than YIELD control or no control. The data collection focused on vehicle making through movements (crossing maneuvers), rather than vehicles making left- or right-turn maneuvers; therefore, an initial screening was conducted to assure that each study site had sufficient through traffic volumes for study Thus, from among many candidate low-volume uncontrolled and YIELD-controlled intersections, we picked those few that appeared to have enough traffic to make a field study productive. Even so, several of the study sites provided on a limited number of useful observations.

Table G-1 summarizes the characteristics of the selected study intersections, including the area type and character of development, the 85th percentile midblock speed on the study approach, and the offsets to corner sight obstructions.

In addition to study sites on urban and suburban residential streets, we had initially planned to include study sites on higher speed rural highways, as well. However, we were unable to locate any suitable data collection sites with sufficient traffic volumes to allow a productive field study.

DATA COLLECTION APPROACH

Figure G-1 illustrates the typical data collection set-up on the approach to an uncontrolled intersection. Speeds were recorded at two positions on each approach: a midblock location, typically 120 to 180 m (400 to 600 ft) from the intersection; and an intersection approach location, typically including the last 60 m (200 ft) of the intersection approach.

Speeds were measured using two Kustom ProLaser speed guns. The ProLaser is a standard laser speed gun intended for use by police for speed enforcement. Laser technology has two advantages over convention radar speed measurement devices for this application. First, the laser beam is much narrower and more difficult to detect than a radar beam. A conventional radar beam spreads out to great widths and is easily reflected, so that not only the radar beam itself, but also reflection from it can be detected. Laser detectors are beginning to come on the market; however, most of the speed measurements for this project were made from behind the vehicle and it is unlikely that a forward facing laser detector would detect a laser beam coming from the rear. Second, unlike radar technology that determines speed based on a frequency shift (i.e., the Doppler effect), laser technology determines speed based on measuring the distance to the target vehicle as it changes over several precisely timed intervals. Therefore, the ProLaser provides a distance (range) measurement with each speed measurement, allowing the speed and position of the vehicle to be tracked through time and space. Thus, the entire speed profile of the vehicle can be determined with the ProLaser allowing the deceleration pattern of each vehicle as it approached the intersection to be evaluated.

Table G-1. CHARACTERISTICS OF FIELD INTERSECTIONS WITH NO CONTROL AND WITH YIELD CONTROL

Site number	Area type	Character of development	Study approach	85th percentile midblock speed on study approach, km/h (mph)	Offset to corner sight obstruction to right of study approach, m (ft)[a]		Offset to corner sight obstruction to left of study approach, m (ft)[a]	
					From crossroad (a_1)	From study approach (b_1)	From crossroad (a_2)	From study approach (b_2)
UNCONTROLLED INTERSECTIONS								
AZ01	Suburban	Residential	Westbound	48 (30)[b]	3 (11)	21 (70)	11 (35)	13 (43)
AZ02	Urban	Residential	Westbound	48 (30)	9 (28)	6 (20)	19 (62)	4 (14)
AZ03	Urban	Residential	Westbound	53 (33)	8 (27)	7 (22)	9 (28)	2 (6)
AZ04	Suburban	Residential	Westbound	48 (30)	8 (26)	10 (34)	16 (54)	3 (10)
AZ05	Suburban	Residential	Westbound	48 (30)[b]	5 (16)	3 (11)	8 (25)	12 (39)
AZ06	Suburban	Residential	Westbound	42 (26)	6 (25)	11 (35)	7 (23)	9 (28)
AZ07	Suburban	Residential	Southbound	52 (32)	10 (34)	8 (27)	9 (29)	11 (36)
YIELD-CONTROLLED INTERSECTIONS								
MO05	Urban	Residential/ commercial	Northbound	48 (30)	12 (38)	9 (28)	7 (22)	35 (114)
MO06	Suburban	Residential	Northbound	43 (27)	13 (44)	16 (52)	10 (32)	20 (66)
MO07	Suburban	Residential	Eastbound	42 (26)	9 (28)	13 (44)	17 (55)	16 (51)
MO08	Suburban	Residential	Northbound	48 (30)	4 (12)	25 (83)	9 (31)	26 (85)

[a] All offsets measured from curbline of the adjacent streets.
[b] Estimated.
NOTE: a_1, b_1, a_2, and b_2 are defined in Figure G-1.

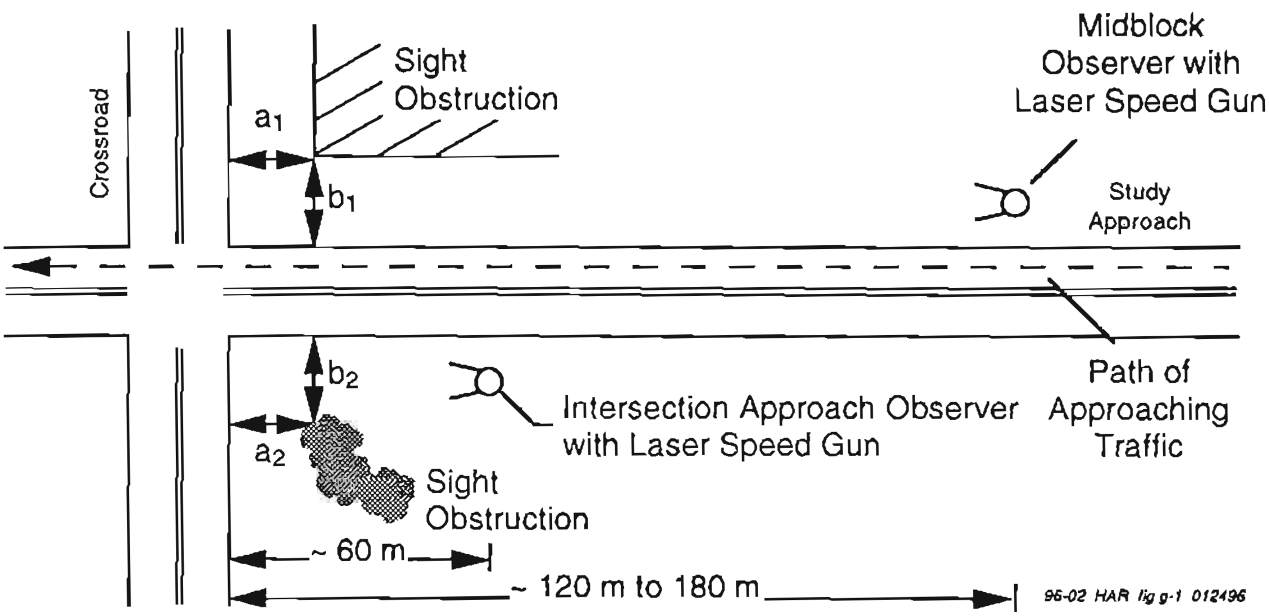


Figure G-1. Typical data collection setup for field studies at uncontrolled and YIELD-controlled intersections.

The laser operators were positioned in as concealed a position as possible. There are no completely concealed positions on a typical residential street, but the observers used parked cars, trees, trash cans, etc. to make themselves as inconspicuous as possible so as to minimize any influence on driver behavior on the study approach.

Each of the ProLaser speed guns was connected to a laptop computer and, as each measurement of speed and distance was made, the data were transmitted from the speed gun to the laptop computer and captured in a file for later analysis. This allowed speed and distance measurements to be taken continuously, at intervals of approximately 0.5 sec, which would not have been possible if the data had to be written down. It also allowed analysis of the data to proceed without the need for key entry of the data and, thus, without the possibility of transcription errors.

Data were taken in the following manner. As a vehicle approached the intersection, its speed/distance profile was recorded first by the midblock laser operator and then by the intersection approach laser operator. Both operators then entered the vehicle description and a common vehicle identification number into the laptop computer to link together the two data sets for that specific vehicle. The linked data sets could also be identified by the times of each speed/distance measurement taken from the laptop computer clocks, which were synchronized.

In a few cases, to increase the available sample size, data were taken for vehicles coming toward the laser operators, in the opposite direction to the vehicle path shown in Figure G-1. In this case, the speed profile of the vehicle was measured as it approached the intersection on the far-side approach, rather than the near-side approach. The midblock speed was measured at the midblock location after the vehicle had passed through the study intersection, rather than before it had reached it.

At uncontrolled intersections, data were collected on whichever of the four approaches appeared to have the most traffic during the study period. At YIELD-controlled intersections, data were collected on whichever of the two YIELD-controlled approaches appeared to have the most traffic during the study period. Data collection periods were selected during the day to correspond to the times when the most traffic was present. Some intersections that were unproductive during most of the day had reasonable volumes during the morning or evening commuting periods, during the noon hour, or at midafternoon when children were returning from school. Because of the relatively low traffic volumes at the study intersections, data were collected for two to three days at most locations.

DATA REDUCTION AND ANALYSIS

The objective of the field study was to determine whether vehicles on the intersection approach being evaluated proceeded through the intersection at their full midblock speed or slowed down. Therefore, data were discarded for all situations in which the vehicle being evaluated was forced by external factors to slow down. For example, data were discarded: (1) if the vehicle being studied turned left or right at the intersection, rather than going straight ahead; (2) if a potentially conflicting vehicle was present on the intersecting approach; or (3) if a pedestrian was observed to cause the vehicle of interest to slow. These are all situations in which the vehicle of interest might find it necessary to slow down. Data were analyzed only for vehicles that proceeded straight through the intersection and were not forced to slow down by external factors. Thus, if the study results indicate that drivers slow down on intersection approaches, this indicates that drivers do so voluntarily, as a precautionary measure, and not as a matter of necessity.

The data reduction consisted primarily of reviewing the data for each approaching vehicle to determine whether it met the criteria described above for consideration in the study. For each vehicle that met these criteria, the following parameters were determined from the speed profile data:

- Maximum speed recorded within the study area (typically in the midblock vicinity).

- Minimum speed recorded within the study area (typically on the intersection approach).

- Classification of speed profile (e.g., slowed to a stop at the intersection; reduced speed without stopping; continued through intersection without noticeable slowing).

Analysis Results for Approaches to Uncontrolled Intersections

Table G-2 summarizes the observed behavior for each of five uncontrolled intersections and for the five intersections combined; the other two uncontrolled intersections had too little valid data to be useful. A total of more than 500 approach maneuvers were observed, less than half of these met the criteria for analysis presented above. The table shows that, for the five intersections, a total of 226 valid speed profiles were obtained.

The combined data for the five intersections shows that 22.6% of the approaching drivers of through vehicles stopped at the intersection. In other words, 22.6% of the drivers stopped even though there was no legal requirement

Table G-2. SUMMARY OF OBSERVED SPEED PROFILES AT UNCONTROLLED INTERSECTIONS IN PHOENIX

Site	No. of vehicles observed	Percent stopping[a]	Midblock speed, km/h (mph)			Intersection approach speed, km/h (mph)			Speed reduction km/h (mph)			
			Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum[b]	Maximum	Mean	Percent
AZ02	79	21.5	24 (15)	58 (36)	40.2 (25.0)	0 (0)	55 (34)	18.5 (11.5)	-5 (-3)	58 (36)	21.7 (13.5)	54.0
AZ03	63	12.7	26 (16)	60 (37)	42.2 (26.2)	0 (0)	58 (36)	28.2 (17.5)	-6 (-4)	55 (34)	13.8 (8.6)	32.8
AZ04	55	36.4	31 (19)	58 (36)	42.0 (26.1)	0 (0)	55 (34)	17.4 (10.8)	-3 (-2)	50 (31)	24.6 (15.3)	58.6
AZ06	25	20.0	26 (16)	53 (33)	35.7 (22.2)	0 (0)	39 (24)	19.1 (11.9)	-3 (-2)	39 (24)	16.6 (10.3)	46.4
AZ07	4	25.0	43 (27)	53 (33)	47.5 (29.5)	0 (0)	53 (33)	27.8 (17.3)	0 (0)	43 (27)	19.8 (12.3)	41.7
TOTAL	226	22.6	24 (15)	60 (37)	40.9 (25.4)	0 (0)	58 (36)	17.2 (10.7)	-6 (-4)	58 (36)	19.6 (12.2)	48.1

[a] The percent of approaching vehicles that came to a full stop at the intersection.

[b] A negative speed reduction indicates an increase in speed from the mid-block location to the intersection approach.

to stop and no potentially conflicting vehicles were present on an intersection approach. The average midblock speed was approximately 40 km/h (25 mi/h) and the average minimum speed on the intersection approach was approximate 18 km/h (11 mi/h). The average speed reduction from the midblock speed to the minimum speed on the intersection approach was 19 km/h (12 mi/h), or 48% of the midblock speed. This finding suggests that it is reasonable to assume that drivers on approaches to uncontrolled intersections on urban and suburban residential streets typically slow on the intersection approach to about half of their midblock running speed.

Analysis Results for YIELD-Controlled Approaches

Table G-3 summarizes the observed behavior for each of four YIELD-controlled intersections and for the four intersections combined. More than 500 approach maneuvers were observed and a total of 234 valid speed profiles were obtained.

The combined data for the four intersections shows that 6.4% of the approaching drivers of through vehicles stopped at the intersection. In other words, 6.4% of the drivers stopped even though there was no legal requirement to stop and no potentially conflicting vehicles were present on an intersection approach. This is a lower percentage of voluntary stops than was observed for the uncontrolled intersections. The average midblock speed was approximately 38 km/h (24 mi/h) and the average minimum speed on the intersection approach was approximate 24 km/h (15 mi/h). The average speed reduction from the midblock speed to the minimum speed on the intersection approach was 14 km/h (9 mi/h), or 37% of the midblock speed. This finding suggests that drivers slow slightly less on approaches to YIELD-controlled intersections than on approaches to uncontrolled intersections. It appears reasonable to assume that drivers on an approach to a YIELD-controlled intersection will typically slow on the intersection approach to approximately 60% of their midblock running speed.

Table G-3. SUMMARY OF OBSERVED SPEED PROFILES AT YIELD-CONTROLLED INTERSECTIONS IN KANSAS CITY

Site	No. of vehicles observed	Percent stopping[a]	Midblock speed, km/h (mph)			Intersection approach speed, km/h (mph)			Speed reduction km/h (mph)			
			Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Percent
MO05	68	10.3	26 (16)	77 (48)	41.8 (26.0)	0 (0)	50 (31)	25.1 (15.6)	0 (0)	61 (38)	16.6 (10.3)	39.8
MO06	44	2.3	19 (12)	63 (39)	34.9 (21.7)	0 (0)	61 (38)	22.2 (13.8)	0 (0)	27 (17)	12.7 (7.9)	36.3
MO07	57	1.8	18 (11)	58 (36)	35.1 (21.8)	0 (0)	51 (32)	26.2 (16.3)	0 (0)	26 (16)	8.8 (5.5)	25.3
MO08	65	9.2	18 (11)	61 (38)	39.6 (24.6)	0 (0)	42 (26)	23.0 (14.3)	3 (2)	42 (26)	16.4 (10.2)	41.7
TOTAL	234	6.4	18 (11)	77 (48)	38.3 (23.8)	0 (0)	61 (38)	24.3 (15.1)	0 (0)	61 (38)	14.0 (8.7)	36.5

[a] The percent of approaching vehicles that came to a full stop at the intersection.

APPENDIX H

FIELD STUDIES OF VEHICLE DIMENSIONS AND VEHICLE STOPPING POSITIONS ON MINOR-ROAD APPROACHES TO STOP-CONTROLLED INTERSECTIONS

This appendix describes the field studies that were performed to determine the distance from the front of the vehicle to the driver's eye and the typical vehicle stopping position on minor-road approaches to STOP-controlled intersections.

Current AASHTO policy assumes for design purposes that drivers of vehicles on STOP-controlled approaches require sight distance along the major road from a position with the driver's eye 6 m (20 ft) from the edge of the major-road traveled way. This value of 6 m (20 ft) is based on the estimate that the vehicle stops in a position with the front of the vehicle at a distance of 3 m (10 ft) from the edge of the major road traveled way and that the distance from the front of the vehicle to the driver's eye is also 3 m (10 ft). These estimates were evaluated in field studies conducted during the research.

VEHICLE STOPPING POSITIONS

The following discussion reviews the collection and reduction of field data on vehicle stopping positions at STOP-controlled intersections.

Data Collection

Field data on vehicle stopping positions were collected as part of most of the field studies performed at STOP-controlled intersections in Illinois, Missouri, and Pennsylvania that have been described in Appendix F. At most of the field study intersections, one of the two video cameras was utilized to record the stopping positions of the vehicles on the minor road. The data collection activities for vehicle stopping positions included 8.0 hr of data collected over 2 days at two intersections in Illinois, 55.0 hr of data over 11 days at three intersections in Missouri, and 138.5 hr over 24 days at seven intersections in Pennsylvania. In addition, stopping position data were collected for 4.0 hr on one day at one STOP-controlled intersection in Arizona (Site AZ08), in connection with the Arizona field studies reported in Appendix G; this intersection was selected because it had much more limited sight distance than any of the other locations. The total data collection effort for vehicle stopping positions included 205.5 hr of observational data collected over 38 days at 13 intersections in four states.

The field studies of vehicle stopping positions were conducted in the following manner. During the equipment setup at each intersection, the centerline of the minor roadway was measured and small paint marks were placed on the pavement at 1.5-m (5-ft) intervals. The first marking was at the edge of the major-road traveled way and each subsequent marking was 1.5 m (5 ft) farther along the centerline of the minor road. The last mark was typically 12 m (40 ft) from the edge of the major-road traveled way. However, in some cases, sight obstructions limited vehicle stopping positions to within 6 m (20 ft) of the traveled way and only that portion of the roadway was marked. Figure 21 in Chapter Three illustrates a typical equipment setup for collection of data on vehicle stopping positions.

At the beginning of each videotape as the field studies were conducted, one of the field crew would stand at each of the marks on the pavement with a range pole. This provided an establishing shot at the beginning of each videotape so that the distances from the edge of the traveled way could be marked on the video screen. The crew member with the range pole was not present in or near the roadway during the subsequent period during which data were collected.

Data Reduction

The stopping position data were reduced using the positions marked on the clear acetate sheet mounted on the video screen representing 1.5-m (5-ft) intervals along the centerline of the minor-road approach that have been described above. Using this approach, vehicle stopping positions could generally be determined to the nearest 0.8 m (2.5 ft) and, in a few cases, to the nearest 0.4 m (1.25 ft). At the Arizona site (Site AZ08), vehicle stopping positions were determined to the nearest 0.3 m (1 ft).

Two stopping positions were noted for each vehicle on the minor-road approach: the initial position at which the minor-road vehicle first came to a complete stop; and the final position from which the minor-road vehicle accelerated to enter or cross the major road. In some cases, the initial and final stopping positions were the same. However, in other cases, the driver of the minor-road vehicle may have crept forward to get a better view of the major-road traffic and then made a second (or third) stop. In general, the final stopping position is of greatest interest for design purposes because this represents the location from which the driver decided that he/she could see well enough to proceed with the turning or crossing maneuver.

If the minor-road vehicle did not come to a complete stop before entering or crossing the major road, then no stopping position data were recorded for that vehicle.

Figure H-1 presents an example of the distribution of the stopping position data that were reduced for one intersection approach (the westbound approach at Site AZ08). This approach had limited sight distance which caused the vehicle to make an initial stop on the approach and then move closer to the edge of the traveled way before completing their turn.

A preliminary screening process was conducted to decide which of the stopping position videotapes should be reduced. A preliminary review of at least one videotape from each field study intersection was performed to determine the relative percentage of final vehicle stopping positions in specific 1.5-m (5-ft) intervals of the distance from the front of the stopped vehicle to the edge of the major-road traveled way. Generally, the videotape selected for this review was the one with the highest traffic volumes (typically, the morning or evening peak hour). Typically, in this preliminary review, vehicle stopping positions were reduced from the videotape for a period of 30 min.

The preliminary review showed that vehicle stopping positions tend to vary between intersections based on the sight distance available at various stopping positions. If the drivers could see well from a position 3 m (10 ft) or more from the edge of the major-road traveled way, then the driver would wait at that position for a suitable gap in the major-road traffic stream. However, where a better view could be obtained from a position closer to the edge of the major-road traveled way, then the driver would either stop at that closer position initially or stop further from the edge of the traveled way and then move forward to the position with a better view.

Based on this finding, it was decided to perform full data reduction for the videotapes of a sample of nine intersection approaches for which the final stopping position varied over a wide range, including intersection approaches on which drivers stopped very close to the major-road traveled way and approaches where drivers stopped farther from the major-road traveled way.

The vehicle stopping position data were first recorded on log sheets and then keyed into computer files. Quality assurance checks were made, both after the initial recording of data and again after the data were keyed.

Data Analysis

The distributions of final stopping positions for the selected intersection approaches are presented in Table H-1. The table shows that complete data reduction for stopping positions was performed for nearly 1,100 vehicles.

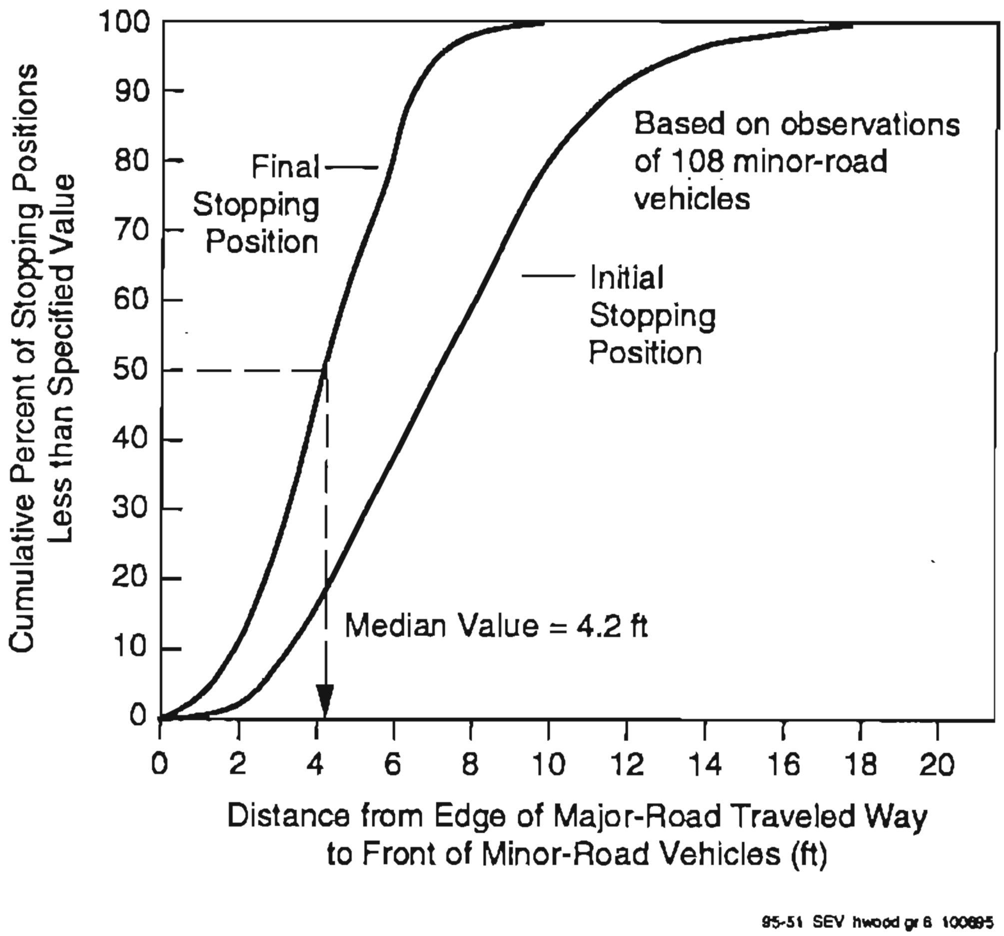


Figure H-1. Cumulative distribution of vehicle stopping positions on a STOP-controlled approach with limited sight distance.

Table H-1 shows that vehicle stopping positions vary substantially from one intersection approach to another. Where sight distance is limited, drivers will choose to move closer to the edge of the major-road traveled way before entering or crossing the major road. Based on the data in the table, a stopping position with the front of the minor-road vehicle 2.0 m (6.6 ft) from the edge of the major-road traveled way is recommended for use in design. This value will accommodate at least 85% of vehicle stopping positions for both intersection approaches on which drivers choose to stop closest to the road.

DISTANCE FROM FRONT OF VEHICLE TO DRIVER'S EYE

A small study of the distance from the front of a passenger car to the driver's eye was conducted by measuring vehicles in the MRI parking lot. Since there was no driver in the vehicles that were measured, a method was needed to estimate where the driver's eye would be if a driver were present. It was decided that a relatively fixed point on each vehicle that could be easily seen from outside the vehicle is the center of the steering wheel. (The center of the steering wheel was chosen because the center would move least if the steering wheel were tilted.) Therefore a study was conducted of the typical longitudinal distance from the center of the steering wheel to the driver's eye.

A small study showed that the distance from the steering wheel to the driver's eye varies over a relatively limited range for a typical group of drivers and vehicles. Ten drivers of different heights, five male and five female, were measured in each of three passenger cars: a 1993 sedan, an older sedan, and a 1993 minivan. Each driver was asked to adjust the front seat of each vehicle to a comfortable driving position; then the longitudinal distance from the driver's eye to the center of the steering was measured. Table H-2 shows the data that were obtained. The average distance from the steering wheel to the driver's eye for the 10 test subjects was 351 mm (13.8 in) for a 1993 Toyota Camry, 330 mm (13.0 in) for a 1979 Pontiac Lemans, and 341 mm (13.4 in) for a 1993 Plymouth Voyager minivan. For each vehicle considered, this distance varied as a function of driver characteristics over a range of 75 to 115 mm (3 to 4.5 in). For all three vehicles, the maximum distance was 394 mm (15.5 in). This maximum distance can be added to the measured distance from the front of the vehicle to the center of the steering wheel to estimate the maximum distance from the front of the vehicle to the driver's eye.

A sample of 101 vehicles was then measured in the MRI parking lot to determine the distance from the front of the vehicle to the driver's eye. This was accomplished by measuring the longitudinal distance from the front of the vehicle to the center of the steering wheel and then adding 394 mm (15.5 in), as described above. The vehicles measured included passenger cars, pickup trucks, and minivans. The distribution of the distance from the front of the vehicle to the driver's eye was as follows:

Table H-1. SUMMARY OF VEHICLE STOPPING POSITIONS ON MINOR-ROAD APPROACHES TO STOP-CONTROLLED INTERSECTION

Site	Approach	No. of vehicles measured	Final stopping position[a]				
			Mean, m (ft)	Std. dev., m (ft)	85th percentile	% ≤ 1.5 m (% ≤ 5 ft)	% ≤ 3 m (% ≤ 10 ft)
AZ08	Westbound	108	1.4 (4.7)	0.6 (1.9)	2.0 (6.6)	66.7	100.0
MO01	Westbound	88	4.9 (16.1)	1.5 (5.0)	6.1 (20.0)	2.3	14.8
MO04	Southbound	216	4.4 (14.4)	1.9 (6.1)	6.1 (20.0)	11.1	33.8
PA01	Southbound (left turn)	220	0.9 (2.8)	1.1 (3.6)	1.5 (5.0)	91.4	98.6
PA01	Southbound (right turn)	54	3.4 (11.2)	0.8 (2.7)	4.2 (13.8)	5.5	37.0
PA02	Westbound	147	4.2 (13.7)	1.8 (5.9)	6.1 (20.0)	15.6	41.5
PA04	Eastbound	77	3.0 (9.9)	2.3 (7.4)	4.6 (15.0)	32.5	66.2
PA07	Eastbound	121	5.7 (18.7)	1.4 (4.6)	7.6 (25.0)	0.0	4.1
PA07	Westbound	58	4.5 (14.6)	2.3 (7.5)	6.5 (21.3)	12.1	32.8
	TOTAL	1,089					

[a] Distance from front of vehicle to edge of major-road traveled way at the last stopped position before the vehicle began to accelerate to enter the minor road.

Table H-2. DISTANCE FROM STEERING WHEEL TO DRIVER'S EYE FOR 10 INDIVIDUALS

Sex	Height, m (in)	Longitudinal distance from steering wheel to driver's eye, m (in)		
		1993 Toyota Camry Sedan	1979 Pontiac Lemans Sedan	1993 Plymouth Voyager Minivan
Female	1,800 (71.0)	394 (15.5)	394 (15.5)	394 (15.5)
	1,770 (69.5)	363 (14.3)	313 (12.3)	369 (14.5)
	1,720 (67.5)	325 (12.8)	338 (13.3)	351 (13.8)
	1,630 (64.0)	318 (12.5)	292 (11.5)	292 (11.5)
	1,630 (64.0)	356 (14.0)	267 (10.5)	318 (12.5)
Male	1,910 (75.0)	356 (14.0)	292 (11.5)	356 (14.0)
	1,780 (70.0)	363 (14.3)	382 (15.0)	331 (13.0)
	1,750 (69.0)	356 (14.0)	356 (14.0)	331 (13.0)
	1,700 (67.0)	331 (13.0)	325 (12.8)	343 (13.5)
	1,630 (64.0)	343 (13.5)	343 (13.5)	331 (13.0)
	MEAN	351 (13.8)	331 (13.0)	341 (13.4)

Minimum	1.8 m (5.8 ft)
Mean	2.2 m (7.3 ft)
Maximum	2.9 m (9.5 ft)
Median	2.2 m (7.3 ft)
85th percentile	2.4 m (8.0 ft)
90th percentile	2.4 m (8.0 ft)
95th percentile	2.6 m (8.5 ft)

Based on this sample, it appears that current vehicles all have less than the existing AASHTO assumed distance of 3.1 m (10 ft) from the front of the vehicle to the driver's eye. The maximum value of 2.9 m (9.5 ft) was measured for a Chevrolet Corvette, which obviously represents a very small fraction of the vehicle population. An assumed distance of 2.4 m (8 ft), which represents both the 85th percentile and the 90th percentile of the sample, appears to be an appropriate value for use in design.

APPENDIX I

TORT LIABILITY ISSUES RELATED TO INTERSECTION SIGHT DISTANCE

Increasing numbers of liability suits are being brought against the states, state highway agencies, and other governmental units. This section reviews existing law involving agency liability for hazardous road conditions, with particular emphasis on ISD problems. This analysis includes a review of general tort liability in analogous road hazard cases which can be predicted to apply in ISD situations. Finally, a survey of several major state highway agencies and state attorney general offices responsible to defend ISD liability suits is presented. These materials should clarify the application of current and expected future legal liability theories to ISD problems. This should aid in risk management by highway design engineers seeking to identify and reduce risk factors for ISD highway safety conditions.

Liability suits brought against the state for ISD design problems are based generally on the tort of negligence. Torts are civil (non-criminal) wrongs in which an injured victim brings suit against those persons or entities allegedly responsible. Negligence suits against state highway agencies or other state agencies typically assert claims that the state agency has failed to follow its duty of due care to design, construct, and maintain intersections so that sight distance is sufficient to avoid collisions. Successful plaintiffs generally convince a judge, or more commonly a jury, that the state agency has been negligent. This entitles the plaintiff to receive monetary damages from the state to cover such personal injuries as medical payments, lost income, property damage, and other types of damage.

State agencies generally have several duties to maintain road safety in their exercise of due care. For example, they must carefully design and plan road construction, carefully manage and oversee construction, carefully inspect existing roads for ISD problems, warn motorists of unimprovable ISD conditions, maintain existing ISD in a reasonably safe condition, and improve older design road conditions as specifications become more stringent. In most states, these rules are developed in the courts through judge-made law which create precedents applied in later cases. Occasionally precedents are borrowed from other states when a state first encounters a novel problem. The next section discusses negligence in greater detail.

NEGLIGENCE

Drivers, passengers, or bystanders injured by inadequate ISD conditions cannot win their case unless they prove a prima facie case of negligence, including the following elements:

1. State agency's *duty* to use reasonable care

2. State agency's *breach* of the duty of care

3. This breach of duty (negligence) *caused* the victim's injuries

4. Victim suffered injury or money *damages*.

State agencies may defend such plaintiff allegations by successfully challenging the plaintiff's proof to the four elements above. In addition, if the state agency acted responsibly through careful design, inspection, warning, maintenance, and improvement, this proof will help the defense. Finally an affirmative defense such as contributory or comparative negligence or the assumption of risk can reduce or eliminate the agency's liability.

Affirmative defenses to negligence may effectively nullify the victim's case where the state agency shows the victim's own negligence contributed to the accident. For example, an intoxicated victim who fails to observe a clearly approaching vehicle on a crossroad may be so contributorily negligent as to deserve no monetary recovery from the state agency. However, few states retain this *all or nothing* contributory negligence rule. Most have adopted a comparative negligence system which permits the partially negligent victim to collect at least a some portion of their damage claim.

Some states still retain the doctrine of sovereign immunity preventing recovery from a governmental unit under the age-old doctrine that "the King can do no wrong." Although this doctrine has been eroded significantly in recent years, most states retain immunity from liability for their discretionary decisions concerning certain elements of highway design and the application of maintenance according to cost-benefit/analysis.

Procedural Matters

Negligence and other tort suits are not treated identically in all states within the United States. The principle of *federalism* permits states to have laws that differ on many points of both procedural and substantive nature. Liability suits may often be brought in one of a number of courtrooms (*venues*) in local, state, or federal courts within the state where the wrong occurred. Nonresidents are often able to use the federal courts which have different, and sometimes more expansive, pretrial procedures giving the plaintiffs greater access to *discovery* for matters contained in the state agency's files.

Typically, an injured plaintiff hires an attorney who is compensated by the hour or on a *contingency fee* basis. The latter arrangement allows the attorney compensation only if the plaintiff wins a settlement or the suit. The time period established by the *statute of limitations*, which begins to run from the time of the accident for one, two, or three years depending on the state law, bars the plaintiff's suit unless a *complaint* is filed within the required period. The plaintiff's attorney files suit in one of the courts chosen. This begins a *pretrial period* in which both sides prepare for trial by interviewing witnesses, examining documents, and researching the applicable law. As the plaintiff's case begins to crystallize, the plaintiff's attorney and the state agency (or state attorney general's office representing the state agency) may participate in *pretrial settlement negotiations.* These typically resolve over 90% of tort disputes. *Pretrial discovery* permits both sides to investigate facts, question witnesses and respond to questions from the opposition, orally, under oath at a *deposition*, or in writing through *interrogatories.* Documents in the state agency files may be examined and copied for use in proving the victim's case under a *production of documents* request. The victim may be subjected to *medical examinations* to verify the extent of injury. It is unlawful to hide evidence, destroy documents, or intimidate *witnesses.* During the trial, the victim and state agency employees may be questioned as witnesses to prove or defend the liability case. Often, expert witnesses in medicine, civil engineering, and economics are used to prove or disprove particular points concerning the road design, the victim's driving and injuries, and the economic equivalency of the victim's injury.

An important caveat should be understood by lay persons: legal processes are uncertain and may not always precisely follow well defined procedural and substantive steps to reach the legal conclusion! Engineers accustomed to applying scientific principles with an air of certainty often find the open-textured, policy-laden, and vague testimonial proof of facts in legal decision-making to be disquieting. It is difficult to accurately predict litigation outcomes or the precise level of risk avoidance from any state agency decision to avoid litigation. This ambiguity results from different laws in the states, the ambiguity of applying apparently precise terms to the rather vague standard of due care in negligence, and the inherent ambiguity in the central term "reasonable." Further ambiguities and unpredictable results result from the limitations of language to represent concepts, particularly among the less technically sophisticated participants in litigation: judges, juries, witnesses, attorneys, or the victim. Judges have considerable discretion in admitting or excluding particular evidence. Juries may be swayed by either a plaintiff's or defendant's lawyer's professionalism. Inconsistent or opposing views between two apparently credible expert witnesses may further confuse the jury's decision-making. Finally, judges and juries are prone to attach great weight to evidence tending to show that compliance with establish standards was ignored or delayed, even for short periods. Given the open texture and vague decision-making process used in law, and the relative ignorance of many highway engineers concerning this process, it is sensible for state agency personnel to become better acquainted with the law of highway negligence. Although precise decision rules may be difficult to articulate, this understanding of the law can nevertheless be used to reduce highway risks from hazardous road conditions and thereby reduce the costs of litigation.

The Duty of Care

All persons, including legal entities such as corporations and governments, must act carefully in everything they do. It is expected that all persons will reduce the risk of harming others whenever they undertake any action. For example, vehicle drivers must drive safely, construction companies must adhere to building codes, professionals such as doctors, lawyers, engineers, or accountants must avoid malpractice, and government agencies must carefully discharge their statutory duties. This duty of care is intended to act as an incentive for all persons to act with due care. By neglecting this duty, a person or entity is exposed to the risk of legal suit and its associated monetary liability if persons are injured.

The basic duty of care is stated as a vague and abstract statement: all persons should act with reasonable prudence by foreseeing risks of harm and guarding against them. During the last two centuries, tens of thousands of court cases from the USA and the UK have been used as precedents setting the expectation for later, similar cases. Precedents establish more particular duties of care than the vague "reasonable person standard" and more precisely specify the particular duties of persons acting in nearly any activity. Particular duties for state agencies with respect to ISD problems are discussed in a later section after further amplification of the negligence standard.

Burden of Proof

Initially an injured victim has the *burden of proving* a suit against a state highway agency by showing the state was negligent in some serious respect. There is no liability for an alleged wrongdoer unless and until the plaintiff/victim proves by a *preponderance of the evidence* that the state agency failed to observe its duty of care with respect to an ISD problem. Therefore, the order of events at trial are:

1. Plaintiff must bring suit and prove:

2. Duty of care

3. Breach of duty

4. Causation

5. Damages

6. Plaintiff must disprove any affirmative defense.

A plaintiff unable to sustain this burden of proof will fail to win the case.

Breach of Duty

When state agencies fail to follow a particular duty of care they may be negligent. For example, if a state agency fails to address a known hazardous condition of which they have notice, fails to repair or maintain a known ISD problem, or fails to warn motorists of a known ISD danger, then a breach of duty has occurred. Breach may be proved in one or more of four ways: misfeasance, malfeasance, nonfeasance, or by negligence per se. *Misfeasance* is an improper attempt to perform some task. For example, a state agency's attempt to cut foliage blocking intersection sight distance that actually makes the condition worse would make the state agency responsible for misfeasance. *Malfeasance* is the commission of an unlawful, prohibited, or wrongful act causing injury. For example, a state agency that intentionally leaves sight obstructions which raise the risks in an ISD context could be liable for malfeasance if design guidelines prohibit the sight obstructions. *Nonfeasance* is a state agency's negligent act of failing or omitting to act when the law requires an act. For example, a state agency might be required to periodically check sight distance at busy intersections according to highway maintenance and repair manual schedules. Evidence of the agency's failure to check this ISD condition as required would be nonfeasance. Finally, *negligence per se* is based on proof of lack of due care where a particular statute defines the legal requirement and the state agency fails to adhere. For example, a motorist would be negligent per se if the signing indicated a slow speed was required in approaching an intersection with limited sight distance and the motorist continued through the intersection at an excessive rate of speed. By violating a statute intended to protect a defined class of persons and a defined risk, the speed limit establishes the minimum required duty. Clearly, if a state agency could prove that it posted a reduced speed limit or warning sign on the approach to an intersection with limited sight distance, then a speeding motorist involved in an accident would be guilty of contributory negligence. Of course, negligence per se can be used against a state agency if state statutory guidelines require particular sight distance procedures, such as the posting of limited sight distance warning signs and speed advisory plates, and if there is evidence the agency failed to comply.

Causation

Negligent acts occur much more frequently than persons are actually harmed. Therefore, the law requires the injured plaintiff to prove the alleged negligent act led to a series of events that resulted in the plaintiff's injuries. A plaintiff unable to show that a dangerous ISD condition led to the victim's injuries would be unable to collect money damages. This is *causation*, a concept divided into two subcategories: actual causation and proximate causation.

Actual causation is a series of physical events which link the highway agency's malfeasance, nonfeasance, or misfeasance directly to a series of events that result in the plaintiff's injuries. For example, if the state agency failed to check for foliage limiting the ISD at a prescribed interval and a motorist is injured due to the lack of ISD, the plaintiff can establish that the agency's failure led to or caused the victim's injuries. This may be represented by the *but for* causation rule, also called *sine qua non*, which states that "had it not been for the highway agency's negligence, the plaintiff's injury would have been avoided." Where there are several hazardous conditions that combine to injure a plaintiff, these may represent concurrent causes of the victim's injuries exposing additional negligent parties to share liability. Some courts resolve this problem by holding any party whose negligence was a *substantial factor* leading to the plaintiff's injuries to be held liable.

A second form of causation, *proximate causation*, should not be confused with the actual cause described above. Proximate causation limits the liability of a defendant where the outcome is not *foreseeable*. Clearly every person's act or omission has later consequences, and some acts may have an impact even into eternity. The law does not hold persons liable for all the endless results of a negligent act; justice requires a limit on liability. Only foreseeable, and not endless remote, consequences are actionable. Juries are permitted to consider what kinds of damages are foreseeable given the expectations placed on a defendant. For example, it is reasonably foreseeable that insufficient ISD visibility could lead to a collision. However, if the collision involved a medical doctor rushing to a hospital to provide surgery, it cannot be foreseeable for the state agency that the patient will die if the physician is late. Therefore, the lack of ISD maintenance could be said to proximately cause injuries to the doctor but not the injuries to the doctor's patient while waiting the surgery at the hospital. In other words, deterioration in the patient's condition is unforeseeable to the state highway agency in making ISD maintenance decisions. Proximate cause insulates an actor from excessively remote damages because they are not reasonably foreseeable.

Damages

Successful negligence plaintiffs must allege they suffered some injury or damages. This is usually expressed in monetary terms: an amount of money necessary to put the plaintiff back in the same condition as before the injury. Therefore, a highway agency's risk of or exposure to financial loss can be minimized where proof is made that the plaintiff sustained little or no damages.

There is considerable controversy over the utility of monetary damages as a measure of the plaintiff's injuries. When a plaintiff suffers property damages or must pay medical and other rehabilitation costs, then monetary damages are a fairly accurate measure of the extent of plaintiff's injuries. For example, automobile repair costs and medical expenses may be fairly accurately estimated in the future or more precisely proved after payment. However, monetary damages are allegedly an imperfect measure of losses suffered where the judge or jury must speculate as to a precise dollar figure. For example, in *wrongful death* cases, the jury must speculate as to the deceased victim's earning power and work life expectancy. Juries must usually speculate as to how long the deceased plaintiff would have lived had it not been for the accident, and how much the plaintiff would have earned during that *work life expectancy*. This figure must be reduced by the projected life maintenance expenses. An interest rate must be arbitrarily chosen to discount these future cash flows to a present value figure used to compensate the deceased victim's next of kin. Clearly, this process is speculative, at best, and the monetary damage figure obtained is often quite high: typically many hundreds of thousands of dollars. For highly-paid professionals, the amount can be in the millions of dollars.

Noneconomic or intangible losses are even more difficult to quantify. For example, *pain and suffering*, loss of *society*, sexual relations, and *consortium* from one's spouse, and *hedonic* damages (loss of life's pleasures) are all highly speculative. They can run much higher than the economic damages discussed above, so tort reformers in many states have recently enacted laws limiting some forms of noneconomic damages. There is a generally held impression that excessive punitive damages are awarded in all cases. This is not true. High punitive damage awards are usually reduced on appeal. Nevertheless, the punitive damage component is another wild card in the difficult problem of projecting risk exposure. Increasingly, in cases settled without going to trial, the defendant or its insurer will agree to a *structured settlement* designed to replace lost future earnings. Annuities are often used. However, plaintiff's attorneys, particularly those working on a contingency fee basis, have disincentives to engaging in structured settlements which can lower their compensation. In response, many insurers are promising an additional lump sum for the plaintiff's attorney paid at the time of settlement.

Clearly this process of computing economic and non-economic damages is controversial, further fueling the tort reform efforts undertaken in many states. Additionally, the mathematical formulas used in the discounted cashflow present value analysis may not accurately account for inflation, taxes, life maintenance expenses, and the victim's expected salary raises for productivity during the lost future income period. State agency liability for damages arising from ISD problems is treated no differently than liability for other hazardous road conditions or other torts in general.

Liability Defenses

ISD cases may be particularly well-suited for state agencies to claim that the plaintiff's own negligence contributed significantly to the plaintiff's injury. For example, consider a situation in which a plaintiff's vehicle is operated on a minor road with sufficient approach signing that clearly indicates the presence of an intersection with a major road. The plaintiff's inattention to the need to decrease vehicle speed in anticipation of traffic on the intersecting road would be a clear indication of contributory negligence. In those few states which still use the contributory negligence standard in its original form, adequate proof of the plaintiff's contributory negligence completely bars the plaintiff's recovery of any money damages from the state agency. However, two factors mitigate this favorable result from the state agency's perspective. First, juries may understand the effect of finding the plaintiff partially negligent and their sympathy for the plaintiff may lead them away from such findings. Second, most states have abandoned the strict "all or nothing" rule of contributory negligence replacing it with some form of comparative negligence.

The general dissatisfaction with the severe hardship placed on victims by the contributory negligence rule has led to the adoption of comparative negligence in most states. Under *comparative negligence*, the all or nothing nature of contributory negligence is abandoned in favor of a "fault apportionment" between the plaintiff and defendant. This requires the judge or jury to separately assess the proportion or percentage of negligence of the plaintiff in relation to the defendant's negligence. Thereafter, the jury reduces the plaintiff's provable monetary damages by the amount of the plaintiff's own negligence. The comparative negligence system holds neither party responsible for the whole burden of losses for which each is partially responsible.

The early courts and legislatures mistrusted juries, believing they were incapable of apportioning the degree of fault among multiple parties. However, recent experience with comparative negligence has shown that this was an unfounded criticism. Three basic formulas for apportioning fault under comparative negligence are in use by various states, each state uses only one of these three methods. For example, assume a motorist proved $100,000 of personal injury and other economic losses from the state agency's negligent attention to an ISD problem, the plaintiff's damages could be reduced by the proportion of the plaintiff's own negligence. If the plaintiff was partially responsible for the accident by not perceiving the approach of a partially visible cross street, the jury might find the plaintiff was one-third negligent. This would reduce the plaintiff's $100,000.00 damages to $66,666.66. Comparative negligence usually requires state agencies to pay for at least some of an injured plaintiff's money damages even where the plaintiff has considerable negligent fault.

The assumption of risk defense is still recognized in most states, even in some of those that have adopted the comparative negligence standard. Where a plaintiff makes a much stronger contribution to the injury than under contributory or comparative negligence, the plaintiff may be denied money damages altogether. *Assumption of the risk* is an individual plaintiff's voluntary assumption of a known risk. For example, if a motorist fully understands the potential risk of cross traffic, yet nevertheless proceeds through an intersection without slowing down, the state's ISD duties may be irrelevant. This can be particularly important for drivers who are accustomed to using a particular roadway and know the risks of cross traffic at a particular intersection. A plaintiff with personal experience with a known road hazard, or any other reliable notice of a dangerous condition who nevertheless proceeds to drive through the intersection without due care can be found to have assumed a known risk and will not collect money damages. This becomes an important question of fact which accident investigators should carefully review. A few states treat assumption of risk like comparative negligence by apportioning fault and therefore monetary damages.

There are other aspects of contributory negligence and assumption of risk which state agencies may seek to prove where the facts warrant. For example, courts consider reckless driving, influence of alcohol or drugs on the motorist, a driver's familiarity with the road hazards in a particular section of road, the driver's speeding as inferred from the length of skid marks, the plaintiff's acknowledgment of reading signs warning of the risk, and other aspects of common knowledge about driving conditions. These can all be proved to show a particular plaintiff's negligent contribution to the injury or voluntary assumption of a known risk. It is interesting to note that the increasing use of anti-lock braking systems (ABS) will reduce the reliability of conventional skid mark computations for inferring vehicle speed.

SOVEREIGN IMMUNITY

Government liability is a relatively new problem that has only become an issue in the United States since the late 1940s. Before that time, the *sovereign immunity* doctrine protected government from liability. Governments were immunized from suit to prevent the fear of suit from contributing to poor governmental decisions. Immunity also protected government's limited resources. However, since the federal government waived its sovereign immunity for tort liability in the Federal Tort Claims Act, most states have also waived their immunity either by legislation or by precedent-setting court decision. The state's potential liability is of great concern in most highway design cases. Even where the states have accepted some federal funding for the construction of roads, most states, municipalities, and counties no longer are immune from negligence damage suits.

A limited form of sovereign immunity is retained by most governments under what is variously termed the "the discretionary function exemption." Authorized government employees with the power and duty to exercise independent judgement in choosing among alternative courses of action are usually protected in the choices they make. These are the essence of political decision making which must evaluate costs and benefits, political, and social impacts from governmental decisions. Highway agencies probably retain a form of discretionary immunity in making such "policy" decisions on the organization of their highway improvement programs, the assessment of property values, the selection of highway routes, the particular design elements of highways, particular highway structures, and the method of executing these plans. Some courts even apply discretionary immunity to protect state agency decisions in maintenance and highway updating decisions where a cost-benefit/analysis or risk-benefit/analysis is performed within budgetary constraints and the agency attempts to optimize the use of their scarce funding resources.

Protected policy decisions are distinguished from other ministerial acts of implementation; the latter are usually exposed to tort liability. Unprotected acts usually require no evaluation of alternative actions and involve more routine operational acts such as maintenance and repair, traffic operations, and the driving of government vehicles. ISD problems will likely involve potential liabilities where the more routine maintenance and identification of hazardous conditions is involved. Even where expensive design change considerations are involved, state agencies may retain liability for ISD problems if warning signs or traffic signals could be employed to warn vehicle operators of the potential problems.

SPECIFIC STATE AGENCY DUTIES RELATING TO ISD PROBLEMS

As discussed above, the negligence tort duty is written in vague terms to permit application in many diverse situations. However, precedents set in case law from the various states illustrate how more specific duties are generalizable from the case law. Generalizations from the litigation experience throughout the United States on hazardous road design and maintenance conditions has led to the classification of precedents in the specific acts of: highway planning, construction, and maintenance. Therefore, it is possible to generalize on state agency ISD duties. In states with no particular precedents addressing ISD problems, duties are borrowed from other analogous contexts of hazardous road conditions. These are used as a guide to establish duties in uncharted "cases of first impression." This reasoning by analogy from similar duty situations is the traditional and accepted form of legal analysis. However, it often fails to provide risk managers with a definitive basis for projecting potential risks. Nevertheless, most lawyers advise their clients based on this analogical reasoning. The next several sections illustrate the most common legal duties for hazardous road conditions.

While the following discussion addresses the duties of state agencies, most of the same points would apply to local agencies, as well.

Notice

State agencies clearly have capacity constraints in their quest to catalog and protect the public from road hazards. However, state police and citizens often report to state agencies concerning emerging hazardous road conditions. The law generally requires a state agency to respond to such notices. After receiving notice, the state agency has a new duty to inspect the reported hazardous condition, warn motorists if warnings would be effective in reducing injury, and repair the condition to a reasonably safe condition. This liability is not unlimited: clearly widespread emergency conditions from sudden hazardous weather can create such a huge list of unaddressed reported hazards that it is unreasonable to expect immediate attention. For example, if numerous notices of hazardous road conditions arrive simultaneously or are received at night when most work crews are unavailable, a state agency has a reasonable amount of time before a repair or warning response would be necessary. Several states have passed laws giving state agencies a minimum period of time, such as five days, before a response to a notified hazardous road condition would be necessary. Nevertheless, notice is generally effective as soon as it is received by the state agency. Such direct communications to the state agency are referred to as *actual notice*. Actual notice may take the form of a motorist's telephone call, letter to the state agency, record made in state police or highway patrol logs or the like. Actual notices that are not date and time stamped on arrival are nevertheless effective notice to the state agency. Actual notice is also effective when state employees conduct regular or extraordinary road inspections as a part of their duties.

The law also recognizes notice not actually received through direct communication but which the law considers equivalent to actual notice. *Constructive notice* is a substitute or presumption of actual notice where the state agency had ample opportunity to investigate the facts. Some injured plaintiff's have successfully claimed the state agency "should have known" of a particular dangerous condition or ISD problem. Despite the state agency's claim of ignorance, if a defect existed for an unreasonable length of time and the agency should have discovered it, there is constructive notice. All state agency employees are considered agents of the government responsible to report any defects they personally observe or defect notices they directly receive from other persons. For this reason, state agencies should educate employees about the importance to communicate notice, observed dangerous conditions, and report them immediately. Such observation should be made a part of state agency employees' job description.

Duty to Design and Plan Construction

State highway authorities must plan and design highways using reasonable care to make them safe. Generally accepted engineering standards and practices are used in the definition of reasonable care. This does not mean roads must be designed to be absolutely safe. Indeed, such inherent conditions as wetness or dampness contributing to slick highways are conditions that motorists must expect. The presence of such natural conditions that degrade the safety of the road's surface or its overall design do not constitute negligence. However, where particularly dangerous conditions exist in such inherent road conditions the governmental entity may have additional responsibility to warn or otherwise ameliorate the danger, e.g., curve warning, speed reduction warning.

In most states, the applicable, generally accepted engineering standards and practices include only those in existence at the time the highway or roadway is first designed. As more modern standards are developed that may reduce certain aspects of danger, roadways need not be upgraded. A few states have exceptions to this general rule. For example, one state requires adherence to all engineering and design improvements as they generally become accepted. Another state requires improvements when the original plan or design, in actual operation under changed physical conditions, such as a significant increase in traffic volume, produces a dangerous condition. A middle ground is adopted by some states which would impose more modern standards only when the roadway is upgraded; whichever design is selected from among the alternatives considered must meet the standards generally prevailing at that time. Such questions become important if evidence at a negligence trial tends to show that an alternate design could have prevented the accident. Design decisions are the essence of governmental discretionary decisions. Therefore, the choice among alternatives that are acceptable at the time are usually considered immune from tort liability under the various forms of the discretionary function exemption.

Design Immunity

Most states shield the basic decisions to build a highway and to approve the plan for its design as nonactionable, i.e., exempt as a discretionary function. Such decisions are high-level discretionary activities requiring expertise and skill in judgement in making choices among alternatives. The discretionary function exemption protects even ill-conceived highway plans and designs whether or not they contain errors or defects. So long as the flawed design is not "obviously inherently dangerous" most state highway agencies will be immune from tort liability under the concept of design immunity.

The implementation of design decisions is typically not immune from tort liability. Any design decisions which do not result from judgement and choice resulting from a conscientious balance between risks and advantages among the alternatives is not immune. Discretionary design decisions deserving of immunity must take into account safety, economics, prevailing standards, recognized engineering practices, and whatever else is appropriate under the circumstances.

In the ISD context, design immunity should protect elements of design decision-making concerning grade, alignment, and obstruction setbacks that could arguable be connected to varying the sight distances achievable under ideal conditions. However, where new grade and alignment designs are envisioned and the particular decisions made ignore prevailing standards or notice about sight distance problems at that location under previous designs, the discretionary function exemption for design immunity may be inapplicable. This means that state agency exposure for ISD problems arising in redesigned or newly designed situations is generally dependent upon engineering standards prevailing at the time of the redesign. The small number of ISD design cases reporting appellate precedents (i.e., written decisions by appeals courts) makes it difficult to predict risk exposure with a high a degree of certainty. However, as they have for other issues, the courts can be expected to draw from precedents in other areas of hazardous road conditions to construct the elements of duty in an ISD case.

Duty to Construct and Execute According to Plan and Design

ISD problems may arise where highway agencies have not met their duty to construct and execute new projects as planned or designed. This suggests two major components to satisfying the duty. First, highway agencies must carefully review bids by outside contractors to assure that the bidder selected is reasonably competent and has a track record of adherence to plans. Second, as construction progresses, the highway agency is responsible to assure that contractors adhere to plans as designed.

In the ISD context, the failure to construct and execute a project as planned and designed is most likely to arise when an injured motorist or bystander can provide evidence that the highway agency failed to monitor the progress of construction, that the contractor's deviation from the stated plans contributed to an injury, and that highway agency monitoring or inspection would have detected the contractor's deviation. In tort litigation against highway agencies, government documents associated with the planning and construction process are opened for discovery by injured plaintiffs. In addition, documents and witnesses from the independent third party construction companies are also available for questioning and testimony. Negligence in construction may expose the contractor to liability, but this does not necessarily absolve the state from liability. For example, if the third party contractor is bankrupt or otherwise "judgement proof," the state's contribution to a negligent condition through failure to monitor the construction process may render the state liable. Of course, a state might assert that deviation from the design was approved after the construction started. However, such convenient approval could be suspect and might not be expected to prevent liability without significant documentation and clear authorization.

Duty to Warn

State highway agencies have a duty to warn motorists of known highway defects, obstructions, or unsafe conditions that cannot be eliminated. ISD may be a potentially unsafe roadway hazard about which public authorities must warn motorists. For example, a reasonable jury might be expected to infer that the highway agency "should have" provided warnings about an approaching intersection if motorists may be unable to slow their vehicles sufficiently to avoid a collision at the intersection. Particularly where grade, alignment, and obstructions limit sight distance, the highway agency may be required provide warning signs or beacons to alert motorists to the intersection.

Highway agencies may also be liable where the warning made is inadequate. For example, if an intersection warning sign is placed too close to the intersection, without providing a reasonable distance for motorists to reduce their speed, then the warning may be considered inadequate and the highway agency held negligent. In the ISD context, signing preceding the intersection should be carefully reviewed to avoid such confusion or inadequacy considering reaction times, typical vehicle speeds, and average stopping distances under normal conditions.

Duty to Maintain

Highway agencies generally have a duty to exercise reasonable care to keep highways, streets, and bridges in reasonably safe condition for their expected uses. Unless a specific state statute requires the highway agency to follow a higher or lower duty, the duty to maintain may have four distinct elements. First, obstructions (e.g., foliage) which could reduce ISD should be properly maintained to minimize the ISD limitations. Second, signing that warns drivers of approaching intersections must be maintained in good and readable conditions for both day and night use and in inclement weather. Third, any warning beacons intended to warn drivers of approaching intersections must be kept in working order. Fourth, if the highway agency becomes aware of new or changing uses of roadways, and if these changes create greater hazard due to limited ISD conditions, then signing, signals, and obstruction maintenance policies may need to be revised. Changes in traffic volume and mix, such as larger trucks which might obscure sight distance or have greater sight distance requirements must be considered periodically to avert a developing hazardous road condition.

Defects in the original construction or subsequent maintenance which adversely affect ISD must also be corrected. For example, signing with insufficient night reflectiveness or incorrectly installed signals must be periodically reviewed for their effectiveness. Complaints or other notice to the public highway authority indicating a difficulty with ISD distances should be reviewed and the appropriate remedial action taken.

SURVEY OF STATE AGENCIES

The following section reports the results of a survey of state highway agencies and state attorney general offices conducted as part of the research.

Methodology

Risk management engineers or state attorneys general were contacted, by telephone, in each of the following states: California, Florida, Indiana, Michigan, Missouri, New York, Ohio, Oklahoma, Pennsylvania, and Washington. The purpose of these contacts was to gain some additional insight into the nature and magnitude of ISD-related highway tort claims. According to data published in a recent paper on state highway tort liability, these 10 states account for approximately 75% of the nearly $350 million paid by states for highway tort settlements and judgments during the three-year period from 1988 through 1990.

Information was requested from each of these states on:

1. The approximate percentage of tort actions (including pre-litigation and litigation actions, but only those actions on which a state settlement payment has been made) that involve alleged ISD

deficiencies, including design, maintenance, or operational-related deficiencies.

2. The approximate distribution of ISD-related tort actions among specific types of deficiencies, such as: original design did not meet design standards of the time; negligent construction; failure to upgrade new design standards; failure to upgrade for changed operating conditions; failure to maintain clear view; etc.

3. Citations on some relevant case law.

4. Opinions on the significance of possible revisions to intersection sight distance design policies.

Findings

In general, ISD-related tort actions constitute only a small percentage of the total highway tort actions and settlements paid each year by the states contacted. Michigan, for example, indicated that approximately 4% of its highway tort claims are associated with ISD, by far the highest percentage reported by any of the states. A surprising result of the contacts with the states was the general lack of information management systems concerning tort liability that would facilitate responses to the questions raised. Five of the states contacted do not maintain a data base on the types of highway elements or contributing factors associated with tort claims. Thus, the responses from these states are necessarily predicated upon the nonempirically-based opinions of the individuals interviewed. None of the five states that do maintain a data base on contributing highway factors list ISD deficiencies as a separate category. Only three of these states (Michigan, Ohio, and Pennsylvania) were able to provide either quantitative estimates or information from which quantitative estimates could be derived on the magnitude of ISD-related tort claims.

Michigan

Approximately 4% of Michigan's tort caseload involves ISD-related liability. The majority of these ISD claims relate to a "tight diamond" interchange design that was commonly used on Michigan freeways approximately 35 years ago. The geometrics of this type of design typically result in poor ISD for motorists on the freeway exit ramps, particularly where there is guardrail protecting crossroad bridge-end abutments.

Michigan typically tries to settle tight diamond design cases prior to trial, because most locations with the tight diamond design do not meet AASHTO ISD policies. It should be noted that there is no highway design immunity in Michigan, either by statute or by precedent. Michigan has taken several steps to improve the safety and to reduce the state's liability exposure associated with tight diamond interchanges. For example, several years ago, advisory speed signs were installed on the crossroad, but these have not been particularly effective. Traffic signals and three-way STOP-sign installations have been used, when warranted, and have proven to be effective.

Ohio

In Ohio, claims of less than $2500 are heard by an Ohio Department of Transportation Court of Claims. Claims of $2500 or more are defended by the state Attorney General's Office and heard by a retired judge. There are no jury trials for highway tort claims.

Over the period 1997 to 1991, there were 1,261 highway-related tort claims filed against the Ohio Department of Transportation. Fourteen of these claims, or approximately 1%, involved alleged ISD deficiencies. Table I-1 shows the distribution of these claims according to the type of physical feature that was creating the ISD problem.

Table I-1. DISTRIBUTION OF ISD-RELATED TORT CLAIMS IN OHIO

Physical feature creating ISD deficiency	Number of claims	Percentage of claims
Roadway sign	5	36
Foliage	6	43
Vertical curvature	2	14
Not specified	1	7
TOTAL	14	

Pennsylvania

In the 1978 case Mayle v. Commonwealth, the Pennsylvania Supreme Court struck down the principle of sovereign immunity in the Commonwealth of Pennsylvania. The Pennsylvania legislature moved swiftly to reinstate sovereign immunity but provided waivers to this immunity in eight specified areas. Four of these areas, including dangerous conditions of the highway, directly expanded the liability exposure of the Pennsylvania Department of Transportation (PennDOT). Between July 1979 and September 1992, PennDOT has paid approximately $115 million in settlements on approximately 13,000 tort actions alleging PennDOT negligence with respect to dangerous highway conditions.

As part of the Commonwealth's tort claims administration, the Bureau of Risk and Insurance Management within the Department of General Services maintains a database on all Commonwealth tort action settlements and judgments. Recorded in this database is information on the highway conditions or elements alleged to have contributed to the tort-related incident. Although this database does not contain any specific entries for intersection sight distance (ISD), it does contain several entries related to sight distance in general. Copies of settlement memorandums in these several categories were reviewed to determine the magnitude and nature of ISD-related tort actions against PennDOT.

Approximately 150 settlement memoranda were evaluated; 73 (or about 50%) of these involved alleged ISD-related deficiencies.* Thus significantly less than 1% of the highway-related tort claims settled by PennDOT through September 1992 involved ISD. If the large number of minor property damage claims related to tar and chip operations are removed from the total tort actions count, then ISD-related cases still represent only a small percentage, just slightly over 1%, of settled torts.

All but nine of the ISD claims resulted from collisions between vehicles using intersecting roadways. The other nine involved vehicles traveling in opposite directions where one of the vehicles attempted a left-hand turn at an intersection. Approximately one-third of the settlement memoranda for the incidents between vehicles using intersecting roadways specified that one of the vehicles was attempting to make a left-hand turn. The remainder of the settlement memoranda did not specify the type of turning action.

Table I-2 shows the distribution of ISD-related claims across the types of physical factors creating the ISD deficiency. It should be noted that most of the ISD claims alleged more than one type of roadway deficiency against PennDOT but, for the 73 claims listed in Table I-2, ISD appears to have been the principal basis for the claim. Likewise, many of the ISD-related claims alleged that more than one physical feature created the ISD deficiency; this is particularly true for claims involving embankments or foliage. For many of the embankment claims, it was also claimed that weeds, vegetation, or other types of foliage also obstructed sight distance. Similarly, for many of the foliage claims, an embankment was also involved. However, the tort claims are classified in Table I-2 by the primary feature that was claimed to limit ISD.

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* Another 13 claims alleged sight distance deficiencies involving driveway entrances onto state highways. The claims may involve many of the same physical factors, DOT responsibilities, and legal issues as the 73 ISD claims.

Table I-2. DISTRIBUTION OF ISD-RELATED TORT CLAIMS IN PENNSYLVANIA

Physical factor creating ISD deficiency	Number of claims	Percentage of claims
Embankment	12	16
Foliage, trees	15	21
Vertical curvature	19	26
Horizontal curvature	5	7
Intersection alignment	3	4
Miscellaneous	6	8
Not specified	13	18
TOTAL	73	

As indicated above, one legal duty of state highway agencies is to plan, design, construct and maintain highways using a reasonable standard of care defined in part by generally accepted engineering standards. In 30 of the 73 ISD-related claims, the available ISD distance did not meet PennDOT's established ISD policies. One-half of these 30 cases involved vertical curvature limiting the available sight distance. Unfortunately, most of the remaining settlement memoranda did not indicate whether or not existing ISD policies were satisfied. Satisfaction of ISD standards would not however, necessarily eliminate PennDOT's liability in an ISD claim. In Pennsylvania, precedents from case law establish the principle that the mere fact that the roadway may have met design standards does not suffice to show that there may not be dangerous characteristics of the roadway. Thus, an intersection that meets all current design standards, but which has a substantial accident history, may create significant liability exposure for PennDOT. Such was the case in four of the ISD claims. Unfortunately, there is no standard judicial definition of "substantial accident history" and judges appear to have a great deal of latitude on the amount and nature of accident history that they will allow to be submitted into evidence.

Washington

The State of Washington does not maintain a database containing the types of physical highway elements associated with highway tort claims. However, the Chief of the Tort Claims Division in the State Attorney General's Office noted that, while most sight distance liability currently seem to involve driveways, ISD-related liability is a potentially troublesome area due to the broad array of situations that can arise. Currently, the most significant sight distance problems at intersections involve foliage, particularly foliage on private property, that the state has limited ability to control.

A very old State appellate court ruling in Washington provides that municipalities and the state have no duty to maintain visibility at intersections. Rather it is the duty of the driver to adjust to the available sight distance. While this old precedent has never been overruled, it has not enabled the State to obtain any summary judgments in ISD cases. The State has been reluctant to appeal any jury verdicts in ISD cases for fear, in part, of having this old ruling overturned.

There is no highway design immunity in Washington. Neither are limited resources (i.e., the economic defense) recognized in the courts. The State has attempted to use a priority array defense linked to available funding but this has not been a very successful approach for the State.

SUMMARY OF FINDINGS

Many aspects of the law concerning tort liability are not as clear as highway engineers would like. In many states, highway designs are considered acceptable if they conform to the design standards in effect at the time the project was designed and built. Upgrading of the design is not required simply because design standards are changed. However, when an intersection is being redesigned, especially if the agency is aware of (has notice of) sight distance problems in the existing design, there may be a duty on the part of the highway agency to upgrade ISD to current standards.

The data collected in this research indicate that ISD-related cases are a relatively minor part of the tort liability problem faced by highway agencies (at most 4%, and typically less than 1%, of total claims settled). Foliage, embankments, and vertical curvature appear to be the major types of sight restrictions for which highway agencies are sued.

IMPLICATIONS OF RECOMMENDED ISD POLICIES FOR TORT LIABILITY OF HIGHWAY AGENCIES

The changes in ISD design policy recommended in this report are not expected to have major tort liability implications for highway agencies. The recommendations concerning intersections with STOP control on the minor road would reduce sight distance values for such intersections; this should be an advantage to highway agencies in tort litigation because, in the past, many highway agencies have found it difficult to provide sight distance that meets the unrealistically large existing sight distance criteria for STOP-controlled intersections. The more limited scope of the recommended sight distances for signalized intersections should also reduce the number of intersections that do not meet the existing criteria. The report does recommend, in some cases, more sight distance than current policy at higher speed uncontrolled intersections and at YIELD-controlled intersections. The recommended change in policy, if adopted, should not have major tort liability implications because the Green Book formally applies to design of new or reconstructed intersections, rather than to existing intersections, and because design policies prevailing at the time the intersection was designed, rather than current policies, may control. However, highway agencies may find it advisable to monitor the safety performance of uncontrolled and YIELD-controlled intersections and consider sight distance improvements (or an appropriate change in the traffic control device) if a pattern of sight-distance-related accidents is found.