IHSDM Intersection Diagnostic Review Model

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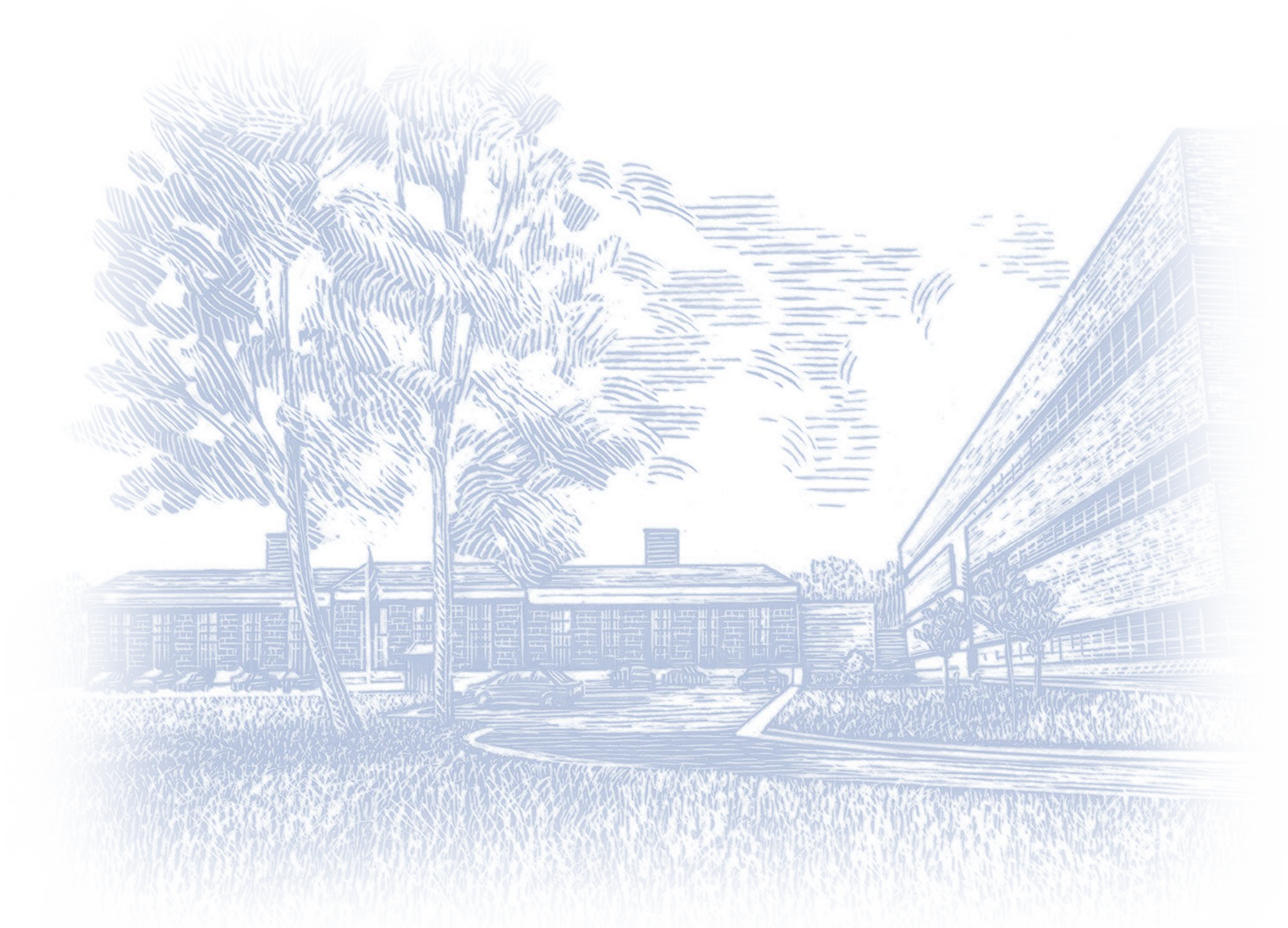

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Federal Highway Administration

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Foreword

This report documents the results of the development of an expert system for intersection safety that is part of the Interactive Highway Safety Design Model (IHSDM). The objective was to develop software to perform a diagnostic review of intersections on rural two-lane highways, referred to as the Intersection Diagnostic Review Model (IDRM). This report focuses on documenting the knowledge base developed for the IDRM software. It also documents the software in that it identifies the knowledge structure, problem definitions, models, decision algorithms, formulas, and parameter values implemented in the software.

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This report documents the results of the study, "Development of an Expert System for the Interactive Highway Safety Design Model (IHSDM)." The objective was to develop software to perform a diagnostic review of intersections on rural two-lane highways, referred to as the Intersection Diagnostic Review Model (IDRM). This report focuses on documenting the knowledge base developed for the IDRM software. It also documents the software in that it identifies the knowledge structure, problem definitions, models, decision algorithms, formulas, and parameter values implemented in the software.</td></tr>
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SI* (Modern Metric) Conversion Factors

Approximate Conversions to SI Units

Symbol	When You Know	Multiply By	To Find	Symbol
Length				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
Area				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
Volume				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
Mass				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
Temperature (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
Illumination				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
Force and Pressure or Stress				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

Symbol	When You Know	Multiply By	To Find	Symbol
Length				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
Area				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
Volume				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
Mass				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
Temperature (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
Illumination				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
Force and Pressure or Stress				
N	newtons	02.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

Table of Contents

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

This report documents the results of Federal Highway Administration (FHWA) Contract No. DTFH61-97-C-00053, "Development of an Expert System for the Interactive Highway Safety Design Model (IHSDM)." The objective of this contract was to develop software to perform a diagnostic review of intersections on rural two-lane highways, referred to as the Intersection Diagnostic Review Model (IDRM). The two main components of the project are:

1. Develop the "knowledge base" – the decision process for performing the diagnostic review.
2. Implement the knowledge base in the software.

This report focuses on documenting the knowledge base developed for IDRM. Prototype software implementing this knowledge base was completed and delivered as part of the project. The software is documented as part of the overall IHSDM software documentation. This report also documents the software in that it identifies the knowledge structure, problem definitions, models, decision algorithms, formulas, and parameter values implemented in the software.

This introduction summarizes the objectives, scope, and approach of IDRM, and its role in IHSDM.

1.1 Role Of The Intersection Diagnostic Review Model (IDRM) In The IHSDM

This project is part of the FHWA's Interactive Highway Safety Design Model (IHSDM). IHSDM is an integrated suite of tools to assist highway designers in evaluating and improving the consideration of safety in their designs. IHSDM is being developed in a modular manner and includes several analysis modules, including:

1. Crash prediction module (CPM) for predicting the safety performance of proposed design alternatives.
2. Driver/vehicle module (D/VM) for studying the interactions of drivers and vehicles with roadway geometrics.
3. Traffic analysis module (TAM) to model the traffic operational interactions of drivers and vehicles with the roadway geometrics and with each other.
4. Policy review module (PRM) for assessing whether a design complies with established roadway segment-related geometric design policies.
5. Design consistency module (DCM) provides information on the extent to which a roadway design conforms to drivers' expectations.
6. Intersection review module (IRM), which includes two components: a review of intersection-related geometric design policy, and IDRM to evaluate the suitability of at-grade intersection designs considering factors that go beyond those in geometric design policy.

The initial priority in IHSDM development is being given to the design of projects on rural two-lane highways. Within that scope, IDRM focuses on the design of intersections on rural two-lane highways.

The role and function of IDRM within IHSDM are illustrated in Figure 1 . An IDRM review of an intersection design typically would be performed after the application of the IHSDM Crash Prediction, Policy Review, and Design Consistency Modules, which generate output that may be used as input to IDRM. IDRM operates within the IHSDM user interface and obtains computer-aided design (CAD) data through the IHSDM CAD interface.

The intended user for IDRM is the working highway designer or traffic engineer. IDRM will be used at most stages of the design process, including engineering studies, functional/conceptual design, preliminary design, and detailed design. For example, an engineer might use IDRM to review a conceptual design option for a study to ensure that it does not contain combinations of geometric features that would require changing the concept at a later stage of design.

1.2 IDRM Objectives

The objective of IDRM is to supplement policy and standards by providing a comprehensive diagnostic review of an intersection design, analogous to a review that might be performed in a design organization *by a senior highway safety engineer*. A primary focus is to identify *combinations of geometric design elements* that suggest potential concerns, even though the elements individually would be considered within acceptable practice. A number of potential issues were identified as candidates to be addressed by IDRM; selection of the issues incorporated in IDRM is discussed in Section 2.1.

IDRM was conceived as an *expert system* – i.e., a software system that emulates the knowledge of a human expert. An expert system is clearly suggested by the objective of providing a function similar to an expert design review. Expert systems differ from other software in that their *intent* is to emulate expert reasoning. They typically provide greater depth and flexibility in representing knowledge. The starting points for an expert system are:

- Define clearly the decision(s) to be made.
- Describe in detail the process by which an expert would make a decision.
- Develop a software structure that can emulate this decision process.

These were the overall tasks in developing the IDRM knowledge base.

A second expert system, referred to as the Project Development Expert System, was included in the scope of this project. Whereas the intent of the IHSDM Expert System is to review a proposed or potential highway design, the Project Development Expert System is intended as a tool to screen existing intersections for improvements. During the course of the project, the research team concluded that the same knowledge and decision process is applicable to both the IHSDM Expert System and the Project Development Expert System. Therefore, it was decided to develop a single, unified knowledge base and software product for both systems.

A key distinction between the IHSDM Expert System and the Project Development System is that crash history data for an existing intersection may be available, whereas such data will not be available for a proposed new design. (Crash data may, however, be available for an actual intersection design and traffic conditions similar to a new design.) Such data may be of value in assessing the need for design improvements. (However, crash frequency may often be too low to be statistically significant, especially for rural two-lane highways.) Accordingly, the unified expert system includes the capability to apply crash data where available, as described in Section 5.0.

1.3 The Knowledge Base Development Process

Members of the IDRM research team are recognized experts in highway design and highway safety research. The team also included expert system development specialists with experience in the process of capturing human expert knowledge into software – "knowledge engineering." In consultation with FHWA, it was decided that the IDRM knowledge base should be derived primarily from the experts who were included in the research team for that purpose, together with relevant published literature and consultation with specialists where appropriate. A relatively small number of experts who are available for extended periods of time greatly facilitate the process of knowledge engineering.

To obtain a broader range of input and to help validate the knowledge base, an Advisory Panel was created. The panel consisted of representatives of six state highway departments, as well as FHWA representatives. The panel met four times over the course of the project to review the knowledge base and to provide general guidance. Advisory Panel participants are listed in Table 1 . The research team wishes to acknowledge the Advisory Panel's substantial contribution to the project.

The knowledge base development process consisted of the following steps:

1. Identify and prioritize design issues with the highest potential for IDRM to provide valuable guidance to the user. These issues are presented in Section 2.1.
2. Identify specific problems or concerns, related to the high-priority issues, that IDRM should be able to identify. These concerns are presented in Section 2.4.
3. Articulate the experts' rationale for identifying the concerns as potential problems. Codifying the expert reasoning process is an essential step in knowledge engineering. This step led to the conclusion that quantitative models, based on fundamental geometric design elements (such as sight distances), could be formulated and used to evaluate the extent to which a problem is present. The models allow evaluation not only of individual potential problems, but also of combinations of problems.
4. Formulate engineering models and select model-based threshold parameters to identify each of the concerns IDRM is to be able to identify. The models are summarized in Section 2.5.
5. Develop a methodology to supplement the engineering models with crash data when such data are available. This methodology is presented in Section 5.0.
6. Develop a methodology to recommend mitigation measures (treatments) that can be suggested to the user to eliminate or mitigate concerns identified by IDRM. This methodology is presented in Section 2.7.

Table 1. IDRM Advisory Panel Participants

Participant	Affiliation
Robert Douglas, P.E.	Maryland State Highway Administration
Ronald Erickson, PE	Minnesota Department of Transportation
Jake Kononov, PE	Colorado Department of Transportation
Lloyd Rue, PE	Federal Highway Administration
Peter Rusch, PE	Wisconsin Department of Transportation
Dewayne Sykes, PE	North Carolina Department of Transportation

1.4 IDRM As An Expert System

Expert systems are intended to "behave" in a manner similar to a consultation with a human expert. To accomplish these goals, expert systems usually use search algorithms to locate and apply knowledge, rather than the sequential execution of program statements of "procedural" software. As discussed in Section 1.3, Expert systems are software tools that are used to capture and make accessible a body of human knowledge that is capable of being codified in a logical structure, such as rules. This body of knowledge is referred to as the "knowledge base." Expert systems are intended to "behave" in a manner similar to a consultation with a human expert. To accomplish these goals, expert systems usually use search algorithms to locate and apply knowledge, rather than the sequential execution of program statements of "procedural" software.

As discussed in Section 1.5, the IDRM knowledge base is composed mainly of engineering models that quantitatively address the concerns IDRM is designed to evaluate. Rule-like structures are used to select the appropriate model for a given situation and to generate model inputs.

Elements of IDRM design and operation that reflect the expert system approach include:

1. An IDRM session provides conclusions similar to the conclusions that would be generated by an expert design review.
2. IDRM results incorporate an indication of the degree of concern (advisory "levels").
3. IDRM identifies possible solutions to identified concerns.
4. IDRM provides access to reference information that is specifically related to identified concerns and recommendations.
5. IDRM applies information as needed to address a particular concern, rather than in "lock-step" procedural fashion.
6. IDRM is capable of searching several locations to find a needed piece of information. For example, if a geometric dimension needed to evaluate a concern is not in the immediate session data set, IDRM can attempt to calculate it or seek a value from the IHSDM roadway model.
7. If no other source for a needed piece of information is available, IDRM queries the user for it when appropriate.
8. IDRM is capable of working with information at varying levels of detail.

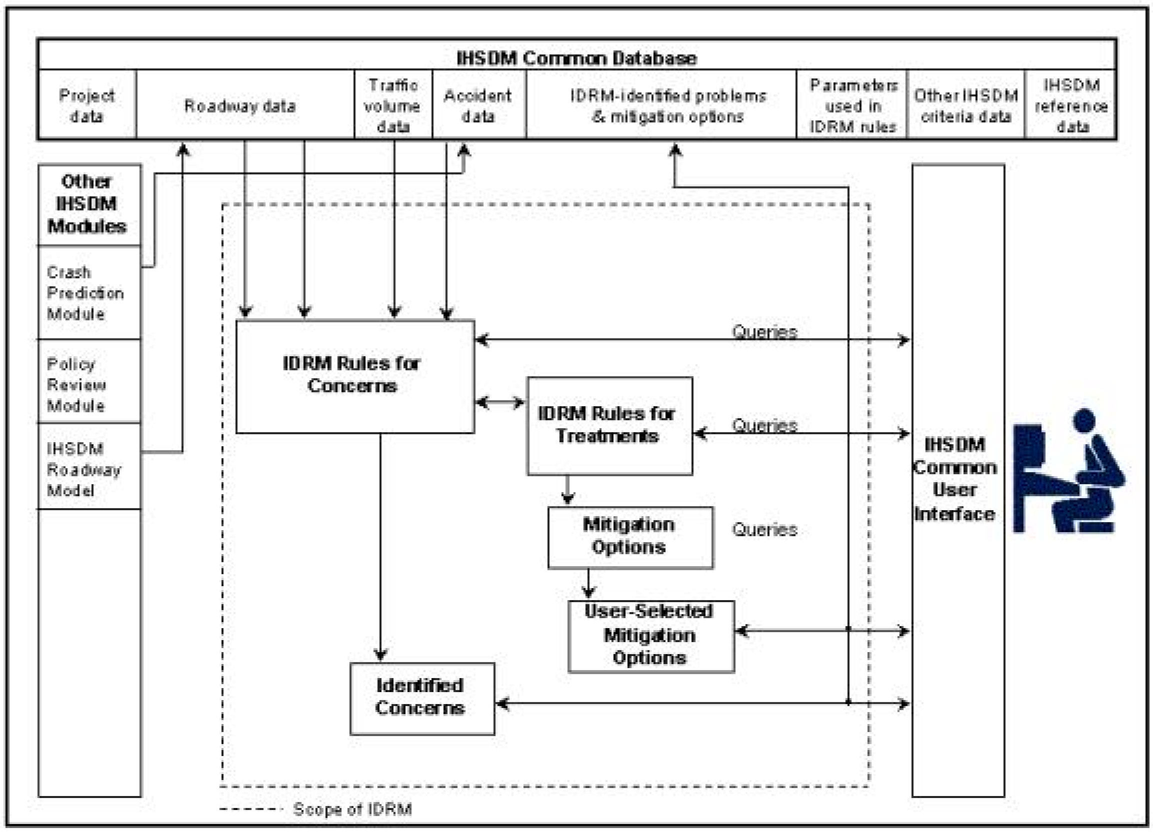


Figure 1. IHSDM Functional Overview

1.5 IDRM Knowledge Base

IDRM, like all expert systems, is developed from a base of expert knowledge concerning the issue at hand – in this case, the design of at-grade intersections on rural two-lane highways. The knowledge base consists of a set of decision rules for determining whether or not each of a set of defined potential design concerns is present. IDRM identifies a level for each concern found to be present:

Level 1 – Concern could indicate a potential safety issue.

Level 2 – Concern could indicate the potential for significant design improvement.

It is emphasized that the basis for identification of a concern by the knowledge base is the presence of an issue that should be *considered* by the designer. A concern identified by the knowledge base *does not* necessarily indicate a problem or a need to change the design. The knowledge base is deliberately designed to be conservative in suggesting concerns to the user, even in cases where no problem may be present.

Designers are generally knowledgeable about the basic geometric and traffic control requirements for intersection design. Most design agencies have well-developed procedures and standards for executing "typical" designs. The problems that emerge, and those for which many designers have little current guidance, involve combinations of geometric problems or unusual conditions in conjunction with the intersection. Many design concerns may be recognized as being important, yet they tend to be treated qualitatively, and hence may not always be addressed by designers. Thus, IDRM focuses on identification of both specific individual problems and combinations of problems related to geometric design.

Whereas many expert systems consist of networks of "if-then" rules, the primary element of the IDRM knowledge base is a set of engineering models. Each potential concern is evaluated by using an engineering model to calculate one or more evaluation parameters. The appropriate model is selected based on the intersection geometry and the concern being evaluated. The user is queried for any information needed by the model that is not available in the design information input. The parameter is then compared to threshold values to determine the presence and level of the concern. These models are presented in detail in Section 3.0 .

IDRM also identifies potential design improvements – "treatments" – that could be considered to address each concern. Potential treatments to address concerns are identified by decision rules in the form of a matrix that relates combinations of concerns and geometric elements to treatments. Candidate treatments are divided into "design improvements," which involve some change to the highway design, and "mitigation measures," which can be implemented without a design change.

The treatment decision rules are documented in Section 6.0 .

These decision rules, models, and threshold values comprise the IDRM knowledge base.

1.6 Use Of IDRM Results

IDRM is intended for use by the working highway designer or traffic engineer. IDRM can be used at most stages of the design process, including engineering studies, functional/conceptual design, preliminary design, and detailed design. For example, an engineer might use IDRM to review a conceptual design option for a study to ensure that it does not contain combinations of geometric features that would require changing the concept at a later stage of design.

A concern identified by IDRM represents an issue that should be *considered* by the designer. It *does not* necessarily indicate a problem or a need to change the design. The knowledge base is deliberately designed to be conservative in suggesting concerns to the user, even in cases where no problem may be present.

Level 1 concerns represent potential safety issues and should be carefully considered by the designer. Level 2 concerns represent potential opportunities for significant design improvement.

IDRM usually identifies multiple potential mitigation measures for identified concerns, with an impact on the intersection design ranging from minor additions or revisions to major geometric redesign. This is intended to give the designer multiple options to address the concern. It is expected that the designer will consider the stage of design, cost, and geometric and other constraints in selecting an appropriate mitigation measure.

KNOWLEDGE BASE SCOPE AND APPROACH

2.1 Issues Addressed

A substantial effort was devoted to identifying the concerns addressed in the knowledge base. The design team identified 111 potential design problems that could be considered for inclusion. Given this large number of concerns and the multitude of possible combinations of them that may be found in intersection designs, priorities were established. The highest priority issues, which the research team recommended that the knowledge base address, are listed in Table 2.

Table 2. Priority Issues Identified for Knowledge Base Development

1. Intersection Configuration
a. Multileg intersections b. Skewed intersections c. Offset T intersections d. More than one minor-road approach on the same side of the major road
2. Horizontal Alignment
a. Intersection on horizontal curve b. Curve on intersection leg c. Approach alignment differs between opposing approaches (lane continuity through intersection
3. Vertical Alignment
a. Intersection on crest vertical curve b. Crest vertical curve on intersection approach c. Steep grade through intersection d. Intersection on sag vertical curve e. Continuity of minor-road profile through intersection
4. Warrants for Auxiliary Lanes
a. Warranted left-turn lane not present b. Warranted right-turn lane not present
5. Intersection Sight Distance (ISD)
a. Lack of ISD in one or more quadrants

The research team concluded that the IDRM knowledge base should be more than a set of expert judgments for each of the above issues (and their permutations). Study of the specific reasons why each issue could result in a design problem led to engineering models that can be used to evaluate the extent to which a problem is present. These models are based on fundamental geometric design elements such as stopping sight distance (SSD), decision sight distance (DSD), intersection sight distance (ISD), and horizontal curve design. Importantly, because they provide quantitative performance measures, the models allow evaluation not only of individual potential problems, but also of combinations of problems. The models are summarized in Section 2.5.

2.2 Guiding Principles Used In Knowledge Base Development

A number of guiding principles were established to help in formulating models and identifying threshold values. These principles identify the types of models and thresholds that are used to trigger concerns and the manner in which parameter values for the models are determined.

1. Maximum use is made of existing models used in geometric design, such as the models for stopping sight distance (SSD), intersection sight distance (ISD), and decision sight distance (DSD). However, these models may be used with different parameter values than are used in established design policies. The use of model parameters that differ from those used in design policies reflects the research team's judgment of good practice in situations different from the standard application of design policy.
2. Traffic volumes should have a role in defining the criticality of concerns. An issue that warrants a Level 2 advisory at a low-volume intersection might well warrant a Level 1 advisory at a high-volume intersection.
3. Whenever possible, the existence and criticality of a problem should be determined from a model that accounts for the site-specific geometrics, traffic volumes, and speeds at and on the approaches to the intersection in question.
4. In general, models used to identify problems in IDRM should be based on the actual or estimated 85th percentile speed of vehicles on an intersection approach, rather than on the design speed that is more traditionally used in geometric design policies. This approach is recommended because the actual 85th percentile speed should provide a more realistic representation of whether a safety problem exists than the design speed shown on the plans, which may be arbitrary. Where field data on actual 85th percentile speeds are not available, predicted values, such as those recently developed by the Texas Transportation Institute in an FHWA study of the design consistency of horizontal and vertical alignment on two-lane highways, may be used.
5. In all models that use a speed variable, speed should be considered separately by the direction of travel. Speeds may differ by the direction of travel because of horizontal alignment, vertical alignment, or cross-section factors.
6. The object heights used in sight distance models should be appropriate to the situation being analyzed and the specific target to be seen in that situation. For example, the basic SSD model may be applied to several different issues with different object heights appropriate to each issue. If the target to be seen is an oncoming vehicle traveling in the opposite direction on the same roadway, the appropriate object height is driver eye height. If the target to be seen is a vehicle traveling in the same direction on the same roadway, the appropriate object height is taillight height. If the target to be seen is a vehicle entering the roadway from a side road, the appropriate object height may be headlight height.
7. Only geometric features within a defined influence area of the intersection are considered. The influence area extends 400 m from the center of the intersection along each approach and at least 200 m upstream from the beginning of any channelization or taper on the approach. The 400-m influence area distance was selected to exceed the maximum DSD for any intersection approach speed. Where geometric data for the entire intersection influence area are not available, IDRM will still operate with whatever data are available, but a significant portion of IDRM's diagnostic ability may be lost.
8. A passenger car is assumed to be the IDRM analysis vehicle with the exception of the Intersection Pavement Area model. The models have been written in such a way that they are suitable to be expanded or modified in the future.

2.3 Highway Design Data

IDRM uses the detailed highway representation model provided by IHSDM. This model provides a detailed representation of horizontal and vertical alignment, lane widths, traffic control, etc. Data can be extracted from CAD files or input through the "IHSDM Edit/View Highway Information" interface.

Data from the IHSDM roadway model is generally sufficient for the application of IDRM. If additional information is needed, the system requests it from the user. One important example is the dimensions of clear sight triangles available at intersections. While the design file can provide information on vertical geometry from which sight obstructions can be identified, it cannot be expected to allow identification of every possible obstruction (e.g., signs, seasonal vegetation) that a designer who has viewed the area would identify. Therefore, in evaluating potential concerns requiring determination of clear sight triangles, IDRM always queries the user to confirm the available clear sight triangle *unless* the presence of a concern has already been established based on design file information alone.

2.4 Concerns Identified By IDRM

From the priority issues listed above in Table 2 and their combinations, 27 concerns or potential problems were identified to be addressed by the IDRM knowledge base. These concerns are summarized in Table 3 . It is important to note that the knowledge base is designed so that additional concerns, and the rules and models to evaluate them, can be added at any time.

2.5 Overview Of IDRM Models

To address the concerns generated by the priority issues listed in Table 2 , 21 quantitative models were developed for the IDRM knowledge base. These models are summarized in Table 4 . Section 3.0 provides a detailed description of each model.

2.6 Use Of IDRM Models To Evaluate Concerns

Table 5 lists the IDRM models used to evaluate each of the 27 concerns. Section 4.0 provides a detailed discussion of each concern, including a description of how the model(s) is used to evaluate the concern.

2.7 Overview Of IDRM Treatment Recommendations

When IDRM identifies a potential intersection design concern, it also identifies design changes and other measures that could eliminate or mitigate the concern. These are referred to as "treatments." Treatments that could mitigate each identified concern are presented to the user through the IDRM user interface.

The IDRM knowledge base relates concerns to the applicable treatments by means of a matrix. A row in this matrix is specified by a concern, a specific geometric condition or other design element related to the concern, and a treatment that addresses that condition. Each treatment is categorized as either a "design improvement" (generally higher cost) or a "mitigation measure" (generally lower cost). For example:

Concern	Design element	Treatment	Treatment type
Insufficient stopping sight distance on leg entering from north	Crest vertical curve on intersection approach	Flatten vertical curve to provide adequate sight distance	Design improvement
Insufficient stopping sight distance on leg entering from north	Crest vertical curve on intersection approach	Install warning flashers on approach	Mitigation measure

In addition, for each treatment, IDRM provides Application Notes that describe the treatment in detail and present design guidelines for using the treatment.

The complete concern/treatment matrix is presented in Section 6.0.

Table 3. IDRM Concerns

Section	Concerns related to the intersection as a whole
4.20	Insufficient left-turn bay storage length between closely spaced intersections
4.21	Insufficient taper length for left-turn lanes between closely spaced intersections
4.22	High traffic conflict index
4.24	Large intersection pavement area
	Concerns related to individual intersection legs
4.1	Insufficient intersection sight distance (ISD)
4.2	Insufficient intersection sight distance (ISD) for intersection on horizontal curve
4.3	Insufficient intersection sight distance (ISD) for a horizontal curve on an intersection approach
4.4	Insufficient intersection sight distance (ISD) for intersection on approaches to crest vertical curve
4.5	Insufficient intersection sight distance (ISD) for multileg intersection
4.6	Insufficient intersection sight distance (ISD) for intersection with more than one minor-road approach on the same side of the major road
4.7	Insufficient intersection sight distance (ISD) for skewed intersection
4.8	Insufficient stopping sight distance (SSD) for a crest vertical curve on an intersection approach
4.9	Insufficient stopping sight distance (SSD) for a horizontal curve on an intersection approach
4.10	Insufficient visibility of traffic signal
4.11	Insufficient visibility of stop sign
4.12	Insufficient visibility of yield sign
4.13	Insufficient decision sight distance (DSD) for a crest vertical curve on an intersection approach
4.14	Insufficient decision sight distance (DSD) for a horizontal curve on an intersection approach
4.15	Insufficient decision sight distance (DSD) for multileg intersection
4.16	Insufficient decision sight distance (DSD) for intersection with more than one minor-road approach on the same side of the major road
4.17	Increased crossing distance
4.18	Warranted left-turn lane not present
4.19	Warranted right-turn lane not present
4.23	Uneven, discontinuous minor-road profile through intersection
4.25	Approach alignment differs between opposing approaches
4.26	Insufficient queue storage
4.27	Loss of control potential due to frequent braking

Table 4. IDRM Models

Section	Model
Intersection sight distance (ISD)-based models	
3.1	Intersection Sight Distance for Case B1 – Left Turn From Minor Road
3.2	Intersection Sight Distance for Case B2 – Right Turn From Minor Road
3.3	Intersection Sight Distance for Case B3 – Crossing Maneuver From Minor Road
3.4	Intersection Sight Distance for Case F – Left Turn From Major Road
Stopping sight distance (SSD)-based models	
3.5	Stopping Sight Distance for Vertical Curves
3.6	Stopping Sight Distance for Horizontal Curves
3.7	Visibility Distance to Traffic Signal
3.8	Visibility Distance to Stop Sign
3.9	Visibility Distance to Yield Sign
Decision sight distance (DSD)-based models	
3.10	Decision Sight Distance for Vertical Curves
3.11	Decision Sight Distance for Horizontal Curves
Clearance time models	
3.12	Clearance Time for Skewed Intersection
Turn-lane models	
3.13	Left-Turn Lane Warrants
3.14	Right-Turn Lane Warrants
3.15	Left-Turn Lane Length for Closely Spaced Intersection
Miscellaneous models	
3.16	Intersection Conflict Index
3.17	Minor-Road Profile
3.18	Intersection Pavement Area
3.19	Change in Approach Alignment Between Opposing Approaches
3.20	Queue Length Prediction
3.21	Horizontal Curve Design for Braking and Cornering

Table 5. Application of IDRM Models to Evaluate Concerns

Section	Concern	Model(s) Used to Evaluate Concern
Concerns related to the intersection as a whole		
4.20	Insufficient Left-Turn Bay Storage and Deceleration Length Between Closely Spaced Intersections	3.15 Left-Turn Lane Length for Closely Spaced Intersection 3.20 Queue Length Prediction
4.21	Insufficient Taper Length for Left-Turn Lanes Between Closely Spaced Intersections	3.15 Left-Turn Lane Length for Closely Spaced Intersection

Section	Concern	Model(s) Used to Evaluate Concern
4.22	High Traffic Conflict Index	3.16 Intersection Conflict Index
4.24	Large Intersection Pavement Area	3.18 Intersection Pavement Area
4.1	Insufficient Intersection Sight Distance	3.1 Intersection Sight Distance for Case B1 – Left Turn From Minor Road 3.2 Intersection Sight Distance for Case B2 – Right Turn From Minor Road 3.3 Intersection Sight Distance for Case B3 – Crossing Maneuver From Minor Road 3.4 Intersection Sight Distance for Case F – Left Turn From Major Road
4.2	Insufficient Intersection Sight Distance for Intersection on a Horizontal Curve	3.1 Intersection Sight Distance for Case B1 – Left Turn From Minor Road 3.2 Intersection Sight Distance for Case B2 – Right Turn From Minor Road 3.3 Intersection Sight Distance for Case B3 – Crossing Maneuver From Minor Road 3.4 Intersection Sight Distance for Case F – Left Turn From Major Road
4.3	Insufficient Intersection Sight Distance for a Horizontal Curve on an Intersection Approach	3.1 Intersection Sight Distance for Case B1 – Left Turn From Minor Road 3.2 Intersection Sight Distance for Case B2 – Right Turn From Minor Road 3.3 Intersection Sight Distance for Case B3 – Crossing Maneuver From Minor Road 3.4 Intersection Sight Distance for Case F – Left Turn From Major Road
4.4	Insufficient Intersection Sight Distance for Intersection on Approaches to Crest Vertical Curve	3.1 Intersection Sight Distance for Case B1 – Left Turn From Minor Road 3.2 Intersection Sight Distance for Case B2 – Right Turn From Minor Road 3.3 Intersection Sight Distance for Case B3 – Crossing Maneuver From Minor Road 3.4 Intersection Sight Distance for Case F – Left Turn From Major Road
4.5	Insufficient Intersection Sight Distance for Multileg Intersection	3.1 Intersection Sight Distance for Case B1 – Left Turn From Minor Road 3.2 Intersection Sight Distance for Case B2 – Right Turn From Minor Road 3.3 Intersection Sight Distance for Case B3 – Crossing Maneuver From Minor Road 3.4 Intersection Sight Distance for Case F – Left Turn From Major Road

Section	Concern	Model(s) Used to Evaluate Concern
4.6	Insufficient Intersection Sight Distance for Intersections With More Than One Minor-Road Approach on the Same Side of the Major Road	3.1 Intersection Sight Distance for Case B1 – Left Turn From Minor Road 3.2 Intersection Sight Distance for Case B2 – Right Turn From Minor Road 3.3 Intersection Sight Distance for Case B3 – Crossing Maneuver From Minor Road 3.4 Intersection Sight Distance for Case F – Left Turn From Major Road
4.7	Insufficient Intersection Sight Distance for Skewed Intersections	3.1 Intersection Sight Distance for Case B1 – Left Turn From Minor Road 3.2 Intersection Sight Distance for Case B2 – Right Turn From Minor Road 3.3 Intersection Sight Distance for Case B3 – Crossing Maneuver From Minor Road 3.4 Intersection Sight Distance for Case F – Left Turn From Major Road
4.8	Insufficient Stopping Sight Distance	3.5 Stopping Sight Distance for Vertical Curves
4.9	Insufficient Stopping Sight Distance for a Horizontal Curve on an Intersection Approach	3.6 Stopping Sight Distance for Horizontal Curves
4.10	Insufficient Visibility of Traffic Signal	3.7 Visibility Distance to Traffic Signal
4.11	Insufficient Visibility of Stop Sign	3.8 Visibility Distance to Stop Sign
4.12	Insufficient Visibility of Yield Sign	3.9 Visibility Distance to Yield Sign
4.13	Insufficient Decision Sight Distance for a Crest Vertical Curve on an Intersection Approach	3.10 Decision Sight Distance for Vertical Curves
4.14	Insufficient Decision Sight Distance for a Horizontal Curve on an Intersection Approach	3.11 Decision Sight Distance for Horizontal Curves
4.15	Insufficient Decision Sight Distance for Multileg Intersection	3.10 Decision Sight Distance for Vertical Curves 3.11 Decision Sight Distance for Horizontal Curves
4.16	Insufficient Decision Sight Distance for Intersections With More Than One Minor-Road Approach on the Same Side of the Major Road	3.10 Decision Sight Distance for Vertical Curves 3.11 Decision Sight Distance for Horizontal Curves
4.17	Increased Crossing Distance	3.12 Clearance Time for Skewed Intersection
4.18	Warranted Left-Turn Lane Is Not Present	3.13 Left-Turn Lane Warrants
4.19	Warranted Right-Turn Lane Is Not Present	3.14 Right-Turn Lane Warrants
4.23	Uneven, Discontinuous Minor-Road Profile Through Intersection	3.17 Minor-Road Profile

Section	Concern	Model(s) Used to Evaluate Concern
4.25	Approach Alignment Differs Between Opposing Approaches	3.19 Change in Approach Alignment Between Opposing Approaches
4.26	Insufficient Queue Storage	3.20 Queue Length Prediction
4.27	Loss of Control Potential Due to Frequent Braking	3.21 Horizontal Curve Design for Braking and Cornering

IDRM MODELS

As discussed in Section 2.0 , IDRM evaluates the presence of potential concerns by applying engineering models to give a quantitative measure of an intersection's performance. The presence and level of a concern are determined by applying thresholds to one or more performance measures generated from the models. One model may be used to evaluate several concerns.

This section documents the 21 models that were developed for the IDRM knowledge base. The models are summarized in Table 4 . The application of these models to the potential concerns evaluated by IDRM is summarized in Table 5 . Section 4.0 presents a detailed discussion of each potential concern and how the models are used to evaluate each concern.

3.1 Intersection Sight Distance For Case B1– Left Turn From Minor Road

Applicability

An intersection sight distance (ISD) model for Case B1 is applied in IDRM wherever a driver may be stopped on the minor road awaiting an opportunity to complete a left-turn maneuver. Similar models for Cases B2, B3, and F are applied for a right-turn maneuver from the minor road, a crossing maneuver from the minor road, and a left-turn maneuver from the major road, respectively (see Sections 3.2 through 3.4).

Basis

Each stop-controlled intersection contains several potential vehicle conflicts. The possibility of these conflicts actually occurring can be greatly reduced through provision of the proper ISD. A driver approaching an intersection should have an unobstructed view of the entire intersection and, when stopped, sufficient lengths of the intersecting highway.

The model used to determine the extent to which a driver can see an intersection is based on the ISD model used in geometric design, which has recently been modified in *Intersection Sight Distance*, NCHRP Report 383. The model, as developed in NCHRP Report 383 and presented in the 2001 AASHTO *A Policy on Geometric Design of Highways and Streets* (known as the Green Book), is:

$$ISD = 0.278 V t \qquad \text{Equation 3.1.1}$$

where:

ISD = intersection sight distance (m)
V = initial speed (km/h)
t = time gap (s)

The available ISD, as limited by vertical geometry (ISD_{vert}), is based on a driver's eye height (h_1) of 1080 mm and an object height (h_2) of 1080 mm. The driver's eye height (h_1) should be adjusted for the profile of the minor road. The limitation of ISD due to the vertical alignment is determined as the maximum distance from the intersection that an object of height h_2 can be seen from a driver's eye at height h_1.

The limitation of ISD due to horizontal alignment and roadside sight obstructions (including terrain, vegetation, man-made obstacles) is determined by evaluating whether particular sight triangles are clear of sight obstructions. Figure 2 illustrates the sight triangle used for ISD Case B1 (i.e., the ISD to the right for a left-turning vehicle). The other sight triangle shown in Figure 2 (i.e., the sight triangle to the left) is not explicitly considered by IDRM for Case B1. A left-turning driver does need sight distance to the left to cross the near lane of the major road in making a left turn, but the sight distance needed to cross the near lane of a two-lane highway (plus any adjacent left-turn lane) will always be less than or equal to the sight distance to the left for ISD Case B2 (right turn onto the major road) and ISD Case B3 crossing the major road; these cases are addressed below in Sections 3.2 and 3.3 , respectively.

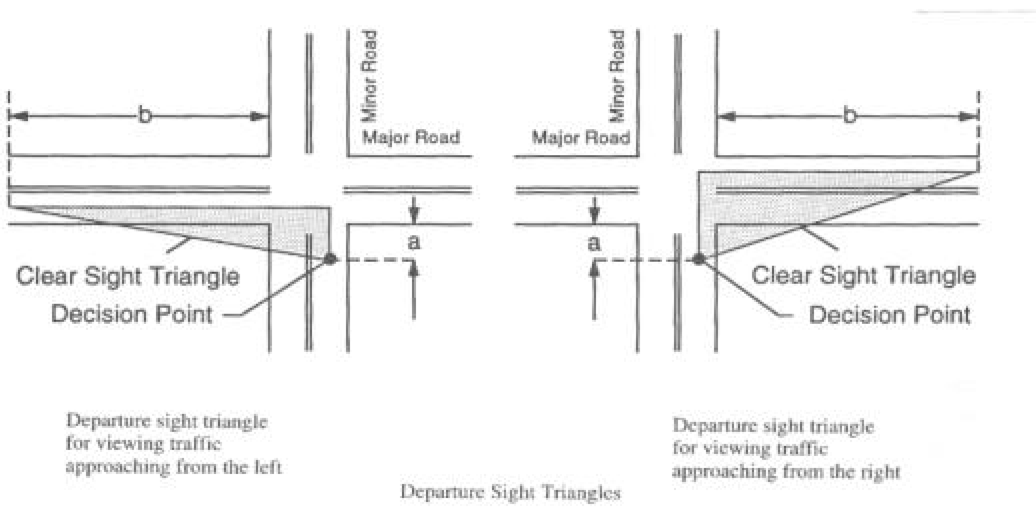


Figure 2. Departure Sight Triangles for ISD Cases B1, B2, and B3

The major difference between the ISD model as it is applied in geometric design practice and the ISD model as it is applied in IDRM is that, in IDRM, the initial speed, V, is set equal to the actual 85th percentile speed of traffic in the roadway, V_{act}, or the best available estimate of V_{act}, rather than being set equal to a particular design speed.

Input Parameters

The input parameters used in the ISD model are:

- V_{act} - actual 85[th] percentile speed of traffic on the selected major road
- P_{xslope} - cross-slope of the major-road pavement (%)
- LW_{major} - lane width of major road (m)
- P_{minor} - grade of minor road (%)
- ADT - average daily traffic volume (veh/day)

The source of data for those input parameters whose values are not specified above are as follows:

- V_{act} - data file or user query
- P_{xslope} - roadway file
- LW_{major} - roadway file
- P_{minor} - roadway file

Evaluation Procedure

An ISD review procedure for the adequacy of sight distance for vehicles stopped on a minor-road approach will be formulated as follows:

1. Select a pair of major- and minor-road approaches to be evaluated. The ISD case to be examined is Case B1, Sight distance for a driver making a left turn (i.e., the minor-road driver must evaluate gaps in major-road traffic approaching from the left and from the right).

2. Determine V_{act}, the actual 85th percentile speed of traffic on the selected major-road approach. V_{act} can be determined from field data, from a speed prediction model like those developed for the IHSDM design consistency module, or from an engineering judgment by the user. The objective is to base the value of V_{act}, to the maximum possible extent, on actual field conditions rather than on an arbitrary design speed.

3. Select an appropriate time-gap value (t_c) for evaluation of ISD. For application of IDRM to a passenger car driver, the recommended time-gap value for left turns is 7.5-s. This time gap is for traffic approaching from the right in the lane of the major road that is entered by the left-turning driver. As explained above, this 7.5 s time gap for ISD Case B1 is not applicable to traffic from the left in crossing the near lane of the major road. The time gap to cross the near lane will always be less than or equal to the gaps for sight distance to the left considered for ISD Cases B2 and B3 (see Sections 3.2 and 3.3, respectively).

Based on NCHRP Report 383, an adjustment should also be made for the approach grade. If the approach grade on the minor road is an upgrade that exceeds 3 percent, add 0.2 s per percent grade to the time-gap value, t_c. Otherwise, make no adjustment for the approach grade.

4. Compute several ISD measures as described below. The required ISD using the identified V_{act} and t_c in the ISD model is determined with Equation 3.1.2:

$$ISD_{des} = 0.278 V_{act}\, t_c \qquad \text{Equation 3.1.2}$$

For certain special situations where more complex geometrics place greater demands on drivers, the value of t_c will be increased by an amount designated as Δt. This would result in Equation 3.1.2 being recast as:

$$ISD_{des} = 0.278 V_{act} \left(t_c + \Delta t\right) \qquad \text{Equation 3.1.3}$$

The value for Δt may differ among the various intersection scenarios considered. Table 6 presents the values for Δt for each scenario. Values are recommended for skewed intersections and a horizontal curve on an intersection approach. Additional human factors studies will be needed to develop values for other scenarios.

Table 6. Values of ΔT for Various Intersection Scenarios

Intersection Scenario	ΔT(s)
Multileg intersection	--
Skewed intersection	0.5
More than one minor-road approach on the same side of the major road	--
Intersection on horizontal curve	1.0
Horizontal curve on an intersection approach	--
Intersection on approach to crest vertical curve	--

The available ISD as limited by vertical geometry (ISD_{vert}) is based on a driver's eye height (h_1) of 1080 mm and an object height (h_2) of 1080 mm.

The driver's eye height (h_1) should be adjusted for the profile of the minor road, in other words:

$$h_1 = 1080 + 10\, P_{xslope}\, LW_{major} + 44\, P_{minor}$$ Equation 3.1.4

where:

P_{xslope} = cross-slope of the major-road pavement expressed as a percentage
LW_{major} = lane width of major road (m)
P_{minor} = grade of minor road expressed as a percentage

Equation 3.1.4 assumes that the driver's eye is 4.4 m from the edge of the major-road traveled way as recommended in NCHRP Report 383. Where the full profile of the minor road is available, this should be used in determining P_{minor} as the average grade over a length 4.4 m from the edge of the major-road traveled way, which is shown as dimension a in Figure 2 . Thus, P_{minor} can be calculated as the elevation difference between the edge of the major-road traveled way and a point on the minor road 4.4 m from the edge of the major-road traveled way divided by the horizontal distance, 4.4 m. Where the full profile of the minor road is not available, P_{minor} should be assumed to be zero.

ISD_{vert} should be determined as the maximum distance from the intersection that an object of height h_2 can be seen from a driver's eye at height h_1. This criterion is applied along the centerline of the roadway, assuming that the driver's eye is located at a position $LW_{minor}/4$ to the right of the center of the intersection.

If $ISD_{vert} \geq ISD_{des}$, then set ISD_{vert} equal to ISD_{des}. This case occurs when there is no crest vertical curve within distance ISD_{des} from the intersection or when the crest is so slight that the driver can see over it.

5. Figure 2 illustrates the sight triangle used for ISD Case B1 to the right. The limitation of ISD due to the vertical alignment of the major road has been addressed above. The limitation of ISD due to horizontal alignment and roadside sight obstructions (including terrain, vegetation, man-made obstacles) should proceed by asking the user whether the particular sight triangles displayed by IDRM are clear of sight obstructions. This logic is specified as follows:

If $ISD_{vert} > ISD_{des}$, then display Figure 3 to the user with the query:

- Is Region 1 clear of roadside sight obstructions?
- Is Region 2 clear of roadside sight obstructions?

NOTE: In displaying Figure 3 to the user, the dimensions of the regions should be shown and the sight triangle should be drawn to scale and superimposed on an intersection plan view. The dimension of Region 1 along the major road is ISD_1 (the equation for computing ISD_1 is shown in Section 4.7). The dimension of Regions 1 and 2 combined along the major road is ISD_{vert}. If the horizontal alignment of the major road is other than tangent, the curvilinear alignment of the major-road leg of the "triangle" must be displayed. The dimension of the leg of the sight triangle along the minor road is 4.4 m to the curb line plus the distance across the intersection to the mid point of the through lane on the far side of the road.

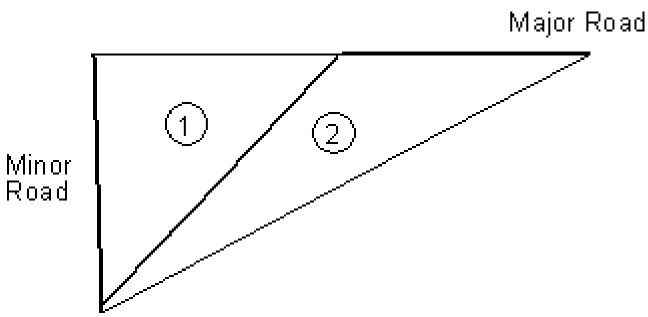


Figure 3. Regions of the Sight Triangle for Which Users Will Be Queried About the Presence of Roadside Sight Obstructions

6. Proceed to consideration of the next pair of major- and minor-road approaches.

Model Output

The model output is the available intersection sight distance as limited by vertical geometry (ISD_{vert}), the critical time gap (t_c), and the user's response to whether the regions in Figure 3 are clear of roadside sight obstructions (YES/NO). The criticality of ISD_{des} is judged by comparison to ISD_{vert} as described in Section 4.

References

1. Harwood, D.W., J. Mason, R. Brydia, M. Pietrucha, and G. Gittings. *Intersection Sight Distance*, NCHRP Report 383. Transportation Research Board, Washington, DC, 1996.
2. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 2001.

3.2 Intersection Sight Distance For Case B2 – Right Turn From Minor Road

Applicability

An intersection sight distance (ISD) model for Case B2 is applied in IDRM wherever a driver may be stopped on the minor road awaiting an opportunity to complete a right-turn maneuver. Similar models for Cases B1, B3, and F are applied for a left-turn maneuver from the minor road, a crossing maneuver from the minor road, and a left-turn maneuver from the major road, respectively (see Sections 3.1, 3.3, and 3.4).

Basis

Each stop-controlled intersection contains several potential vehicle conflicts. The possibility of these conflicts actually occurring can be greatly reduced through the provision of proper ISD. A driver approaching an intersection should have an unobstructed view of the entire intersection and, when stopped, sufficient lengths of the intersecting highway.

The model used to determine the extent to which a driver can see an intersection is based on the ISD model used in geometric design, which has recently been modified in NCHRP Report 383. The model, as developed in NCHRP Report 383 and presented in the 2001 AASHTO *Green Book*, is:

$$ISD = 0.278 V t \quad \text{Equation 3.2.1}$$

where:

ISD = intersection sight distance (m)
V = initial speed (km/h)
t = driver perception-brake reaction time (s)

The available ISD as limited by vertical geometry (ISD_{vert}) is based on a driver's eye height (h_1) of 1080 mm and an object height (h_2) of 1080 mm. The driver's eye height (h_1) should be adjusted for the profile of the minor road. The limitation of ISD due to the vertical alignment is determined as the maximum distance from the intersection that an object of height h_2 can be seen from a driver's eye at height h_1.

The limitation of ISD due to horizontal alignment and roadside sight obstructions (including terrain, vegetation, man-made obstacles) is determined by evaluating whether particular sight triangles are clear of sight obstructions. Figure 2 illustrates the sight triangle used for ISD to the left.

The major difference between the ISD model as it is applied in geometric design practice and the ISD model as it is applied in IDRM is that, in IDRM, the initial speed, V, is set equal to the actual 85th percentile speed of traffic in the roadway, V_{act}, or the best available estimate of V_{act}, rather than being set equal to a particular design speed.

Input Parameters

The input parameters used in the ISD model are:

- V_{act} - actual 85th percentile speed of traffic on the selected major road
- P_{xslope} - cross-slope of the major-road pavement (%)
- LW_{major} - lane width of major road (m)
- P_{minor} - grade of minor road (%)
- ADT - average daily traffic volume (veh/day)

The source of data for those input parameters whose values are not specified above are as follows:

- V_{act} - data file or user query

•P_{xslope} - roadway file
•LW_{major} - roadway file
•P_{minor} - roadway file

Evaluation Procedure

An ISD review procedure for the adequacy of sight distance for vehicles stopped on a minor-road approach will be formulated as follows:

1. Select a pair of major- and minor-road approaches to be evaluated. The ISD case to be examined is Case B2, Sight distance for a driver making a right turn (i.e., the minor-road driver must evaluate gaps in major-road traffic approaching from the left).

2. Determine V_{act}, the actual 85th percentile speed of traffic on the selected major-road approach. V_{act} can be determined from field data, from a speed prediction model like those developed for the IHSDM design consistency module, or from an engineering judgment by the user. The objective is to base the value of V_{act}, to the maximum possible extent, on actual field conditions rather than on an arbitrary design speed.

3. Select an appropriate time-gap value (t_c) for evaluation of ISD. For application of IDRM to a passenger car driver, the recommended time-gap value for right turns is 6.5 s.

Based on NCHRP Report 383, an adjustment should also be made for approach grade. If the approach grade on the minor road is an upgrade that exceeds 3 percent, add 0.2 s per percent grade to the time-gap value, t_c. Otherwise, make no adjustment for approach grade

4. Compute several ISD measures as described below. The required ISD using the identified V_{act} and t_c in the ISD model is determined with Equation 3.2.2.

$$ISD_{des} = 0.278 V_{act} t_c \qquad \text{Equation 3.2.2}$$

The available ISD as limited by vertical geometry (ISD_{vert}) is based on a driver's eye height (h_1) of 1080 mm and an object height (h_2) of 1080 mm.

To address human factors considerations for specific intersection scenarios that require greater driver attention, Equation 3.2.2 would be recast as shown in Equation 3.1.3 in Section 3.1. Values of Δt would be used as shown in Table 6 in Section 3.1. [NOTE: Values still to be determined from human factors studies.]

The driver's eye height (h_1) should be adjusted for the profile of the minor road, in other words:

$$h_1 = 1080 + 10 P_{xslope} LW_{major} + 44 P_{minor} \qquad \text{Equation 3.2.3}$$

where:

P_{xslope} = cross-slope of the major-road pavement expressed as a percentage
LW_{major} = lane width of major road (m)
P_{minor} = grade of minor road expressed as a percentage

Equation 3.2.3 assumes that the driver's eye is 4.4 m from the edge of the major-road traveled way as recommended in NCHRP Report 383. Where the full profile of the minor road is available, this should be used in determining P_{minor} as the average grade over a length 4.4 m from the edge of the major-road traveled way, which is shown as dimension "a" in Figure 2. Where the full profile of the minor road is not available, P_{minor} should be assumed to be zero.

ISD_{vert} should be determined as the maximum distance from the intersection that an object of height h_2 can be seen from a driver's eye at height h_1. This criterion is applied along the centerline of the roadway assuming that the driver's eye is located at a position $LW_{minor}/4$ to the right of the center of the intersection.

If $ISD_{vert} \geq ISD_{des}$, then set ISD_{vert} equal to ISD_{des}. This case occurs when there is no crest vertical curve within distance ISD_{des} from the intersection or when the crest is so slight that the driver can see over it.

5. Figure 2 illustrates the sight triangle used for ISD to the left. The limitation of ISD due to the vertical alignment of the major road has been addressed above. The limitation of ISD due to horizontal alignment and roadside sight obstructions (including terrain, vegetation, man-made obstacles) should proceed by asking the user whether particular sight triangles displayed by IDRM are clear of sight obstructions. This logic is specified as follows:

If $ISD_{vert} > ISD_{des}$, then display Figure 3 (or, in this case, its equivalent to the left) to the user with the query:

- Is Region 1 clear of roadside sight obstructions?
- Is Region 2 clear of roadside sight obstructions?

NOTE: In displaying Figure 3 to the user, the dimensions of the regions should be shown and the sight triangle should be drawn to scale and superimposed on an intersection plan view. The dimension of Region 1 along the major road is ISD_1 (the equation for computing ISD_1 is shown in Section 4.x). The dimension of Regions 1 and 2 combined along the major road is ISD_{vert}. If the horizontal alignment of the major road is other than tangent, the curvilinear alignment of the major-road leg of the "triangle" must be displayed. The dimension of the leg of the sight triangle along the minor road is 4.4 m to the curb line plus the distance across the intersection to the mid point of the near side of the road.

6. Proceed to consideration of the next pair of major- and minor-road approaches.

Model Output

The model output is the available intersection sight distance as limited by vertical geometry (ISD_{vert}), the critical time gap (t_c), and the user's response to whether the regions in Figure 3 are clear of roadside sight obstructions (YES/NO). The criticality of ISD_{des} is judged by comparison to ISD_{vert} as described in Section 4.

References

1. Harwood, D.W., J. Mason, R. Brydia, M. Pietrucha, and G. Gittings. *Intersection Sight Distance*, NCHRP Report 383. Transportation Research Board, Washington, DC, 1996.
2. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 2001.

3.3 Intersection Sight Distance For Case B3 – Crossing Maneuver From Minor Road

Applicability

An intersection sight distance (ISD) model for Case B3 is applied in IDRM wherever a driver may be stopped on the minor road awaiting an opportunity to complete a crossing maneuver. Similar models for Cases B1, B2, and F are applied for a left-turn maneuver from the minor road, a right-turn maneuver from the minor road, and a left-turn maneuver from the major road, respectively (see Sections 3.1, 3.2, and 3.4).

Case B3 addresses the sight distance required for a vehicle to accelerate and cross the major road from a stopped position on the minor-road approach to a stop-controlled intersection. The sight distance for a crossing maneuver is based on the time it takes for the stopped vehicle to clear the intersection and the distance that a vehicle will travel along the major road at V_{act} in that amount of time.

Basis

Each stop-controlled intersection contains several potential vehicle conflicts. The possibility of these conflicts actually occurring can be greatly reduced through the provision of proper ISD. A driver approaching an intersection should have an unobstructed view of the entire intersection and, when stopped, sufficient lengths of the intersecting highway.

The model used to determine the extent to which a driver can see an intersection is based on the ISD model used in geometric design, which has recently been modified in NCHRP Report 383. The model, as developed in NCHRP Report 383 and presented in the 2001 AASHTO *Green Book*, is:

$$ISD = 0.278\,V\,t \qquad \text{Equation 3.3.1}$$

where:

ISD = intersection sight distance (m)
V = initial speed (km/h)
t = driver perception-brake reaction time (s)

The available ISD as limited by vertical geometry (ISD_{vert}) is based on a driver's eye height (h_1) of 1080 mm and an object height (h_2) of 1080 mm. The driver's eye height (h_1) should be adjusted for the profile of the minor road. The limitation of ISD due to the vertical alignment is determined as the maximum distance from the intersection that an object of height h_2 can be seen from a driver's eye at height h_1.

The limitation of ISD due to horizontal alignment and roadside sight obstructions (including terrain, vegetation, man-made obstacles) is determined by evaluating whether particular sight triangles are clear of sight obstructions. Figure 2 illustrates the sight triangles used for ISD to the left and to the right.

The major difference between the ISD model as it is applied in geometric design practice and the ISD model as it is applied in IDRM is that, in IDRM, the initial speed, V, is set equal to the actual 85th percentile speed of traffic in the roadway, V_{act}, or the best available estimate of V_{act}, rather than being set equal to a particular design speed.

Input Parameters

The input parameters used in the ISD model are:

- •V_{act} - actual 85th percentile speed of traffic on the selected major road
- •P_{xslope} - cross-slope of the major-road pavement (%)
- •LW_{major} - lane width of major road (m)
- •P_{minor} - grade of minor road (%)
- •ADT - average daily traffic volume (veh/day)

The source of data for those input parameters whose values are not specified above are as follows:

- •V_{act} - data file or user query
- •P_{xslope} - roadway file
- •LW_{major} - roadway file
- •P_{minor} - roadway file

Evaluation Procedure

An ISD review procedure for the adequacy of sight distance for vehicles stopped on a minor-road approach will be formulated as follows:

1. Select a pair of major- and minor-road approaches to be evaluated. The ISD case to be examined is Case B3, Sight distance for a driver making a crossing maneuver (i.e., the minor-road driver must evaluate gaps in major-road traffic approaching from the left and from the right).

2. Determine V_{act}, the actual 85th percentile speed of traffic on the selected major-road approach. V_{act} can be determined from field data, from a speed prediction model like those developed for the IHSDM design consistency module, or from an engineering judgment by the user. The objective is to base the value of V_{act}, to the maximum possible extent, on actual field conditions rather than on an arbitrary design speed.

3. Select an appropriate time-gap value (t_c) for evaluation of ISD. For application of IDRM to a passenger car driver, the recommended time-gap value for crossing maneuvers is 6.5 s plus 0.5 s for each additional lane to be crossed in addition to the two basic lanes.

Based on NCHRP Report 383, an adjustment should also be made for approach grade. If the approach grade on the minor road is an upgrade that exceeds 3 percent, add 0.2 s per percent grade to the time-gap value, t_c. Otherwise, make no adjustment for approach grade

4. Compute several ISD measures as described below. The required ISD using the identified V_{act} and t_c in the ISD model is determined with Equation 3.3.2.

$$ISD_{des} = 0.278\, V_{act}\, t_c \qquad \text{Equation 3.3.2}$$

The available ISD as limited by vertical geometry (ISD_{vert}) is based on a driver's eye height (h_1) of 1080 mm and an object height (h_2) of 1080 mm.

To address human factors considerations for specific intersection scenarios that require greater driver attention, Equation 3.3.2 would be recast as shown in Equation 3.1.3 in Section 3.1. Values of Δ t would be used as shown in Table 6 in Section 3.1 . [NOTE: Values still to be determined from human factors studies.]

The driver's eye height (h_1) should be adjusted for the profile of the minor road, in other words:

$$h_1 = 1080 + 10\, P_{xslope}\, LW_{major} + 44\, P_{minor} \qquad \text{Equation 3.3.3}$$

where:

P_{xslope} = cross-slope of the major-road pavement expressed as a percentage
LW_{major} = lane width of major road (m)
P_{minor} = grade of minor road expressed as a percentage

Equation 3.3.3 assumes that the driver's eye is 4.4 m from the edge of the major-road traveled way as recommended in NCHRP Report 383. Where the full profile of the minor road is available, this should be used in determining P_{minor} as the average grade over a length 4.4 m from the edge of the major-road traveled way.

ISD_{vert} should be determined as the maximum distance from the intersection that an object of height h_2 can be seen from a driver's eye at height h_1. This criterion is applied along the centerline of the roadway assuming that the driver's eye is located at a position $LW_{minor}/4$ to the right of the center of the intersection.

If $ISD_{vert} \geq ISD_{des}$, then set ISD_{vert} equal to ISD_{des}. This case occurs when there is no crest vertical curve within distance ISD_{des} from the intersection or when the crest is so slight that the driver can see over it.

5. Figure 2 illustrates the sight triangles used for ISD to the left and to the right. The limitation of ISD due to the vertical alignment of the major road has been addressed above. The limitation of ISD due to horizontal alignment and roadside sight obstructions (including terrain, vegetation, man-made obstacles) should proceed by asking the user whether particular sight triangles displayed by IDRM are clear of sight obstructions. This logic is specified as follows:

If $ISD_{vert} > ISD_{des}$, then display Figure 3 (and its equivalent to the left) to the user with the query:

- Is Region 1 clear of roadside sight obstructions?
- Is Region 2 clear of roadside sight obstructions?

NOTE: In displaying Figure 3 to the user, the dimensions of the regions should be shown and the sight triangle should be drawn to scale and superimposed on an intersection plan view. The dimension of Region 1 along the major road is ISD_1 (the equation for computing ISD_1 is shown in Section 4.x). The dimension of Regions 1 and 2 combined along the major road is ISD_{vert}. If the horizontal alignment of the major road is other than tangent, the curvilinear alignment of the major-road leg of the "triangle" must be displayed. The dimension of the leg of the sight triangle along the minor road is 4.4 m to the curb line plus the distance across the intersection to the mid point of the appropriate through lane.

6. Proceed to consideration of the next pair of major- and minor-road approaches.

Model Output

The model output is the available intersection sight distance as limited by vertical geometry (ISD_{vert}), the critical time gap (t_c), and the user's response to whether the regions in Figure 3 are clear of roadside sight obstructions (YES/NO). The criticality of ISD_{des} is judged by comparison to ISD_{vert} as described in Section 4.

References

1. Harwood, D.W., J. Mason, R. Brydia, M. Pietrucha, and G. Gittings. *Intersection Sight Distance*, NCHRP Report 383. Transportation Research Board, Washington, DC, 1996.
2. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 2001.

3.4 Intersection Sight Distance For Case F – Left Turn From Major Road

Applicability

An intersection sight distance (ISD) model for Case F is applied in IDRM wherever a driver may be stopped on the major road awaiting an opportunity to complete a left-turn maneuver. Similar models for Cases B1, B2, and B3 are applied for a left-turn maneuver from the minor road, a right-turn maneuver from the minor road, and a crossing maneuver from the minor road, respectively (see Sections 3.1, 3.2, and 3.3).

All locations along a major highway from which vehicles are permitted to turn left across opposing traffic, including at-grade intersections and driveways, should have sufficient sight distance to accommodate left-turn maneuvers. Left-turning drivers need sufficient sight distance to decide when it is safe to turn left across the lane(s) used by opposing traffic. Sight distance should be based on a left turn by a stopped vehicle, since a vehicle that turns left without stopping would need less sight distance.

If stopping sight distance has been provided continuously along the major road and if sight distance for Case B (Stop control) has been provided for each minor-road approach, sight distance will generally be adequate for left turns from the major road. Thus, no separate check of sight distance for Case F is generally required. However, in the following situations, it is advisable to check the availability of sight distance for left turns from the major roadway:

- At three-leg intersections located on or near a horizontal curve on the major road.
- Where left turns are being made from a divided highway because of the possibility of sight obstructions in the median.
- At four-leg intersections on divided highways, where opposing vehicles turning left can block a driver's view of oncoming traffic.

Basis

Each stop-controlled intersection contains several potential vehicle conflicts. The possibility of these conflicts actually occurring can be greatly reduced through the provision of proper intersection sight distance. A driver approaching an intersection on the major road should have an unobstructed view of the entire intersection, including a sufficient distance ahead on the opposing approach.

The model used to determine the extent to which a driver can see an intersection is based on the ISD model used in geometric design, which has recently been modified in NCHRP Report 383. The model, as developed in NCHRP Report 383 and presented in the 2001 AASHTO *Green Book*, is:

$$ISD = 0.278 V t \quad \text{Equation 3.4 .1}$$

where:

ISD = intersection sight distance (m)
V = initial speed (km/h)
t = driver perception-brake reaction time (s)

The available ISD as limited by vertical geometry (ISD_{vert}) is based on a driver's eye height (h_1) of 1080 mm and an object height (h_2) of 1080 mm. The driver's eye height (h_1) should be adjusted for the profile of the major road. The limitation of ISD due to the vertical alignment is determined as the maximum distance from the intersection that an object of height h_2 can be seen from a driver's eye at height h_1.

The limitation of ISD due to horizontal alignment and roadside sight obstructions (including terrain, vegetation, man-made obstacles) is determined by evaluating whether the area on the inside of a horizontal curve, created by a sight line from the driver making the left turn to an oncoming vehicle, and the outside edge of the shoulder is clear of sight obstructions.

The major difference between the ISD model as it is applied in geometric design practice and the ISD model as it is applied in IDRM is that, in IDRM, the initial speed, V, is set equal to the actual 85th percentile speed of traffic in the roadway, V_{act}, or the best available estimate of V_{act}, rather than being set equal to a particular design speed.

Input Parameters

The input parameters used in the ISD model are:

- V_{act} - actual 85th percentile speed of traffic on the selected major road
- P_{major} - grade of minor road (%)
- ADT - average daily traffic volume (veh/day)

The source of data for those input parameters whose values are not specified above are as follows:

- V_{act} - data file or user query
- P_{major} - roadway file

Evaluation Procedure

An ISD review procedure for the adequacy of sight distance for vehicles stopped on a minor-road approach will be formulated as follows:

1. Select a pair of approaches to be evaluated, one major-road approach from which the left turn will be made and the opposing major-road approach where a potentially conflicting major-road vehicle may be present. The ISD case to be examined is Case F, Sight distance for a driver making a left-turn maneuver from the major road (i.e., the major-road driver must evaluate gaps in oncoming major-road traffic).

2. Determine V_{act}, the actual 85th percentile speed of traffic on the major road. V_{act} can be determined from field data, from a speed prediction model like those developed for the IHSDM design consistency module, or from an engineering judgment by the user. The objective is to base the value of V_{act}, to the maximum possible extent, on actual field conditions rather than on an arbitrary design speed.

3. Select an appropriate time-gap value (t_c) for evaluation of ISD. For application of IDRM to a passenger car driver, the recommended time-gap value for left-turning maneuvers from the major road is 5.5 s plus 0.5 s for each additional lane to be crossed in the left-turn maneuver.

Based on NCHRP Report 383, an adjustment should also be made for approach grade. If the approach grade on the major road is an upgrade that exceeds 3 percent, add 0.2 s per percent grade to the time-gap value, t_c. Otherwise, make no adjustment for approach grade.

4. Compute several ISD measures as described below. The required ISD using the identified V_{act} and t_c in the ISD model is determined with Equation 3.4.2 :

$$ISD_{des} = 0.278\, V_{act}\, t_c \qquad \text{Equation 3.4.2}$$

The available ISD as limited by vertical geometry (ISD_{vert}) is based on a driver's eye height (h_1) of 1080 mm and an object height (h_2) of 1080 mm.

ISD_{vert} should be determined as the maximum distance from the intersection that an object of height h_2 can be seen from a driver's eye at height h_1. This criterion is applied along the centerline of the roadway assuming that the driver's eye is located at a position $LW_{major}/4$ to the right of the center of the intersection.

If $ISD_{vert} \geq ISD_{des}$, then set ISD_{vert} equal to ISD_{des}. This case occurs when there is no crest vertical curve within distance ISD_{des} from the intersection or when the crest is so slight that the driver can see over it.

5. The limitation of ISD due to horizontal alignment and roadside sight obstructions (including terrain, vegetation, man-made obstacles) should proceed by asking the user whether the area on the inside of a horizontal curve, created by a sight line from the driver making the left turn to an oncoming vehicle, and the outside edge of the shoulder is clear of sight obstructions.

6. Proceed to consideration of the next pair of major- and minor-road approaches.

Model Output

The model output is the available intersection sight distance as limited by vertical geometry (ISD_{vert}), the critical time gap (t_c), and the user's response to whether the region between the sight line and the outside edge of the shoulder is clear of roadside sight obstructions (YES/NO). The criticality of ISD_{des} is judged by comparison to ISD_{vert} as described in Section 4.

References

1. Harwood, D.W., J. Mason, R. Brydia, M. Pietrucha, and G. Gittings. *Intersection Sight Distance*, NCHRP Report 383. Transportation Research Board, Washington, DC, 1996.

2. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 2001.

3.5 Stopping Sight Distance For Vertical Curves

Applicability

A stopping sight distance (SSD) model for vertical curves is applied in IDRM wherever the driver's view of an intersection or a potentially conflicting vehicle is limited by a crest vertical curve. A similar SSD model is applied when the sight restriction is an obstruction on the inside of a horizontal curve (see Section 3.6). In some situations, a more conservative model based on ISD is used (see Sections 3.1 through 3.4). All crest vertical curves within the intersection influence area, as defined in Section 2.2, should be considered.

Basis

At crest vertical curves, the pavement at some point in the vertical curve may become an obstruction that limits the driver's view of the road ahead. The model used to determine the distance ahead that a driver can see, as limited by crest vertical curves, is based on the SSD model used in geometric design. This model, as developed in NCHRP Report 400 and presented in the 2001 AASHTO *Green Book,* is:

$$SSD = 0.278Vt + \frac{V^2}{254\left[\left(\frac{a}{9.81}\right) \pm G\right]}$$ Equation 3.5.1

where:

SSD = stopping sight distance (m)
V = initial speed (km/h)
t = driver perception-brake reaction time (s)
a = deceleration rate (m/s^2)
G = local percent grade divided by 100

The length of vertical curve needed to provide any specified value of sight distance, SSD, for the sight line from a specified eye height (h_1) to a specified object height (h_2) is determined from the following equations:

$$L_1 = \frac{|A|(SSD)^2}{100\left(\sqrt{2h_1} + \sqrt{2h_2}\right)^2}$$ Equation 3.5.2

$$L_2 = 2(SSD) - \frac{200(\sqrt{h_1} + \sqrt{h_2})^2}{|A|}$$ Equation 3.5.3

where:

A = algebraic difference in grade (%)
h_1 = height of eye above the roadway surface (m)
h_2 = height of object above the roadway surface (m)

The appropriate vertical curve length, L, is equal to L_1 when SSD is less than L and is equal to L_2 when SSD is greater than L.

The major difference between the SSD model as it is applied in geometric design practice and the SSD model as it is applied in IDRM is that, in IDRM, the initial speed, V, is set equal to the actual 85th percentile speed of traffic in the roadway, V_{act}, or the best available estimate of V_{act}, rather than being set equal to a particular design speed.

Input Parameters

- •V_{act} - actual 85th percentile speed of traffic on the selected major road
- •t - driver perception-brake reaction time [2.5 s]
- •a - driver deceleration [3.4 m/s^2]
- •G - local percent grade divided by 100
- •A - algebraic difference in grade (%)
- •h_1 - height of eye above the roadway surface [1.08 m]
- •h_2 - height of object above the roadway surface [0.60 m]
- •L_{act} - -actual length of vertical curve (m)

The source of data for those input parameters whose values are not specified above are as follows:

- •V_{act} - data file or user query
- •t - roadway file
- •a - roadway file
- •G - roadway file

Evaluation Procedure

1. Determine V_{act}, the actual 85th percentile speed of traffic on the selected curve in the direction of travel toward the intersection. V_{act} can be determined from field data, from a speed prediction model like those developed for the IHSDM design consistency module, or from engineering judgment by the user. The objective is to base the value of V_{act}, to the maximum possible extent, on actual field conditions rather than on an arbitrary design speed.

2. Compute the desired SSD using the identified V_{act} in the SSD model:

The SSD model is applied to the evaluation of crest vertical curves as follows:

$$SSD_{des} = 0.278 V_{act} t + \frac{V_{act}^{2}}{254\left[\left(\frac{a}{9.81}\right) \pm G\right]} \qquad \text{Equation 3.5.4}$$

where:

SSD_{des} = desired stopping sight distance (m)
V_{act} = actual or estimated 85th percentile speed (km/h)

3. Calculate L_1 (when SSD_{des} is less than L) and L_2 (when SSD_{des} is greater than L):

$$L_1 = \frac{|A|(SSD_{des})^2}{100\left(\sqrt{2h_1} + \sqrt{2h_2}\right)^2} \qquad \text{Equation 3.5.5}$$

$$L_2 = 2(SSD_{des}) - \frac{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}{|A|} \qquad \text{Equation 3.5.6}$$

where:

L_1 = length of vertical curve when SSD is less than L (m)
L_2 = length of vertical curve when SSD is greater than L (m)

4. Determine L_{des}, the length of vertical curve needed to provide SSD_{des}:

If $SSD_{des} \leq L_1$, then $L_{des} = L_1$.

If $SSD_{des} > L_2$, then $L_{des} = L_2$.

5. If $L_{act} \geq L_{des}$, then there is not a potential problem present. Proceed to Step 9 without triggering any advisory messages.

6. If $L_{act} < L_{des}$, then compute SSD_{act} from the appropriate equation:

When SSD_{des} is less than L_{act},

$$SSD_{act} = SSD_{des}\sqrt{\frac{L_{act}}{L_{des}}}$$ Equation 3.5.7

When SSD_{des} is greater than L_{act},

$$SSD_{act} = SSD_{des}\left(\frac{L_{act} - \frac{200(\sqrt{h_1} + \sqrt{h_2})^2}{|A|}}{L_{des} - \frac{200(\sqrt{h_1} + \sqrt{h_2})^2}{|A|}}\right)$$ Equation 3.5.8

7. Compute V_{eff} by backsolving:

8. Calculate the difference between V_{eff} and V_{act}. Assess the need to trigger an SSD advisory message by referring to threshold values presented in Section 4.

$$SSD_{act} = 0.278V_{eff}\,t + \frac{V_{eff}^{\;2}}{254\left[\left(\frac{a}{9.81}\right) \pm G\right]}$$ Equation 3.5.9

9. Proceed to consideration of the next pair of major- and minor-road approaches.

The equations in the proceeding procedure are applicable to isolated vertical curves. IDRM actually uses an equivalent numerical method that can address not only isolated vertical curves, but also more complex situations such as compound vertical curves and vertical curves followed by short straight grades. This numerical procedure is also used in the IHSDM policy review module (PRM) and has been documented in the PRM Functionality Document.

Model Output

The model output is the effective speed for which SSDis provided, V_{eff}. The criticality of V_{eff} is judged by comparison to V_{act} as described in Section 4.

References

1. Fambro, D.B., R. Koppa, and K. Fitzpatrick. *Determination of Stopping Sight Distances*, NCHRP Report 400. Transportation Research Board, Washington, DC, 1997.
2. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994.

3.6 Stopping Sight Distance For Horizontal Curves

Applicability

A stopping sight distance (SSD) model for horizontal curves is applied in IDRM wherever the driver's view of an intersection or a potentially conflicting vehicle is limited by an obstruction on the inside of a horizontal curve. A similar SSD model is applied when the sight restriction is the crest of a vertical curve (see Section 3.5). In some situations, a more conservative model based on ISD is used (see Sections 3.1 through 3.4). All horizontal curves within the intersection influence area, as defined in Section 2.2, should be considered.

Basis

At horizontal curves, sight obstructions (such as walls, cut-slopes, buildings, and longitudinal barriers) on the inside of the curves may limit the driver's view of the road ahead. The model used to determine the distance ahead that a driver can see, as limited by the horizontal sight obstruction, is based on the SSD model used in geometric design. This model, as developed in NCHRP Report 400 and presented in the 2001 AASHTO *Green Book,* is:

$$SSD = 0.278Vt + \frac{V^2}{254\left[\left(\frac{a}{9.81}\right) \pm G\right]} \qquad \text{Equation 3.6.1}$$

where:

SSD = stopping sight distance (m)
V = initial speed (km/h)
t = driver perception-brake reaction time (s)
a = deceleration rate (m/s^2)
G = local percent grade divided by 100

The major difference between the SSD model as it is applied in geometric design practice and the SSD model as it is applied in IDRM is that, in IDRM, the initial speed, V, is set equal to the actual 85th percentile speed of traffic in the roadway, V_{act}, or the best available estimate of V_{act}, rather than being set equal to a particular design speed.

Input Parameters

The input parameters used in the SSD model are:

- V_{act} - actual 85th percentile speed of traffic on the selected major road
- t - driver perception-brake reaction time [2.5 s]
- a - driver deceleration [3.4 m/s^2]
- G - local percent grade divided by 100
- L_c - length of horizontal curve (m)
- R - radius (m)
- LW - lane width (m)
- CSW_{avail} - obstruction offset available on the inside of the horizontal curve

The source of data for those input parameters whose values are not specified above are as follows:

- V_{act} - data file or user query
- G - roadway file
- R - roadway file
- LW - roadway file
- CSW_{avail} - roadway file or user query
- L_c - roadway file

Evaluation Procedure

1. Determine V_{act}, the actual 85th percentile speed of traffic on the selected curve in the direction of travel toward the intersection. V_{act} can be determined from field data, from a speed prediction model like those developed for the IHSDM design consistency module, or from engineering judgment by the user. The objective is to base the value of V_{act}, to the maximum possible extent, on actual field conditions rather than on an arbitrary design speed.

2. Compute the desired SSD using the identified V_{act} in the SSD model:

$$SSD_{des} = 0.278 V_{act} t + \frac{V_{act}^{2}}{254\left[\left(\frac{a}{9.81}\right) \pm G\right]} \quad \text{Equation 3.6.2}$$

where:

SSD_{des} = desired stopping sight distance (m)
V_{act} = initial speed (km/h)

3. Compute the desired obstruction offset on the inside of the horizontal curve, CSW_{des}.

For a horizontal curve to the right for which the length of curve (L_c) ^{3} SSD_{des}:

$$CSW_{des} = (R - 0.25LW)\left(1 - \cos\frac{SSD_{des}}{2(R - 0.25LW)}\right) - 0.75LW$$ Equation 3.6.3

where:

CSW_{des} = desired clear sight width (m)

For a horizontal curve to the left for which L_c ³ SSD_{des}:

$$CSW_{des} = (R + 0.25LW)\left(1 - \cos\frac{SSD_{des}}{2(R + 0.25LW)}\right) - 1.25LW$$ Equation 3.6.4

For a horizontal curve to the right for which $L_c < SSD_{des}$:

$$CSW_{des} = \sqrt{\frac{0.41L_c(2SSD_{des} - L_c)}{R - 0.25LW}} - 0.75LW$$ Equation 3.6.5

For a horizontal curve to the left for which $L_c < SSD_{des}$:

$$CSW_{des} = \sqrt{\frac{0.41L_c(2SSD_{des} - L_c)}{R + 0.25LW}} - 1.25LW$$ Equation 3.6.6

4. Obtain obstruction offset available (CSW_{avail}) on the inside of the horizontal curve from the roadway file or ask the user to enter it.

5. If $CSW_{avail} \geq CSW_{des}$, then there is no potential problem present. Proceed to Step 8.

6. If $CSW_{avail} < CSW_{des}$, then calculate the effective speed (V_{eff}) for which SSD is available by backsolving Equation 3.6.2 and the appropriate equation from among Equation 3.6.3 through Equation 3.6.6 .

7. Calculate the difference between V_{eff} and V_{act}. Assess the need to trigger an SSD advisory message by referring to threshold values presented in Section 4.

8. Proceed to consideration of the next horizontal curve.

The equations in the previous steps are applicable to isolated horizontal curves. IDRM actually uses an equivalent numerical method that can address not only isolated horizontal curves, but also more complex situations such as compound horizontal curves or horizontal curves followed by short tangents. This numerical procedure has also been used in the IHSDM PRM and has been documented in the PRM Functionality Document.

Model Output

The model output is the effective speed for which SSD is provided, V_{eff}. The criticality of V_{eff} is judged by comparison to V_{act} as described in Section 4.

References

1. Fambro, D.B., R. Koppa, and K. Fitzpatrick. *Determination of Stopping Sight Distances*, NCHRP Report 400. Transportation Research Board, Washington, DC, 1997.
2. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994.

3.7 Visibility Distance To Traffic Signal

Applicability

A stopping sight distance (SSD) model for traffic signals is applied in IDRM to ensure that drivers approaching a signalized intersection or other signalized area, such as a mid-block crosswalk, shall be given a clear and unmistakable indication of their right-of-way assignment. A similar SSD model is applied to stop- and yield-controlled intersections (see Sections 3.8 and 3.9, respectively).

Basis

The primary consideration in signal face placement is visibility to approaching drivers. Critical elements are lateral and vertical angles of sight toward a signal face, as determined by a typical driver's eye position; vehicle design; and the vertical, longitudinal, and lateral position of the signal face. The geometry of each intersection to be signalized, including vertical grades, horizontal curves, and obstructions, is considered in signal face placement.

Input Parameters

The input parameters used in the SSD model are:

•V_{act}	-	actual 85th percentile speed of traffic (km/h)
•VD_{avail}	-	available visibility distance (m)
•Location	-	of traffic signal (over the roadway or on the side of the roadway at the far side of the intersection)
•w	-	intersection width from stop line to far-side signal (m)

The source of data for those input parameters whose values are not specified above are as follows:

•V_{act}	-	data file or user query
•VD_{avail}	-	roadway file
•Location	-	roadway file or user query
•w	-	roadway file

Evaluation Procedure

The visibility of the signal for each approach to an intersection for the vertical component of SSD is evaluated as follows:

1. For through traffic, a minimum of two signal faces shall be provided and should be continuously visible to traffic approaching the signals from a point at least the value of the SSD indicated in Table 7 until the traffic reaches the stop line. This range of continuous visibility should be provided unless precluded by a physical obstruction or if there is another signalized intersection within this range. To better account for the effect of grade, it is desirable to use Equation 3.6.1 in place of Table 7.

2. From Equation 3.6.1 or Table 7 , determine the desired minimum visibility distance, VD_{des}, to the traffic signal using V_{act}. VD_{des} is the sum of SSD_{des} and w, the width of the intersection from the stop line to the signal.

Table 7. Minimum Sight Distance on Approach to Traffic Signal

V_{act} (km/h)	Minimum Stopping Sight Distance, SSD_{des} (m)
30	35
40	50
50	65
60	85
70	105
80	130
90	160
100	185
110	220
120	250

3. To check the available vertical sight distance, compose a triangular diagram as in Figure 4 :

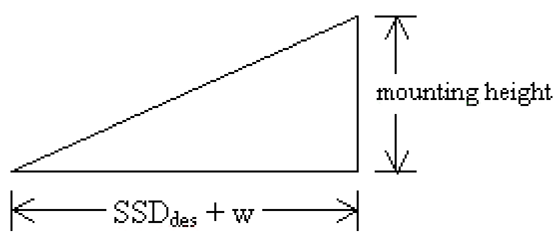


Figure 4. Visibility Distance to Traffic Signal

The dimensions of the triangle are as follows:

•hypotenuse	-	clear sight line
•horizontal leg (along roadway)	-	$VD_{des} = SSD_{des} + w$ (m)
•vertical leg	-	mounting height (m)

The mounting height of a traffic signal is dependent on whether the signal is mounted over the roadway or on the side of the roadway. If the location of the traffic signal is not known (e.g., not stored in the IHSDM

Highway Data file), ask the user where the traffic signal is located. The following mounting heights should be used:

- For a signal mounted over the roadway, mounting height = 18 ft [5.5 m].
- For a signal mounted on the side of the roadway, mounting height = 12 ft [3.7 m].

All signals are assumed to be located on the far side of the intersection at distance w from the stop line.

4. Determine the available visibility distance, VD_{avail}, to the traffic signal. VD_{avail} is the maximum distance over which the sight line to the signal (the hypotenuse in Figure 4) is clear and unobstructed as viewed by a driver on the approach. If $VD_{avail} \geq VD_{des}$, then there is no potential problem present. Proceed to Step 7.

5. If $VD_{avail} \geq VD_{des}$, then determine from Equation 3.6.1 or Table 7 (whichever was used in Step 2), the effective speed (V_{eff}) for which VD_{des} is available.

6. Calculate the difference between V_{eff} and V_{act}. Assess the need to trigger an SSD advisory message by referring to threshold values presented in Section 4.10 .

7. Proceed to consideration of the next signal-controlled approach.

The horizontal component of SSD to the signal should be evaluated by presenting to the user a clear sight area defined by the approach centerline, the signal location, and the driver's eye position at a distance equal to SSD_{des} from the stop line. If the signal is mounted over the roadway, it should be assumed to be located along the extended centerline of the approach being evaluated. If the signal is mounted on the roadside, it should be assumed to be at the stop line on the far right side of the intersection 0.6 m (2 ft) outside the curb. If the clear sight line extends outside the roadway shoulder, the user should be asked whether this area is clear of sight obstructions. This user query is not necessary if the clear sight area is contained totally within the traveled way and the shoulder. In this situation, it can be presumed that the user's response to the question would be YES.

If the user's response to the above question is NO, then at least a Level 2 advisory should be issued. The clear sight area should then be reconfigured based on SSD for V_{act} - 5 km/h or V_{act} - 10 km/h, as indicated for the appropriate traffic volume level in Table 22 in Section 4.10, and the question should be posed to the user again. If the answer to this second question is NO, a Level 1 advisory should be issued; if YES, the Level 2 advisory remains appropriate.

Model Output

The model output for the vertical component of SSD is the effective speed for which SSDis provided, V_{eff}. The criticality of V_{eff} is judged by comparison to V_{act} as described in Section 4. The model output for the horizontal component of SSD is the user's response to the questions concerning the clear sight area (YES/NO).

References

1. *Manual on Uniform Traffic Control Devices.* U.S. Department of Transportation, Federal Highway Administration, Washington, DC, 1988.

2. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994.

3.8 Visibility Distance To Stop Sign

Applicability

A stopping sight distance (SSD) model for stop signs is applied in IDRM to ensure that drivers approaching a stop-controlled intersection shall be given a clear and unmistakable indication of their right-of-way assignment. A similar SSD model is applied to signalized and yield-controlled intersections (see Sections 3.7 and 3.9, respectively).

Basis

The primary consideration in the placement of a stop sign is visibility to approaching drivers. Critical elements are lateral and vertical angles of sight toward a stop sign, as determined by a typical driver's eye position; vehicle design; and the vertical, longitudinal, and lateral position of the stop sign. The geometry of each stop-controlled approach, including vertical grades, horizontal curves, and obstructions, is considered in stop sign placement.

Input Parameters

The input parameters used in the SSD model are:

- V_{act} - actual 85th percentile speed of traffic (km/h)
- VD_{avail} - available visibility distance (m)
- Area type - rural or urban

The source of data for those input parameters whose values are not specified above are as follows:

- V_{act} - data file or user query
- VD_{avail} - roadway file
- Area type - roadway file or user query

Evaluation Procedure

The visibility of a stop sign for each stop-controlled approach to the intersection for the vertical component of SSD is evaluated as follows:

1. The stop sign should be continuously visible to approaching traffic from a point at least the value of the SSD indicated in Table 8 until the traffic reaches the stop line. This range of continuous visibility should be provided unless precluded by a physical obstruction or if there is another stop-controlled or signalized intersection within this range. To better account for the effect of grade, it is desirable to use Equation 3.6.1 in place of Table 8.

2. From Equation 3.6.1 or Table 8, determine the desired minimum visibility distance, VD_{des}, to the stop sign using V_{act}. VD_{des} is equal to SSD_{des}.

Table 8. Minimum Sight Distance on Approach to Stop Signs

V_{act} (km/h)	Minimum Stopping Sight Distance, SSD_{des} (m)
30	35
40	50
50	65
60	85
70	105
80	130
90	160
100	185
110	220
120	250

3. To check the available vertical sight distance, compose a triangular diagram similar to Figure 4 in Section 3.7 but with the following dimensions.

The dimensions of the triangle are as follows:

•hypotenuse - clear sight line
•horizontal leg (along roadway) - $VD_{des} = SSD_{des}$ (m)
•vertical leg - mounting height (m)

The mounting height for a stop sign is dependent on whether the intersection is located in a rural or urban area. If the location of the stop sign is not known, ask the user where the stop sign is located. The following mounting heights should be used:

- For a stop sign in a rural area, mounting height = 6 ft [1.8 m].
- For a stop sign in an urban area, mounting height = 8 ft [2.4 m].

4. Determine the available visibility distance, VD_{avail}, to the stop sign. VD_{avail} is the maximum distance over which the sight line to the stop sign (the hypotenuse in Figure 4) is clear and unobstructed as viewed by a driver on the approach. If $VD_{avail} \geq VD_{des}$, then there is no potential problem present. Proceed to Step 7.

5. If $VD_{avail} < VD_{des}$, then determine from Equation 3.6.1 or Table 8 (whichever was used in Step 2), the effective speed (V_{eff}) for which VD_{des} is available.

6. Calculate the difference between V_{eff} and V_{act}. Assess the need to trigger an SSD advisory message by referring to threshold values presented in Section 4.11.

7. Proceed to consideration of the next stop-controlled approach.

The horizontal component of SSD to the stop sign should be evaluated by presenting to the user a clear sight area defined by the approach centerline, the stop sign location, and the driver's eye position at a distance equal to SSD_{des} from the stop line. The stop sign should be assumed to be located on the near right side of the intersection 0.6 m (2 ft) outside the curb. The user should be asked whether this area is clear of sight obstructions.

If the user's response to the above question is NO, then at least a Level 2 advisory should be issued. The clear sight area should then be reconfigured based on SSD for V_{act} - 5 km/h or V_{act} - 10 km/h, as indicated for the appropriate traffic volume level in Table 23 in Section, and the question should be posed to the user again. If the answer to this second question is NO, a Level 1 advisory should be issued; if YES, the Level 2 advisory remains appropriate.

Model Output

The model output for the vertical component of SSD is the effective speed for which SSDis provided, V_{eff}. The criticality of V_{eff} is judged by comparison to V_{act} as described in Section 4. The model output for the horizontal component of SSD is the user's response to the questions concerning the clear sight area (YES/NO).

References

1. *Manual on Uniform Traffic Control Devices.* U.S. Department of Transportation, Federal Highway Administration, Washington, DC, 1988.
2. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994.

3.9 Visibility Distance To Yield Sign

Applicability

A stopping sight distance (SSD) model for yield signs is applied in IDRM to ensure that drivers approaching a yield-controlled intersection shall be given a clear and unmistakable indication of their right-of-way assignment. A similar SSD model is applied to signalized and stop-controlled intersections (see Sections 3.7 and 3.8, respectively).

Basis

The primary consideration in the placement of a yield sign is visibility to approaching drivers. Critical elements are lateral and vertical angles of sight toward a yield sign, as determined by a typical driver's eye position; vehicle design; and the vertical, longitudinal, and lateral position of the yield sign. The geometry of each yield-controlled approach, including vertical grades, horizontal curves, and obstructions, is considered in yield sign placement.

Input Parameters

The input parameters used in the SSD model are:

- V_{act} - actual 85th percentile speed of traffic (km/h)
- VD_{avail} - available visibility distance (m)
- Area type - rural or urban

The source of data for those input parameters whose values are not specified above are as follows:

- V_{act} - data file or user query
- VD_{avail} - roadway file
- Area type - roadway file or user query

Evaluation Procedure

The visibility of a yield sign for each yield-controlled approach to the intersection for the vertical component of SSD is evaluated as follows:

1. The yield sign should be continuously visible to approaching traffic from a point at least the value of the SSD indicated in Table 9 until the traffic reaches the stop line. This range of continuous visibility should be provided unless precluded by a physical obstruction or if there is another stop-controlled or signalized intersection within this range. To better account for the effect of grade, it is desirable to use Equation 3.6.1 in place of Table 9.

2. From Equation 3.6.1 or Table 9, determine the desired minimum visibility distance, VD_{des}, to the yield sign using V_{act}. VD_{des} is equal to SSD_{des}.

Table 9. Minimum Sight Distance on Approach to Yield Signs

V_{act} (km/h)	Minimum Stopping Sight Distance, SSD_{des} (m)
30	35
40	50
50	65
60	85
70	105
80	130
90	160
100	185
110	220
120	250

3. To check the available vertical sight distance, compose a triangular diagram similar to Figure 4 in Section 3.7 but with the following dimensions.

The dimensions of the triangle are as follows:

- hypotenuse - clear sight line
- horizontal leg (along roadway) - $VD_{des} = SSD_{des}$ (m)
- vertical leg - mounting height (m)

The mounting height of a yield sign is dependent on whether the intersection is located in a rural or urban area. If the location of the stop sign is not known, ask the user where the yield sign is located. The following mounting heights should be used:

- For a yield sign in a rural area, mounting height = 6 ft [1.8 m].

- For a yield sign in an urban area, mounting height = 8 ft [2.4 m].

4. Determine the available visibility distance, VD_{avail}, to the yield sign. VD_{avail} is the maximum distance over which the sight line to the yield sign (the hypotenuse in Figure 4) is clear and unobstructed as viewed by a driver on the approach. If $VD_{avail} \geq VD_{des}$, then there is no potential problem present. Proceed to Step 7.

5. If $VD_{avail} < VD_{des}$, then determine from Equation 3.6.1 or Table 9 (whichever was used in Step 2), the effective speed (V_{eff}) for which VD_{des} is available.

6. Calculate the difference between V_{eff} and V_{act}. Assess the need to trigger an SSD advisory message by referring to threshold values presented in Section 4.12.

7. Proceed to consideration of the next yield-controlled approach.

The horizontal component of SSD to the yield sign should be evaluated by presenting to the user a clear sight area defined by the approach centerline, the yield sign location, and the driver's eye position at a distance equal to SSD_{Des} from the stop line. The yield sign should be assumed to be located on the near right side of the intersection 0.6 m (2 ft) outside the curb. The user should be asked whether this area is clear of sight obstructions.

If the user's response to the above question is NO, then at least a Level 2 advisory should be issued. The clear sight area should then be reconfigured based on SSD for V_{act} - 5 km/h or V_{act} - 10 km/h, as indicated for the appropriate traffic volume level in Table 24 in Section 4.12, and the question should be posed to the user again. If the answer to this second question is NO, a Level 1 advisory should be issued; if YES, the Level 2 advisory remains appropriate.

Model Output

The model output for the vertical component of SSD is the effective speed for which SSDis provided, V_{eff}. The criticality of V_{eff} is judged by comparison to V_{act} as described in Section 4. The model output for the horizontal component of SSD is the user's response to the questions concerning the clear sight area (YES/NO).

References

1. *Manual on Uniform Traffic Control Devices.* U.S. Department of Transportation, Federal Highway Administration, Washington, DC, 1988.
2. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994.

3.10 Decision Sight Distance For Vertical Curves

Applicability

In geometric design, SSD is usually sufficient to ensure safety unless drivers are confronted with a complex or unexpected situation. Decision sight distance (DSD) is applied on approaches to intersections and other locations where drivers need generous sight distance because they may be called upon to make decisions. DSD is an extended version of SSD that is employed in areas where drivers face multiple demands.

The DSD model for vertical curves is applied in IDRM wherever the driver's view of an intersection or potentially conflicting vehicle is limited by a crest vertical curve. All crest vertical curves within the intersection influence area, as defined in Section 2.2, should be considered. A similar DSD model is applied when the sight restriction is the inside of a horizontal curve (see Section 3.11).

Basis

At crest vertical curves, the pavement at some point in the vertical curve may become an obstruction that limits the driver's view of the road ahead. When the driver encounters an intersection, he or she is faced with a more complex situation. The model used to determine the distance ahead that a driver can see and make a decision on the course of action, as limited by crest vertical curves, is based on the DSD model used in geometric design. The 2001 AASHTO *Green Book* presents the criteria for DSD calculations.

The length of a crest vertical curve to provide the adequate sight lines for any specified value of DSD can be determined as follows:

When DSD is less than *L*,

$$L = \frac{|A|(DSD)^2}{100\left(\sqrt{2h_1} + \sqrt{2h_2}\right)^2} \qquad \text{Equation 3.10.1}$$

When DSD is greater than *L*,

$$L = 2(DSD) - \frac{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}{|A|} \qquad \text{Equation 3.10.2}$$

where:

A = algebraic difference in grade (%)
h_1 = height of eye above the roadway surface (mm)
h_2 = height of object above the roadway surface (mm)

The recommended value for driver's eye height (h_1) is 1080 mm and the recommended value for object height (h_2) is also 1080 mm (to ensure that the approaching driver can see other vehicles at the intersection).

On horizontal tangents, the obstruction that limits the driver's sight distance is the road surface at some point on a crest vertical curve.

Input Parameters

- V_{act} - actual 85th percentile speed of traffic (km/h)
- A - algebraic difference in grade (%)
- h_1 - height of eye above the roadway surface [1.08 m]
- h_2 - height of object above the roadway surface [1.08 m]
- L_{act} - actual length of vertical curve (m)

The source of data for those input parameters whose values are not specified above are as follows:

- V_{act} - data file or user query
- A - roadway file
- L_{act} - roadway file

Evaluation Procedure

The DSD model is applied to evaluate crest vertical curves as follows:

1. Determine V_{act}, the higher of the actual 85th percentile speeds of traffic on the selected curve in two directions of travel. V_{act} can be determined from field data, from a speed prediction model like those developed for the IHSDM design consistency module, or from an engineering judgment by the user. The objective is to base the value of $V_{act,}$ to the maximum possible extent, on actual field conditions rather than on an arbitrary design speed.

2. Determine DSD_{des} by entering Table 10 with V_{act}. The columns in Table 10 are defined as follows:

- Column A – applies to any curve on a stop- or signal-controlled approach in a rural area
- Column B – applies to any curve on a stop- or signal-controlled approach in an urban or suburban area
- Column C – applies to any curve on a major-road (uncontrolled) approach to an intersection in a rural area
- Column D – applies to any curve on a major-road (uncontrolled) approach to an intersection in a suburban area
- Column E – applies to any curve on a major-road (uncontrolled) approach to an intersection in an urban area

In IDRM, which deals with rural two-lane highways, only Columns A and C in Table 10 are needed. Column A should be applied in determining DSD for stop- and signal-controlled approaches. Column C should be applied in determining DSD on major-road (uncontrolled) approaches to unsignalized intersections.

Interpolation in Table 10 should be performed linearly for values of V_{act} between 50 and 120 km/h. For values of V_{act} less than 50 km/h, interpolate linearly between the value in Column A or C and zero. For values of V_{act} greater than 120 km/h, use the value in Column A or C for 120 km/h.

Table 10. Decision Sight Distance (Table III-3 in 1994 **Green Book**)

Speed V (km/h)	**Decision Sight Distance for Avoidance Maneuver (meters)**				
	A	**B**	**C**	**D**	**E**
50	75	160	145	160	200
60	95	205	175	205	235
70	125	250	200	240	275
80	155	300	230	275	315
90	185	360	275	320	360
100	225	415	315	365	405
110	265	455	335	390	435
120	305	505	375	415	470

3. Calculate L_1 (when DSD_{des} is less than L) and L_2 (when DSD_{des} is greater than L):

$$L_1 = \frac{|A|(DSD_{des})^2}{100\left(\sqrt{2h_1} + \sqrt{2h_2}\right)^2}$$ Equation 3.10.3

$$L_2 = 2(DSD_{des}) - \frac{200(\sqrt{h_1} + \sqrt{h_2})^2}{|A|}$$ Equation 3.10.4

where:

L_1 = length of vertical curve when DSD is less than L (m)

L_2 = length of vertical curve when DSD is greater than L (m)

DSD_{des} = desired decision sight distance (m)

4. Determine L_{des}, the length of vertical curve needed to provide DSD_{des}:

If $DSD_{des} \leq L_1$, then $L_{des} = L_1$.
If DSDdes > L_2, then Ldes = L_2.

5. If Lact ≥Ldes, then there is not a potential problem present. Proceed to Step 9.

6. If $L_{act} < L_{des}$, then compute DSD_{act} from the appropriate equation:

When DSD_{des} is less than L_{act},

$$DSD_{act} = DSD_{des}\sqrt{\frac{L_{act}}{L_{des}}}$$ Equation 3.10.5

When DSD_{des} is greater than L_{act},

$$DSD_{act} = DSD_{des}\left(\frac{L_{act} - \frac{200(\sqrt{h_1}+\sqrt{h_2})^2}{|A|}}{L_{des} - \frac{200(\sqrt{h_1}+\sqrt{h_2})^2}{|A|}}\right)$$ Equation 3.10.6

7. Determine V_{eff} by entering Table 10. Use Column A or C of Table 10, as appropriate. V_{eff} can be determined by linear interpolation for values within the range from 50 to 120 km/h. When the value of DSD_{act} is less than the value in Column A or C of Table 10 corresponding to 50 km/h, interpolate linearly between 0 and 50 km/h to determine V_{eff}. When the value of DSD_{act} is greater than the value in Column A or C of Table 10 corresponding to 120 km/h, set V_{eff} equal to 120 km/h.

8. Calculate the difference between V_{eff} and V_{act}. Assess the need to trigger a DSD advisory message by referring to threshold values presented in Section 4.

9. Proceed to consideration of the next vertical curve.

The equations in the previous steps are applicable to isolated vertical curves. IDRM actually uses an equivalent numerical method that can address not only isolated vertical curves, but also more complex situations such as compound vertical curves and vertical curves followed by short straight grades. This numerical procedure is also used in the IHSDM PRM and has been documented in the PRM Functionality Document.

Model Output

The model output is the effective speed for which DSD is provided, V_{eff}. The criticality of V_{eff} is judged by comparison to V_{act} as described in Section 4.

References

1. American Association of State Highway and Transportation Officials, Washington, DC, 1994.
2. McGee, H.W., W. Moore, B.G. Knapp, and J.H. Sanders. *Decision Sight Distance for Highway Design and Traffic Control Requirements*, Report No. FHWA-RD-78-078. Federal Highway Administration, Washington, DC, 1978.

3.11 Decision Sight Distance For Horizontal Curves

Applicability

In geometric design, SSD is usually sufficient to ensure safety unless drivers are confronted with a complex or unexpected situation. Decision sight distance (DSD) is applied on approaches to intersections and other locations where drivers need generous sight distance because they may be called upon to make decisions. DSD is an extended version of SSD that is employed in areas where drivers face multiple demands.

DSD model for horizontal curves is applied in IDRM wherever the driver's view of an intersection or potentially conflicting vehicle is limited by an obstruction on the inside of a horizontal curve. All horizontal curves within the intersection influence area, as defined in Section 2.2, should be considered. A similar DSD model is applied when the sight restriction is the crest of a vertical curve (see Section 3.10).

Basis

At horizontal curves, sight obstructions (such as walls, cut slopes, trees, buildings, and longitudinal barriers) on the inside of the curves may limit the driver's view of the road ahead. When the driver encounters an intersection, he or she is faced with a more complex situation. The model used to determine the distance ahead that a driver can see and make a decision on the course of action, as limited by the horizontal sight obstruction, is based on the DSD model used in geometric design. The 2001 AASHTO *Green Book* presents the criteria for DSD calculations.

Input Parameters

The input parameters used in the DSD model are:

- V_{act} - actual 85th percentile speed of traffic (km/h)
- L_c - length of horizontal curve (m)
- R - radius (m)
- LW - lane width (m)
- CSW_{avail} - obstruction offset available on the inside of the horizontal curve

The source of data for those input parameters whose values are not specified above are as follows:

- V_{act} - data file or user query
- R - roadway file
- LW - roadway file
- CSW_{avail} - roadway file
- L_c - roadway file

Evaluation Procedure

The DSD model is applied to evaluate a horizontal curve as follows:

1. Determine V_{act}, the actual 85th percentile speed of traffic on the selected curve in the direction of travel toward the intersection. V_{act} can be determined from field data, from a speed prediction model like those developed for the IHSDM design consistency module, or from engineering judgment by the user. The objective is to base the value of V_{act}, to the maximum possible extent, on actual field conditions rather than on an arbitrary design speed.

2. Determine the desired DSD from Table 10 in the same way this was done in Step 2 for vertical curves.

3. Compute the desired obstruction offset on the inside of the horizontal curve, CSW_{des}.

For a horizontal curve to the right for which the length of curve (L_c) ≥ DSD_{des}:

$$CSW_{des} = (R - 0.25LW)\left(1 - \cos\frac{DSD_{des}}{2(R - 0.25LW)}\right) - 0.75LW \quad \text{Equation 3.11.1}$$

where:

CSW_{des} = desired clear sight width (m)

For a horizontal curve to the left for which $L_c \geq DSD_{des}$:

$$CSW_{des} = (R + 0.25LW)\left(1 - \cos\frac{DSD_{des}}{2(R + 0.25LW)}\right) - 1.25LW \quad \text{Equation 3.11.2}$$

For a horizontal curve to the right for which $L_c < DSD_{des}$:

$$CSW_{des} = \sqrt{\frac{0.41L_c(2\,DSD_{des} - L_c)}{R - 0.25LW}} - 0.75LW \quad \text{Equation 3.11.3}$$

For a horizontal curve to the left for which $L_c < DSD_{des}$:

$$CSW_{des} = \sqrt{\frac{0.41L_c(2\,DSD_{des} - L_c)}{R + 0.25LW}} - 1.25LW \quad \text{Equation 3.11.4}$$

4. Obtain the obstruction offset available (CSW_{avail}) on the inside of the horizontal curve from the roadway file or ask the user to enter it.

5. If $CSW_{avail} \geq CSW_{des}$, then there is no potential problem present. Proceed to Step 8.

6. If $CSW_{avail} < CSW_{des}$, then calculate the effective speed (V_{eff}) for which DSD is available by backsolving the appropriate equation from among Equations 3.11.5 through 3.11.6 to determine DSD_{act} and then using Table 10 to determine V_{eff} in the same manner described for Step 8 in Section 3.10 .

7. Calculate the difference between V_{eff} and V_{act}. Access the need to trigger a DSD advisory message by reference to threshold values presented in Section 4.

8. Proceed to consideration of the next horizontal curve.

The equations in the previous steps are applicable to isolated horizontal curves. IDRM actually uses an equivalent numerical method that can address not only isolated horizontal curves, but also more complex situations such as compound horizontal curves or horizontal curves followed by short tangents. This numerical procedure has also been used in the IHSDM PRM and has been documented in the PRM Functionality Document.

Model Output

The model output is the effective speed for which DSD is provided, V_{eff}. The criticality of V_{eff} is judged by comparison to V_{act} as described in Section 4.

References

1. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994.
2. McGee, H.W., W. Moore, B.G. Knapp, and J.H. Sanders. *Decision Sight Distance for Highway Design and Traffic Control Requirements*, Report No. FHWA-RD-78-078. Federal Highway Administration, Washington, DC, 1978.

3.12 Clearance Time For Skewed Intersection

Applicability

Clearance time models are proposed for use in IDRM for skewed intersection approaches at both signalized and unsignalized intersections.

Similar considerations also apply to intersections where the approach alignment differs between opposing approaches, at multileg intersections, and at intersections with more than one minor-road approach on the same side of the major road.

Basis

A clearance time model is required to address safety and operational issues that arise from the additional distance (and time) that vehicles require to cross skewed intersections versus right-angle intersections.

At unsignalized intersections, the need for additional clearance time is safety-related. Additional clearance time is required for stopped vehicles on the minor approach to cross the intersection, resulting in greater exposure of the vehicle to conflict. The sight distance for a crossing maneuver from one minor-road leg to the other is based on the time it takes for the stopped vehicle to clear the intersection. The time gap for ISD for crossing the major road at an unsignalized intersection should thus be increased by Δt at a skewed intersection.

At signalized intersections, the additional time needed to cross the skewed intersection is more of an operational issue than a safety issue. Increased crossing time at a skewed intersection will have a negative effect on the operational efficiency of a signalized intersection by requiring an increase in the yellow and/or all-red clearance time. The function of the all-red clearance time is to allow the vehicle that has entered the intersection to safely clear the intersection before the conflicting movement is released.

Input Parameters

The following input data are required to utilize the clearance time model. Data can be obtained from the IHSDM roadway model or by prompting the user for relevant input data.

- Intersection angle (degrees).
- Length of design vehicle (m) – data may be obtained from 1994 AASHTO Policy, Table II-1.
- Major approach lane width (m).

- Major approach turn bay width (m).
- Distance vehicle stops behind stop bar on minor approach (m).
- Acceleration rate from a stopped condition (m/s^2) – data may be obtained from NCHRP Report 383.
- Actual approach travel speed of vehicle on major approach (m/s).

Evaluation Procedure

The following rationale is used by IDRM to calculate additional clearance time at skewed intersections. Two cases of clearance time models at skewed intersections are considered: unsignalized intersections and signalized intersections. Each of these cases is discussed below.

Unsignalized Intersections

At an unsignalized intersection at which the major- and minor-road legs intersect at an angle other than 90 degrees, the clearance time analysis applies to the minor-road legs (i.e., the stop-controlled legs). The sight distance for a crossing maneuver from one minor-road leg to the other is based on the time it takes for the stopped vehicle to clear the intersection. This clearance time is increased by the intersection skew. Thus, for crossing maneuvers at skewed intersections, the S distance (the distance that the crossing vehicle must travel to clear the major highway) is larger than for right-angle intersections (see Figure 5 below). That is, the roadway width on the path of the crossing vehicle, W, is the actual traveled way width divided by the sine of the intersection angle:

$$W = \frac{w}{\sin N}$$ Equation 3.12.1

where:

W = roadway width on the path of the crossing vehicle (m)
w = actual traveled way width (m)
N = intersection angle

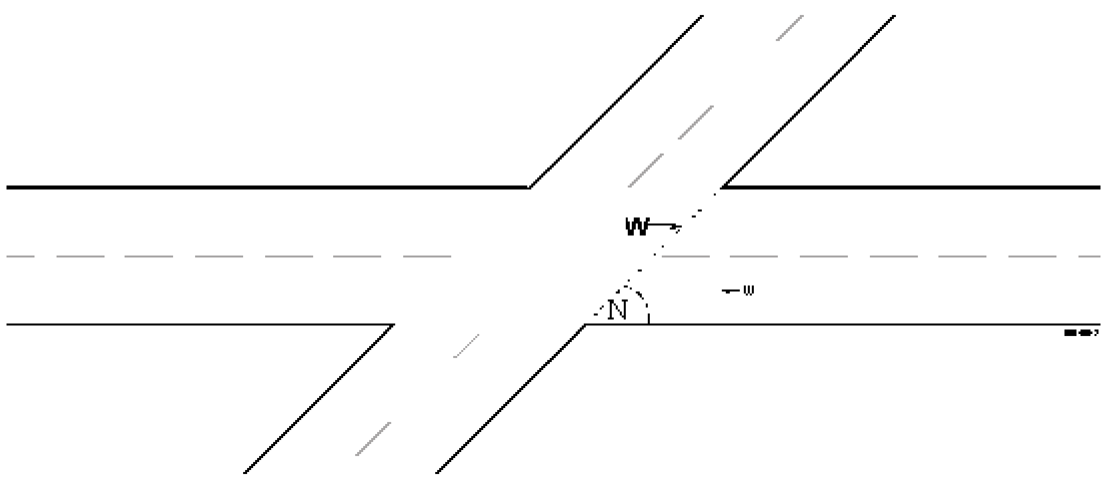


Figure 5. Skewed Intersection

The time to accelerate from a stop and travel distance w at a right-angle intersection is:

$$t_{90} = \sqrt{\frac{2w}{a}} \qquad \text{Equation 3.12.2}$$

where:

t_{90}	=	crossing time at a right-angle intersection (s)
a	=	acceleration rate from a stop (use 1.38 m/s^2 based on NCHRP Report 383)

While the time to accelerate from a stop and travel distance W at a skewed intersection is:

$$t_{skew} = \sqrt{\frac{2W}{a}} \qquad \text{Equation 3.12.3}$$

where:

t_{skew}	=	crossing time at a skewed intersection,

the additional time required to cross the intersection is:

$\Delta t = t_{skew} - t_{90}$

Signalized Intersections

The same model applies to signalized intersections. At signalized intersections, however, the additional time needed to cross the skewed intersection is more of an operational issue than a safety issue. Increasing the crossing time will reduce the operational efficiency of a signalized intersection.

The efficiency of an approach depends on the ratio of effective green to the cycle length (g/C ratio). A higher ratio represents greater efficiency for that approach. The additional time needed for a vehicle to cross a skewed intersection, Δt , will be provided during the all-red clearance time. The function of the all-red clearance time is to allow the vehicle that has entered the intersection to safely clear the intersection before the conflicting movement is released. The design vehicle for computing the length of the all-red clearance time is a truck and is computed as:

$$t = \left(\frac{W + ds + L}{V}\right) \qquad \text{Equation 3.12.4}$$

where:

t	=	all-red clearance time (s)
W	=	width of the intersection (m)
ds	=	distance from the edge of the major road traveled way to the stop bar (m)
L	=	length of the design vehicle (m)

V = approach speed (km/h)

This equation demonstrates that an increase in the crossing width of a skewed intersection increases the all-red clearance time. An increase in the all-red clearance time represents an increase in an approach's unused time or, for a given cycle length, a decrease in an approach's effective green time. This results in a lower g/C ratio for that particular approach.

At skewed intersections, drivers at all four approaches encounter longer crossing distances and need additional time to cross. This Δt will be taken from the effective green of all four approaches, resulting in a lower g/C ratio or a lower operating efficiency for the entire intersection.

Model Output

Model output is summarized in the tables presented below. Data provided is the additional time required for a vehicle to cross skewed intersections relative to a 90-degree intersection. Model output is provided for both the unsignalized and signalized conditions.

Unsignalized Intersections

Change in clearance time (s) for a skewed intersection relative to a 90-degree intersection (with median/turn bay on major approaches):

Table 11. Skewed Unsignalized Intersection – Additional Clearance Seconds (With Median/Turn Bay on Major Approaches)

	Intersection Angle (degrees)			
Lane Width (m)	**90**	**75**	**60**	**45**
3.6	0.00	0.06	0.25	0.65
3.3	0.00	0.06	0.24	0.63
3.0	0.00	0.05	0.23	0.60
2.7	0.00	0.05	0.22	0.58

Change in clearance time (s) for a skewed intersection relative to a 90-degree intersection (without median/turn bay on major approaches):

Table 12. Skewed Unsignalized Intersection – Additional Clearance Seconds (Without Median/Turn Bay on Major Approaches)

	Intersection Angle (degrees)			
Lane Width (m)	**90**	**75**	**60**	**45**
3.6	0.00	0.04	0.16	0.43
3.3	0.00	0.04	0.16	0.41
3.0	0.00	0.03	0.14	0.37
2.7	0.00	0.03	0.13	0.34

Signalized Intersections

Change in clearance time (s) for a skewed intersection relative to a 90-degree intersection (with median/turn bay on major approaches [3.6-m lanes]):

Table 13. Skewed Signalized Intersection – Additional Clearance Seconds (With Median/Turn Bay on Major Approaches)

	Intersection Angle (degrees)			
Speed (km/h)	**90**	**75**	**60**	**45**
50	0.00	0.01	0.09	0.38
60	0.00	0.01	0.08	0.32
70	0.00	0.01	0.07	0.27
80	0.00	0.01	0.06	0.24
90	0.00	0.01	0.05	0.21
100	0.00	0.01	0.05	0.19

For values of V_{act} less than 50 km/h, use the 50-km/h value from the appropriate column. For values of V_{act} greater than 120 km/h, use the value from the appropriate column for 120 km/h.

Change in clearance time (s) for a skewed intersection relative to a 90-degree intersection (without median/turn bay on major approaches [3.6-m lanes]):

Table 14. Skewed Signalized Intersection – Additional Clearance Seconds (Without Median/Turn Bay on Major Approaches)

	Intersection Angle (degrees)			
Speed (km/h)	**90**	**75**	**60**	**45**
50	0.00	0.01	0.05	0.21
60	0.00	0.01	0.04	0.18
70	0.00	0.01	0.04	0.15
80	0.00	0.00	0.03	0.13
90	0.00	0.00	0.03	0.12
100	0.00	0.00	0.03	0.11

For values of V_{act} less than 50 km/h, use the 50-km/h value from the appropriate column. For values of V_{act} greater than 120 km/h, use the value from the appropriate column for 120 km/h.

References

1. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994 (Table II-1: Design Vehicle Dimensions, p. 21).
2. Harwood, D.W., J. Mason, R. Brydia, M. Pietrucha, and G. Gittings. *Intersection Sight Distance*, NCHRP Report 383. Transportation Research Board, Washington, DC, 1996(acceleration rate from a stop).

3.13 Left-Turn Lane Warrants

Applicability

Left-turn lane warrant models are proposed for use in IDRM for the situation where left-turn lanes are not present on the major unstopped approach. This model does not address the geometric design characteristics of the turn lane, such as length, taper design, etc., which are addressed in the PRM.

Basis

A model is required to identify the need for left-turn lanes at intersections and to highlight locations where lack of left-turn lanes presents a potential safety concern. For rural, unsignalized intersections along the through or unstopped approach, left-turn lanes serve a safety and operational efficiency function by removing decelerating and stopped vehicles waiting to turn from the higher speed through lanes.

Input Parameters

The following input data are required to utilize the left-turn lane warrant model. Data can be obtained from the IHSDM roadway model or by prompting the user for relevant input data.

- Peak- or design-hour traffic volume, by movement, on each unstopped approach.
- Vehicle approach operating speed on the major unstopped approach.

Evaluation Procedure

The following general steps would be undertaken by IDRM to evaluate the left-turn lane warrants:

1. For each unstopped approach to an intersection, determine whether a left-turn lane is present or not.
2. From data provided by the designer, determine the peak-hour volume of each unstopped approach. If peak-hour volume is not available, use design-hour volume.
3. Determine the 85th percentile speed. The speed can be determined from actual data, from a speed prediction model like those developed for the IHSDM design consistency module, or from engineering judgment by the user. (Note that both directions of travel need to be evaluated.)
4. Look up the appropriate warranting condition and display an appropriate message.

No formulas or calculations are required to obtain output from the left-turn lane warrant model. Model output is obtained via a look-up table.

Model Output

Model output is summarized in Table 15 . Determination of whether a left-turn lane is warranted is based on consulting the table for a particular operating speed and opposing design-hour volume. If the advancing volume is greater than the value shown (for a given percentage of left turns), a left-turn lane is warranted.

Table 15. Volume Warrants for Left-Turn Lanes

Opposing Volume/Hour	Advancing Volume/Hour 5% Left Turns	10% Left Turns	20% Left Turns	30% Left Turns
60-km/h Operating Speed				
800	330	240	180	160
600	410	305	225	200
400	510	380	275	245
200	640	470	350	305
100	720	515	390	340
80-km/h Operating Speed				
800	280	210	165	135
600	350	260	195	170
400	430	320	240	210
200	550	400	300	270
100	615	445	335	295
100-km/h Operating Speed				
800	230	170	125	115
600	290	210	160	140
400	365	270	200	175
200	450	330	250	215
100	505	370	275	240

References

1. *A Policy on Geometric Design of Highways and Street (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994 (Table II-1: Design Vehicle Dimensions, p. 21).
2. *Intersection Channelization Design Guide*, NCHRP Report 279. Transportation Research Board, Washington, DC (Figure 4-12 [Harmelink study]).

3.14 Right-Turn Lane Warrants

Applicability

Right-turn lane warrant models are proposed for use in IDRM for the situation where right-turn lanes are not present on the major unstopped approach.

Basis

A model is required to identify the need for right-turn lanes at intersections and to highlight locations where lack of right-turn lanes presents a potential safety concern. For rural, unsignalized intersections along the through or unstopped approach, right-turn lanes serve a safety and operational efficiency function by removing decelerating vehicles waiting to turn from the higher speed through lanes.

Input Parameters

The following input data are required to utilize the right-turn lane warrant model. Data can be obtained from the IHSDM roadway model or by prompting the user for relevant input data.

- Peak- or design-hour traffic volume, by movement, on each intersection approach.

Evaluation Procedure

The following general steps would be undertaken by IDRM to evaluate the right-turn lane warrants:

1. For each unstopped approach to an intersection, determine whether a right-turn lane is present or not.
2. From data provided by the designer, determine the peak-hour volume of each unstopped approach. If peak-hour volume is not available, use design-hour volume.
3. Look up the appropriate warranting condition and display an appropriate message.

No formulas or calculations are required to obtain output from the right-turn lane warrant model. Model output is obtained via the table below.

Model Output

Model output is summarized in Table 16 below. Determination of whether a right-turn lane is warranted is based on a comparison of the approach design-hour volume (DHV) and the actual right-turn volume. If the actual right-turn volume is greater than that in the table, an exclusive right-turn lane is warranted.

Table 16. Threshold Volumes for Right-Turn Lane

Approach Volume (DHV)	Right-Turn Volume (DHV)
100	100
200	94
300	80
400	68
500	54
600	40
700	40

References

1. *The Development of Criteria for the Treatment of Right-Turn Movements on Rural Roads*. Virginia Highway and Transportation Council, March 1981.

3.15 Left-Turn Lane Length For Closely Spaced Intersections

Applicability

The left-turn lane length model is proposed for use in IDRM to deal with the adequacy of storage lengths, deceleration lengths, and taper lengths for back-to-back left-turn lanes between closely spaced intersections on the major road.

Basis

A model is required to address safety and operational issues that arise from the often restricted dimension along a major road between closely spaced intersections. Drivers turning off a highway at an intersection are usually required to reduce their speed before turning. When rapid deceleration takes place directly on the highway through lanes, it disrupts the flow of through-lane traffic. Another function of left-turn lanes is to store vehicles waiting to turn off a major roadway. Intersections with high turning-traffic volumes and/or opposing-traffic volumes generally require greater storage lengths. This model will provide guidance as to the minimum required dimension between intersections.

Input Parameters

The following input data are required to utilize the left-turn lane length for the closely spaced intersections model. Data can be obtained from the IHSDM roadway model or by prompting the user for relevant input data.

- Spacing between intersections (from edge of pavement to edge of pavement).
- Vehicle approach speed (posted speed or predicted speed from DCM).
- Left-turn lane width.
- Left-turn queue length (output from queue prediction model).

Evaluation Procedure

The following procedures would be used by IDRM to calculate the minimum required dimension between intersections. As part of this process, three components of left-turn lane length are reviewed: storage length, deceleration length, and taper length. Each of these components is discussed below.

For the case with back-to-back left-turn lanes on the major road between closely spaced intersections, threshold values of storage length are based on total left-turn volumes at both intersections. The anticipated number of queued vehicles at each intersection is converted to a dimension and compared to the available storage dimension provided at the respective intersection.

Deceleration Length

At closely space intersections, the left-turn lane may not be of sufficient length to enable a driver to maneuver a vehicle into it properly and make the necessary reduction in speed. For this scenario, threshold values for the minimum spacing between intersections are based on AASHTO deceleration lengths for V_{act}.

The required deceleration lengths for various values of V_{act} are as follows:

Table 17. Required Deceleration Lengths

V_{act} (km/h)	Deceleration Length (m)
50	70
60	100
70	110
80	130
90	145
100	170
110	180

For IDRM, the model will assume that no deceleration occurs in the through lanes and that the taper is not part of the deceleration length.

Taper Length

For minimum taper length, the *Green Book* refers to the *Manual on Uniform Traffic Control Devices*, which recommends that the minimum length of taper can be calculated as:

$$V_{act} \geq 70\ \text{km/h} \qquad L = 0.6 V_{act} W \qquad \text{Equation 3.15.1}$$

$$V_{act} \leq 60\ \text{km/h} \qquad L = \frac{W V_{act}^2}{155} \qquad \text{Equation 3.15.2}$$

where:

- L = length of taper (m)
- V_{act} = actual travel speed of vehicle (km/h)
- W = width of left-turn lane (m)

Note: For programming purposes the second equation will be used when $V_{act} < 70$.

Model Output

Model output is summarized in Figure 6 . Determination of a minimum distance between closely spaced intersections is obtained by consulting the chart using the approach speed of the vehicle and the expected queue condition at the intersection.

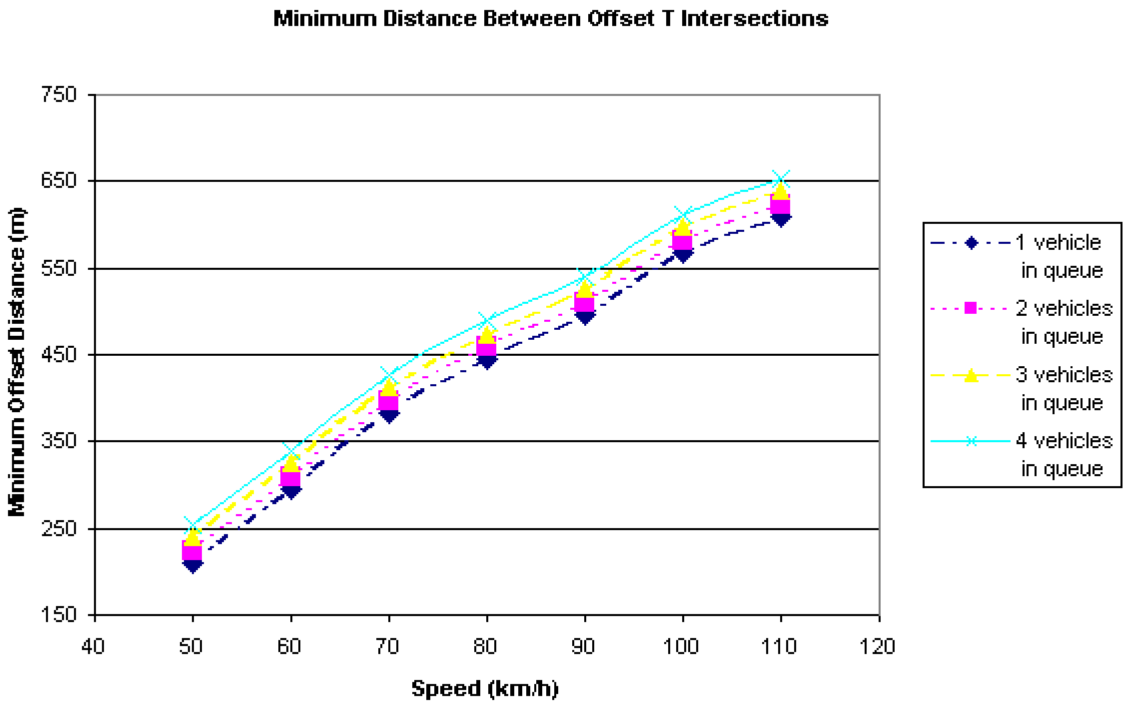


Figure 6. Minimum Distance Between Closely Spaced Intersections

References

1. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994 (deceleration length requirements, p. 780).
2. *Manual on Uniform Traffic Control Devices.* U.S. Department of Transportation, Federal Highway Administration, Washington, DC, 1988 (Figure 3-10, Typical lane transition markings, p. 3B-13).
3. *Highway Capacity Manual*. Transportation Research Board, 1997 (Chapter 10, Unsignalized Intersections).

3.16 Intersection Conflict Index

Applicability

Intersection conflict index models are proposed for use in IDRM to characterize both the absolute and relative safety of a multileg intersection configuration. Multileg intersections are potential problems in that they produce a greater number of conflict points relative to four-leg intersections.

Basis

The intersection conflict index is used to measure the relative safety of an intersection configuration as a function of the number and types of intersection conflicts. Intersection conflict analysis is a well-understood means of addressing intersection safety. For example, it has long been known that three-leg intersections operate more safely than four-leg intersections because three-leg intersections have fewer conflict points at which conflicting traffic streams cross, merge, or diverge. Intersection conflicts reflect the crossing or conflicting paths of vehicles moving from one leg to another. Depending on the type of movement (right or left turn, crossing the intersection), any one vehicle can encounter or create one or more different conflicts. The different types of conflicts include diverging, merging, or crossing conflicts.

It is proposed to extend the same concept to the evaluation of multileg intersections. The intersection conflict index proposed for IDRM recognizes two principles of intersection conflicts and accidents. First, conflicts (and the associated risk of a particular type of crash) are related to the traffic volume of the conflicting movements. Second, the different conflicts have differing importance. This is a reflection of the severity of crashes associated with a conflict type.

Input Parameters

The following input data are required to utilize the intersection conflict index model. Data can be obtained from the IHSDM roadway model or by prompting the user for relevant input data.

- Design-hour traffic volume, by movement, on each intersection approach.
- Type of traffic control.

Evaluation Procedure

The following procedures would be used by IDRM to calculate the intersection conflict index.

The intersection conflict index (ICI) is defined as follows:

$$ICI = \sum_{all\ conflict\ types} TV_{mi} TV_{nj} W_k \qquad \text{Equation 3.16.1}$$

where:

ICI	=	intersection conflict index
TV_{mi}	=	peak-hour or design-hour traffic volume for turning movement *m* from approach *i*
TVnj	=	peak-hour or design-hour traffic volume for conflicting turning movement *n* from approach *j*
W_k	=	weight factor based on types of conflicting movements and types of traffic control

ICI is computed by systematic consideration of all pairs of turning movements at the intersection (i.e., through, left-turn, and right-turn movements from each approach) that conflict with one another. Turning movements would be considered conflicting whenever their paths cross.

The weight factor (W_k) is used to incorporate the concept that not all conflicting movements are equally likely to result in a crash. Proposed weights are shown in Table 18 below. Higher weights are assigned to pairs of conflicting movements that appear to have the highest risk of a crash. Zero weight is assigned to traffic streams that do not cross or that represent negligible risk.

Table 18. Weights for Use in Computing the Intersection Conflict Index

Type of Conflict	Type of Traffic Control	
	Unsignalized	Signalized
Crossing		
Through/Through	3	0
Left Turn/Through	3	0
Left Turn/Left Turn	0.5	0
Merging		
Right Turn/Through	2	0
Left Turn/Through	2	0
Left Turn/Right Turn	0.5	0
Diverging (all types)	1	1

ICI is based on the assumption that a traffic signal separates conflicts in time; hence, the only conflicts of interest related to signalized intersection configuration are diverging conflicts. This assumes the use of protected phasing for all movements. If the traffic signal phasing is such that particular movements do conflict, then the same weights as for unsignalized intersections should be used.

Model Output

Model output is a dimensionless numerical value based on the equation described above in detail. This number can then be compared to the established ICI threshold values, noted in Section 4.22, to determine if the designer should be shown a Level 1 or Level 2 alert message.

References

1. *Manual on Uniform Traffic Control Devices.* U.S. Department of Transportation, Federal Highway Administration, Washington, DC, 1988 (traffic signal warrants, pp. 4C-1 through 4C-12).

3.17 Minor-Road Profile

Applicability

The minor-road profile model is proposed for use in IDRM at intersections with a discontinuous minor-road profile through the intersection with the major road.

Basis

The profile of minor roads at intersections can present operational problems if not properly designed. Often, designers are focused on achieving an optimal profile for the major, unstopped road, but have less concern about the minor road. Issues of concern where there is not continuity of the minor-road profile through an intersection include:

- Pavement elevations and drainage patterns across the intersection result in flat spots at corners or through the intersection.

- Amount of grade change from the minor road to the major road may result in an alignment that is uncomfortable to drive, necessitating lower speeds.
- Presence of a reasonable platform for drivers stopped on the minor approach.
- Presence of vertical curves connecting significantly different grades that may result in vehicles "bottoming out".

Input Parameters

The following input data are required to utilize the minor-road profile model. Data can be obtained from the IHSDM roadway model or by prompting the user for relevant input data.

- Centerline grade of the through road.
- Centerline grade of each stopped approach.
- Typical cross section of the major road, including normal cross-slope, or slope if superelevated.
- Edge of pavement elevations for all curb returns.
- Horizontal plan, lane width, and other geometry for the intersection.
- Traffic volume on the minor approach and major, unstopped road.

Evaluation Procedure

The following general steps would be undertaken by IDRM to utilize the minor-road profile model:

1. Determine each minor-road stopped approach.
2. Determine the grade within 100 m of the centerline intersection of the two roadways on each minor approach.
3. Refer to the traffic volume and determine the desirability or need for a "platform" for drivers stopped on the minor approach. The criteria for a platform is considered to be any local grade of ± 2 percent. Display appropriate message.
4. Determine the cross-slope of the major road through the intersection.
5. For each minor road, determine the relative difference in grades between the cross-slope of the major road and the minor road. Refer to Table 19 below, which relates to design controls on grade; produce message as appropriate.
6. Check the presence of a vertical curve where grade changes are significant (see table notes); produce message as appropriate.

Table 19. Design Controls on Difference Between Major- and Minor-Road Slopes

Type of Minor Road	Grade Change From Major Road	
	Desirable	Maximum
Collector/Arterial	0%	± 3%
Local Road	± 3%	± 6%
Low-Volume Local Road or Local Street	± 6%	± 15%

Note: Vertical curves are not required for the "Desirable" grade in each case, but are recommended (10 ft to 50 ft in length). For the "Maximum" grade change, vertical curves are required (minimum length, 10 ft) to prevent significant vehicle bounce and scraping of the chassis [1 ft = 0.305 m].

Model Output

Model output is guidance provided to the designer via the messages generated by applying the procedure documented above.

References

1. *Planning and Design Guide for At-Grade Intersections* (Course workbook developed by Jack E. Leisch and Associates), 1990.

3.18 Intersection Pavement Area

Applicability

The intersection pavement area model is proposed for use in IDRM to deal with the large, open pavement areas associated with multileg intersections, skewed intersections, and intersections on a horizontal curve. Additional pavement is also required to serve large trucks.

Basis

Intersections with large, open pavement areas can produce operational problems. Large, open pavement areas generally occur at multileg intersections, skewed intersections, and intersections on a horizontal curve. Larger intersections are more costly to construct and maintain. The open pavement areas can be more difficult to drain, which may create icing or other vehicle control problems. In addition, large open pavement areas at intersections may also be difficult for unfamiliar drivers to navigate.

The need to accommodate the operation of long and wide vehicles also produces special problems at intersections. Vehicle turning paths, which are a function of the characteristics of the vehicles, take up considerable space as the vehicle makes either a right or a left turn. The amount of space and potential impacts on the operation and safety of the intersection are influenced by the type of large vehicle and the angle of the intersection. The types and severity of potential turning path problems are based on the frequency of large vehicle turns and which approach legs (i.e., stopped or unstopped) are skewed. Turning-path requirements are a concern at all intersections, but are particularly important at skewed and multileg intersections. An intersection on a relatively sharp horizontal curve will also result in one or more turning movements occurring through a skew.

Both left- and right-turning geometric elements are affected by the turning paths of large vehicles. For right-turning vehicles, the design of the curb return (simple radius curve, multi-centered curve, or other variations), the width of the roadway the vehicle is turning onto, and the proximity and type of opposing lane are features of concern. For left-turning vehicles, the type of traffic control (signal versus stop) and the width of roadway the vehicle is turning onto are also factors.

Input Parameters

The following input data are required to utilize the intersection pavement area model. Data can be obtained from the IHSDM roadway model or by prompting the user for relevant input data.

- Intersection angle (degrees).
- Type of design vehicle.
- Length of design vehicle (m) – data may be obtained from 1994 AASHTO Policy, table II-1.
- Percentage of heavy vehicles in the traffic stream.
- Major approach lane width (m).
- Major approach turn-bay width (m).
- Minor approach lane width (m).

Evaluation Procedure

The following general steps would be undertaken by IDRM to utilize the intersection pavement area model:

1. Check if the intersection is a multileg intersection; display appropriate message to the designer.
2. Compute the intersection skew angle and compare to threshold value presented in Section 4.24; display appropriate message to the designer.
3. Check the intersection design vehicle and compare to threshold design vehicle presented in Section 4.24; display appropriate message to the designer.
4. Compute the percentage of heavy vehicles on each approach leg and compare to threshold values presented in Section 4.24; display appropriate message to the designer.

Model Output

Model output is guidance provided to the designer via the messages generated by applying the procedure documented above. The following figure was used to determine the skew angle threshold. Refer to Section 4.24 Basis for more details.

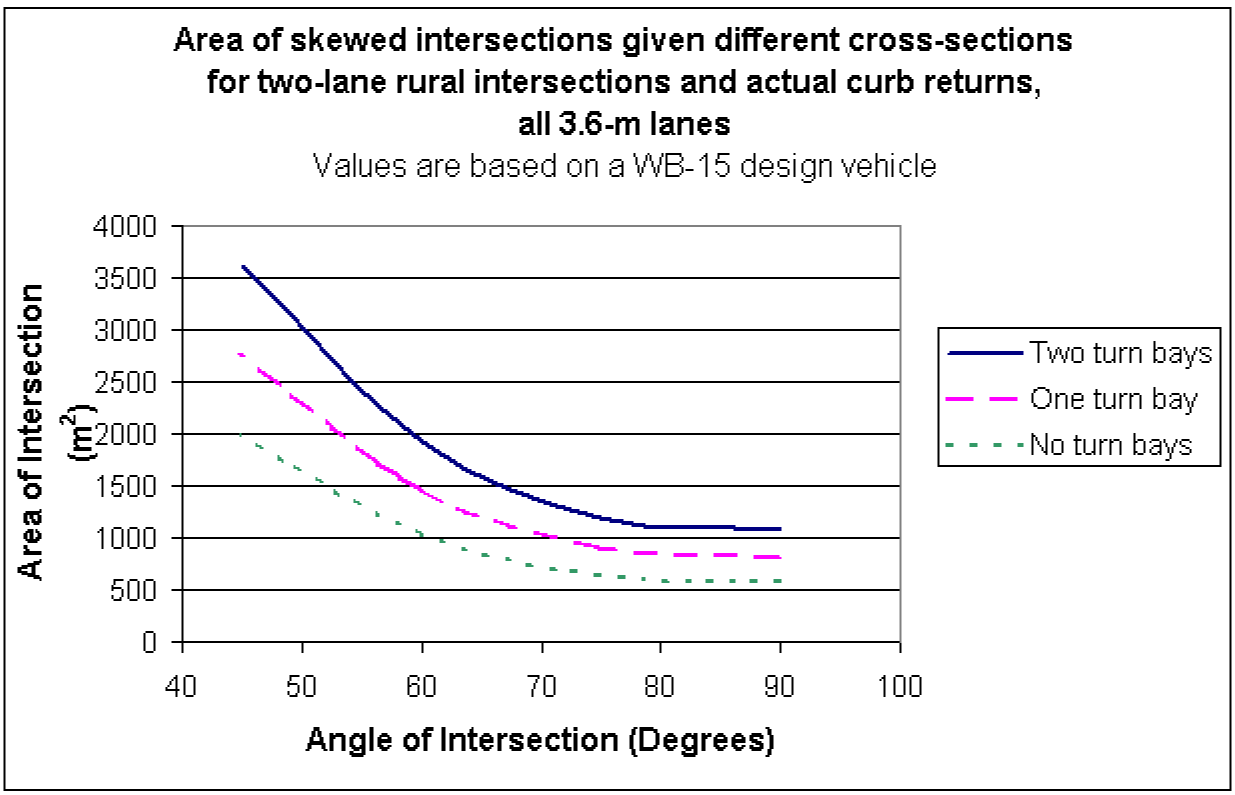


Figure 7. Area of Skewed Intersections for Two-Lane Rural Intersections

References

1. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994 (Table IX-1, Minimum edge of traveled way designs for turns at intersections, pp. 648-649).

3.19 Change In Approach Alignment Between Opposing Approaches

Applicability

The change in approach alignment model is proposed for use in IDRM to deal with forced directional changes for through vehicles as they proceed through an intersection. Forced directional changes may be difficult for unfamiliar drivers to navigate.

Basis

Intersections with substantial changes between approach alignments can produce operational and safety problems. Forced path changes for through vehicles violate driver expectations.

Input Parameters

The following input data are required to utilize the change in approach alignment model. Data can be obtained from the IHSDM roadway model or by prompting the user for relevant input data.

- Intersection angle (degrees).
- Design speed for each approach leg (km/h) or 85th percentile speed (km/h).

Evaluation Procedure

The following general steps would be undertaken by IDRM to utilize the change in approach alignment model:

1. Obtain the design speed or 85th percentile speed for the approach leg(s) being examined.
2. Compute the deflection angle between intersection legs for each direction of travel.
3. Compare the angle with the threshold values; display appropriate message to the designer.

Model Output

Model output is a calculated value of the difference in angles between opposing intersection legs.

References

1. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994.

3.20 Queue Length Prediction

Applicability

Aqueue length prediction model is proposed for use in IDRM to characterize locations where there may be inadequate queue storage on a major road between intersections or where stopped drivers on an approach may be hidden from other drivers on the same approach.

Basis

A traffic operational model is needed to identify situations in which expected queues of vehicles (e.g., at a stopped approach) will pose an unusual hazard because of the presence of a particular geometric condition or feature. A queue prediction model would estimate a level of queuing for a given approach-traffic volume and translate that volume to a design dimension.

Example cases in which a queue prediction model would be useful

- Determining critical dimensions at offset T intersections (with left turns queued between each intersection).
- Determining critical dimensions on stopped approaches with limiting geometric features such as vertical curves, horizontal curves, or steep grades on the approach.
- Flagging critical operational conditions where queued turning traffic without the benefit of a left-turn lane may occur frequently enough to pose an unusually great hazard.

Input Parameters

The following input data are required to utilize the queue length prediction model. Data can be obtained from the IHSDM roadway model or by prompting the user for relevant input data.

- Design-hour traffic volume, by movement, on each major, unstopped intersection approach.

Evaluation Procedure

*Highway Capacity Manual*procedures for unsignalized intersections (1997 edition, chapter 10) were used as the basis for queue prediction model development. The procedures were used to translate volume and geometric conditions into an expected number of queued vehicles.

Use the left-turn design-hour traffic volume and the sum of through and right-turning vehicles for each unstopped approach when reading Figure 8 below.

Model Output

Model output is summarized in Figure 8. An estimate of the number of vehicles queued is obtained by consulting the chart using design-hour volume for the left turn and the opposing through/right volumes for a major, unstopped approach to a stop-controlled intersection.

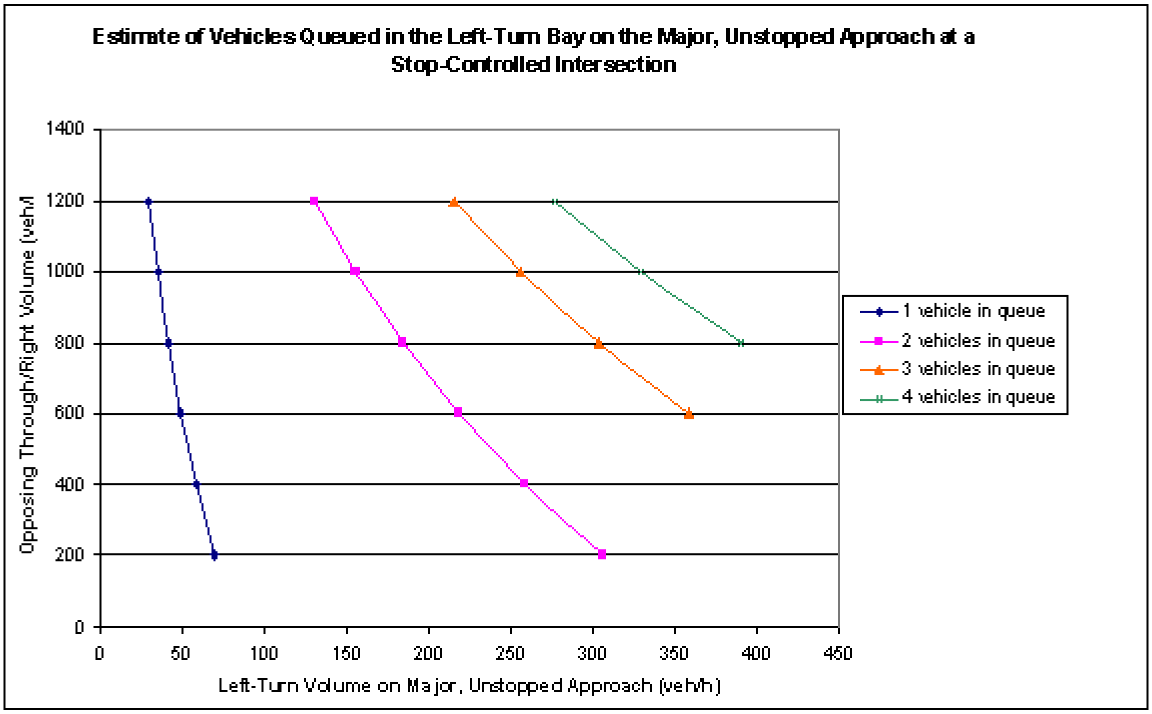


Figure 8. Estimate of Left-Turn Vehicles Queued

References

1. *Highway Capacity Manual*. Transportation Research Board, 1997 (Chapter 10, Unsignalized Intersections).

3.21 Horizontal Curve Design For Braking And Cornering

Applicability

A horizontal curve review procedure for the adequacy of cornering and braking friction is applied in IDRM wherever there is a horizontal curve on an intersection approach within the influence area of the intersection for the direction of travel leading toward the intersection. The purpose of this procedure is to determine whether the combination of braking and cornering that may occur when an intersection is on or near a curve is likely to result in vehicle loss of control due to skidding.

Basis

Horizontal curves are designed to ensure that a driver can not only traverse a horizontal curve (i.e., make a cornering maneuver) without loss of control, but also do so within tolerable limits of lateral acceleration that have been set to ensure driver comfort. The compliance of any horizontal curve with these tolerable limits of lateral acceleration is checked by the PRM.

Where an intersection is located in a horizontal curve or a horizontal curve is present on the intersection approach, the ability of an approaching driver to brake in response to the actions of other vehicles approaching the intersection is reduced because the driver may be simultaneously braking and cornering.

The purpose of this procedure is to determine whether the combination of braking and cornering that may occur when an intersection is on or near a curve is likely to result in loss of vehicle control due to skidding. Checks for such combinations of braking and cornering are not addressed by the PRM and, therefore, are included in IDRM.

Input Parameters

- V_{act} - actual 85th percentile speed of traffic
- SN_{40} - skid number at 64 km/h (40 mi/h) [assumed value = 35]
- e - superelevation rate for horizontal curve
- R - radius (m)

The source of data for those input parameters whose values are not specified above are as follows:

- V_{act} - data file or user query
- e - roadway file
- R - roadway file

Evaluation Procedure

The specific procedure will be formulated as follows:

1. Determine V_{act}, the actual 85th percentile speed of traffic on the selected major-road approach. V_{act} can be determined from field data, from a speed prediction model like those developed for the IHSDM design consistency module, or from engineering judgment by the user. The objective is to base the value of V_{act}, to the maximum possible extent, on actual field conditions rather than on an arbitrary design speed.

2. Estimate the available coefficient of cornering friction (f_{cor}) for wet-pavement conditions at V_{act} as:

$$f_{cor} = 1.45\frac{SN_{40}}{100}\exp(-0.00715(V_{act} - 64))$$ Equation 3.21.1

The estimated value of SN_{40}, the skid number at 64 km/h (40 mi/h), should be 35. This value is consistent with revised AASHTO criteria for SSD design.

3. Estimate the maximum braking friction demand (f_{brake}) at V_{act} as:

$$f_{brake} = \frac{SN_{40}}{100}e^{-0.00715(V_{act} - 64)}$$ Equation 3.21.2

U.S. Department of Transportation
Federal Highway Administration

The estimated value of SN_{40} for this application should also be 35.

4. Determine the speed at impending skid (V_{skid}) for combined cornering and braking on wet pavement:

$$V_{skid} = \sqrt{127R((f_{cor}{}^2 - f_{brake}{}^2)^{0.5} + e)}$$ Equation 3.21.3

where:

e = superelevation rate for horizontal curve

5. Compute the margin of safety (V_{ms}) as V_{skid} - V_{act}, procedures to compare VMS to appropriate threshold values are presented in Section 4.27.

Model Output

The model output is the speed margin of safety against skidding, VMS The criticality of VMS is judged by comparison to threshold values as described in Section 4.27.

References

1. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994.

IDRM CONCERNS

"Concerns" are the potential problem areas that IDRM is capable of evaluating. Twenty-seven concerns were defined for the initial knowledge base. These concerns are summarized in Table 3. This section provides a detailed description of each concern and specifies how each concern is evaluated by means of IDRM models. Threshold values are given for identification of each concern at Level 1 and Level 2.

4.1 Insufficient Intersection Sight Distance

Description

At every intersection, even where no horizontal or vertical curves are present, roadside sight obstructions can limit intersection sight distance (ISD). The ability of a driver on the major road to see the intersection is critical, as is the ability of a driver stopped on the minor approach to view the major road. In both cases, this view can be compromised or obstructed by roadside obstructions.

Concern Type

Leg concern

Geometric Elements Involved

- Cross-slope of the major-road pavement.
- Lane width of major road.
- Grade of minor road.
- Approach grade.
- Traffic volume levels.

Associated Accident Types

The following accident types are associated with insufficient ISD on intersection approaches:

- Rear-end collision.
- Angle collision.

Model(s) Used

The models used to determine if there is sufficient ISD at an intersection are the ISD models presented in Sections 3.1 through 3.4 . Where no complicating factors such as horizontal or vertical curves are present, the value of $\Delta t$is zero.

Evaluation Variable

The variable used to evaluate ISD is V_{eff}, the effective speed for which ISD is provided.

Another variable used to evaluate ISD is the user's response (YES/NO) to the question concerning whether the sight triangles shown in Figure 3in Section 3.1 are clear.

Evaluation Procedure

The procedure presented here should be applied to both vertical and horizontal sight obstructions for each ISD case listed below in the section entitled "Concern Statement Message." The entire algorithm is presented here for completeness, but Steps 1 and 2 do not apply to this concern. The models used for these checks are those presented in Sections 3.1 through 3.4.

1. Compute the threshold ISD for a Level 1 advisory condition (ISD_1) as:

$$ISD_1 = 0.278(V_{act} - X)(t_c + \Delta t) \qquad \text{Equation 4.1.1}$$

where:

X = 10 km/h (if ADT ≥ 5,000 veh/day) or 25 km/h (if ADT < 5,000 veh/day)
Δt = __ [to be determined]

2. Compute the threshold ISD for a Level 2 advisory condition (ISD_2) as:

$$ISD_2 = 0.278(V_{act} - X)(t_c + \Delta t) \qquad \text{Equation 4.1.2}$$

where:

X = 0 km/h (independent of ADT)
Δt = __ [to be determined]

3. The following checks should be applied for horizontal sight obstructions:

- Is Region 1 clear of roadside sight obstructions?
  - – If response is NO, then LEVEL 1 ADVISORY applies for horizontal sight obstructions. Proceed to Step 4.
  - – If response is YES, then proceed to next question.
- Is Region 2 clear of roadside sight obstructions?
  - – If response is NO, then LEVEL 2 ADVISORY applies. Proceed to Step 4.
  - – If response is YES, proceed to Step 4.

4. If either a LEVEL 1 ADVISORY or LEVEL 2 ADVISORY is triggered based on Step 3, since no horizontal curve is present within the applicable distance to the left or right of the intersection, as appropriate to the ISD case being evaluated, then no postscript should be included after the advisory message.

5. Display and/or record the appropriate safety advisory message.

Threshold Values

Table 20. Tentative Threshold Values and Types of Safety Advisory Messages for Evaluation of ISD

ADT Level	$ISD_{avail} < ISD_{des}$			$ISD_{avail} \geq ISD_{des}$
	$V_{eff} \leq V_{act} - 25$	$V_{act} - 25 < V_{eff} \leq V_{act} - 10$	$V_{act} - 10$ $V_{eff} < V_{act}$	
≥ 5,000 veh/day	Level 1 advisory	Level 1 advisory	Level 2 advisory	OK
< 5,000 veh/day	Level 1 advisory	Level 2 advisory	Level 2 advisory	OK

Concern Statement Message

Insufficient ISD to right (Case B1) for ___ leg

Insufficient ISD to left (Case B2) for ___ leg

Insufficient ISD to right (Case B3) for ___ leg

Insufficient ISD to left (Case B3) for ___ leg

Insufficient ISD for left turn from major road (Case F) for ___ leg

Basis

The thresholds are based on the judgment of the expert team.

Supplementary Information for the User

None known at this time.

References

1. Harwood, D.W., J. Mason, R. Brydia, M. Pietrucha, and G. Gittings. *Intersection Sight Distance*, NCHRP Report 383. Transportation Research Board, Washington, DC, 1996.
2. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994.

4.2 Insufficient Intersection Sight Distance For Intersection On A Horizontal Curve

Description

The presence of a horizontal curve on an intersection approach represents an additional risk beyond that of a typical intersection. Two issues related to ISD include:

- Increased probability of roadside sight obstructions.
- Difficult turning maneuvers.

•

Increased Probability of Roadside Sight Obstructions

The ability of a driver on the major road to see the intersection is critical, as is the ability of a driver stopped on the minor approach to view the major road. In both cases, this view can be compromised or obstructed along the inside of the curve due to roadside obstructions, or even normal slopes. The likelihood and severity of this problem increase with the sharpness of the curve. Also, for curves that are long and for intersections located at the middle of the curve, the severity of this problem may be greater.

Difficult Turning Maneuvers

The presence of a curve through an intersection can create difficult or awkward turning maneuvers for drivers and vehicles. These include acute-angle right turns such as those that occur at skewed intersections. They also include "reverse path" turns, i.e., those in which the vehicle tracking the main road is turning in one direction, with the turning movement (either left or right) in the opposing direction. This reverse turning movement can be further exacerbated if the mainline curve is significantly superelevated and the vehicle must turn against the superelevation. Such awkward turns may take longer to complete, increasing the exposure of the vehicle to conflict. In the extreme, such turns by heavy vehicles or those with a high center of gravity may lead to loss of control.

Concern Type

Leg concern

Geometric Elements Involved

- Cross-slope of the major-road pavement.
- Lane width of major road.
- Grade of minor road.
- Approach grade.
- Traffic volume levels.

Associated Accident Types

The following accident types are associated with insufficient ISD for a horizontal curve:

- Rear-end collision.
- Head-on collision.
- Angle collision.

Model(s) Used

The models used to determine if there is sufficient ISD for a horizontal curve are the ISD models presented in Sections 3.1 through 3.4, with additional time, Δt_c, being added to the time gaps.

Evaluation Variable

The variable used to evaluate ISD for a horizontal curve is V_{eff}, the effective speed for which ISD is provided.

Another variable used to evaluate ISD for a horizontal curve is the user's response (YES/NO) to the question concerning whether the sight triangles shown in Figure 3 in Section 3.1 are clear.

Evaluation Procedure

The procedure presented here should be applied to both vertical and horizontal sight obstructions for each ISD case listed below in the section entitled "Concern Statement Message." The entire algorithm is presented here for completeness, but Steps 1 and 2 do not apply to this concern. The models used for these checks are those presented in Sections 3.1 through 3.4 .

1. Compute the threshold ISD for a Level 1 advisory condition (ISD_1) as:

$$ISD_1 = 0.278(V_{act} - X)(t_c + \Delta t) \qquad \text{Equation 4.2.1}$$

where:

X = 10 km/h (if ADT ≥ 5,000 veh/day) or 25 km/h (if ADT < 5,000 veh/day)
Δt = __ [to be determined]

2. Compute the threshold for an ISD Level 2 advisory condition (ISD_2) as:

$$ISD_2 = 0.278(V_{act} - X)(t_c + \Delta t) \qquad \text{Equation 4.2.2}$$

where:

X = 0 km/h (independent of ADT)
Δt = __ [to be determined]

3. The following checks should be applied for horizontal sight obstructions:

- Is Region 1 clear of roadside sight obstructions?
  - – If response is NO, then LEVEL 1 ADVISORY applies for horizontal sight obstructions. Proceed to Step 4.
  - If response is YES, then proceed to next question.
- Is Region 2 clear of roadside sight obstructions?
  - – If response is NO, then LEVEL 2 ADVISORY applies. Proceed to Step 4.
  - – If response is YES, proceed to Step 4.

4. If either a LEVEL 1 ADVISORY or LEVEL 2 ADVISORY is triggered based on Step 3, and a horizontal curve is present within the applicable distance to the left or right of the intersection, as appropriate to the ISD case being evaluated, then the postscript "- horizontal curve" should be included after the advisory message.

5. If either a LEVEL 1 ADVISORY or LEVEL 2 ADVISORY is triggered based on Step 3, but no horizontal curve is present within the applicable distance to the left or right of the intersection, as appropriate to the ISD case being evaluated, then no postscript should be included after the advisory message.

6. Display and/or record the appropriate safety advisory message.

Threshold Values

Threshold values can be found in Table 20 in Section 4.1.

Concern Statement Message

Insufficient ISD to right (Case B1) for ___ leg
- horizontal curve

Insufficient ISD to left (Case B2) for ___ leg
- horizontal curve

Insufficient ISD to right (Case B3) for ___ leg
- horizontal curve

Insufficient ISD to left (Case B3) for ___ leg
- horizontal curve

Insufficient ISD for left turn from major road (Case F) for ___ leg
- horizontal curve

Basis

The thresholds are based on the judgment of the expert team.

Supplementary Information for the User

None known at this time.

References

1. Harwood, D.W., J. Mason, R. Brydia, M. Pietrucha, and G. Gittings. *Intersection Sight Distance*, NCHRP Report 383. Transportation Research Board, Washington, DC, 1996.
2. *A Policy on Geometric Design of Highways and Streets*. American Association of State Highway and Transportation Officials, Washington, DC, 1994.

4.3 Insufficient Intersection Sight Distance For A Horizontal Curve On An Intersection Approach

Description

The presence of a horizontal curve on an intersection approach represents an additional risk beyond that of a typical intersection. This scenario is similar to the scenario of an intersection on a horizontal curve, which was previously discussed. Both scenarios have an increased probability of roadside sight obstructions.

Concern Type

Leg concern

Geometric Elements Involved

- Cross-slope of the major-road pavement.
- Lane width of major road.
- Grade of minor road.
- Approach grade.
- Traffic volume levels.

Associated Accident Types

The following accident types are associated with insufficient ISD for a horizontal curve on an intersection approach:

- Rear-end collision.
- Head-on collision.
- Angle collision.

Model(s) Used

The models used to determine if there is sufficient ISD for a horizontal curve are the ISD models presented in Sections 3.1 through 3.4, with additional time, Δt_c, being added to the time gaps.

Evaluation Variable

The variable used to evaluate ISD for a horizontal curve on an intersection approach is V_{eff}, the effective speed for which ISD is provided.

Another variable used to evaluate ISD for this scenario is the user's response (YES/NO) to the question concerning whether the sight triangles shown in Figure 3 in Section 3.1 are clear.

Evaluation Procedure

The procedure presented here should be applied to both vertical and horizontal sight obstructions for each ISD case listed below in the section entitled "Concern Statement Message." The entire algorithm is presented here for completeness, but Steps 1 and 2 do not apply to this concern. The models used for these checks are those presented in Sections 3.1 through 3.4.

1. Compute the threshold ISD for a Level 1 advisory condition (ISD_1) as:

$$ISD_1 = 0.278\left(V_{act} - X\right)\left(t_c + \Delta t\right) \qquad \text{Equation 4.3.1}$$

where:

X = 10 km/h (if ADT ≥ 5,000 veh/day) or 25 km/h (if ADT < 5,000 veh/day)

Δt = __ [to be determined]

2. Compute the threshold for an ISD_2 Level 2 advisory condition (ISD2) as:

$$ISD_2 = 0.278(V_{act} - X)(t_c + \Delta t) \qquad \text{Equation 4.3.2}$$

where:

X = 0 km/h (independent of ADT)
Δt = __ [to be determined]

3. The following checks should be applied for horizontal sight obstructions:

Is Region 1 clear of roadside sight obstructions?

If response is NO, then LEVEL 1 ADVISORY applies for horizontal sight obstructions. Proceed to Step 4.

If response is YES, then proceed to next question.

Is Region 2 clear of roadside sight obstructions?

If response is NO, then LEVEL 2 ADVISORY applies. Proceed to Step 4.

If response is YES, proceed to Step 4.

4. If either a LEVEL 1 ADVISORY or LEVEL 2 ADVISORY is triggered based on Step 3, and a horizontal curve is present within the applicable distance to the left or right of the intersection, as appropriate to the ISD case being evaluated, then the postscript "- horizontal curve" should be included after the advisory message.

5. If either a LEVEL 1 ADVISORY or LEVEL 2 ADVISORY is triggered based on Step 3, but no horizontal curve is present within the applicable distance to the left or right of the intersection, as appropriate to the ISD case being evaluated, then no postscript should be included after the advisory message.

6. Display and/or record the appropriate safety advisory message.

Threshold Values

Threshold values can be found in Table 20 in Section 4.1.

Concern Statement Message

Insufficient ISD to right (Case B1) for ___ leg
- horizontal curve

Insufficient ISD to left (Case B2) for ___ leg
- horizontal curve

Insufficient ISD to right (Case B3) for ___ leg
- horizontal curve

Insufficient ISD to left (Case B3) for ___ leg
- horizontal curve

Insufficient ISD for left turn from major road (Case F) for ___ leg
- horizontal curve

Basis

The thresholds are based on the judgment of the expert team.

Supplementary Information for the User

None known at this time.

References

Harwood, D.W., J. Mason, R. Brydia, M. Pietrucha, and G. Gittings. *Intersection Sight Distance*, NCHRP Report 383. Transportation Research Board, Washington, DC, 1996.

A Policy on Geometric Design of Highways and Streets (Green Book). American Association of State Highway and Transportation Officials, Washington, DC, 1994.

4.4 Insufficient Intersection Sight Distance For Intersection On Approaches To Crest Vertical Curve

Description

The presence of a crest vertical curve on an intersection approach represents an additional risk beyond that of a typical intersection. Two potential problems related to ISD that can occur at intersections on crest vertical curves include:

- Through traffic on major road may be hidden from view of driver on minor-road approach.
- Approaching drivers in the opposite direction of travel may be hidden from the view of drivers stopped to make a left turn on a major-road approach.

Concern Type

Leg concern

Geometric Elements Involved

- Local grade.
- Length of vertical curve.

Associated Accident Types

The following accident types are associated with insufficient ISD for an intersection on an approach to a crest vertical curve:

- Rear-end collision.
- Head-on collision.

- Angle collision.

Model(s) Used

The models used to determine if there is sufficient ISD for intersections on an approach to a vertical curve are the ISD models presented in Sections 3.1 through 3.4 , with additional time, Δt_c, being added to the time gaps.

Evaluation Variable

The variable used to evaluate ISD for intersections on an approach to a vertical curve is V_{eff}, the effective speed for which ISD is provided.

Another variable used to evaluate ISD for this scenario is the user's response (YES/NO) to the question concerning whether the sight triangles shown in Figure 3 in Section 3.1 are clear.

Evaluation Procedure

The procedure presented here should be applied to both vertical and horizontal sight obstructions for each ISD case listed below in the section entitled "Concern Statement Message." The models used for these checks are those presented in Sections 3.1 through 3.4.

1. Compute the threshold ISD for a Level 1 advisory condition (ISD_1) as:

$$ISD_1 = 0.278(V_{act} - X)(t_c + \Delta t) \quad \text{Equation 4.4.1}$$

where:

X = 10 km/h (if ADT ≥ 5,000 veh/day) or 25 km/h (if ADT < 5,000 veh/day)
Δt = __ [to be determined]

2. Compute the treshold for an ISD Level 2 advisory condition (ISD_2) as:

$$ISD_2 = 0.278(V_{act} - X)(t_c + \Delta t) \quad \text{Equation 4.4.2}$$

where:

X = 0 km/h (independent of ADT)
Δt = __ [to be determined]

3. If $ISD_{vert} \leq ISD_1$, then LEVEL 1 ADVISORY applies for vertical sight obstructions.

If $ISD_{vert} > ISD_1$ and $ISD_{vert} \leq ISD_2$, then LEVEL 2 ADVISORY applies for vertical sight obstructions.

4. If either a LEVEL 1 ADVISORY or LEVEL 2 ADVISORY is triggered based on Step 3, then the postscript "- crest vertical curve" should be included after the advisory message.

5. Display and/or record the appropriate safety advisory message.

Threshold Values

Threshold values can be found in Table 20 in Section 4.1.

Concern Statement Message

Insufficient ISD to right (Case B1) for ___ leg
- crest vertical curve

Insufficient ISD to left (Case B2) for ___ leg
- crest vertical curve

Insufficient ISD to right (Case B3) for ___ leg
- crest vertical curve

Insufficient ISD to left (Case B3) for ___ leg
- crest vertical curve

Insufficient ISD for left turn from major road (Case F) for ___ leg
- crest vertical curve

Basis

The thresholds are based on the judgment of the expert team.

Supplementary Information for the User

None known at this time.

References

Harwood, D.W., J. Mason, R. Brydia, M. Pietrucha, and G. Gittings. *Intersection Sight Distance*, NCHRP Report 383. Transportation Research Board, Washington, DC, 1996.

A Policy on Geometric Design of Highways and Streets (Green Book). American Association of State Highway and Transportation Officials, Washington, DC, 1994.

4.5 Insufficient Intersection Sight Distance For Multileg Intersection

Description

Multileg intersections are those with five or more intersection legs. The inclusion of additional approach(es) to an intersection represents an additional risk beyond that of a typical four-leg intersection. A multileg intersection may violate driver expectancy and present an additional burden to the driver's decision-making process. For example, drivers may have difficulty perceiving the correct route to follow.

Concern Type

Leg concern

Geometric Elements Involved

- Local grade.
- Length of vertical curve.
- Length of horizontal curve.
- Radius of horizontal curve.
- Lane width.
- Clear sight width available on the inside of the horizontal curve.

Associated Accident Types

The following accident types are associated with insufficient ISD for a multileg intersection:

- Rear-end collision.
- Head-on collision.
- Angle collision.

Model(s) Used

The models used to determine if there is sufficient ISD for a multileg intersection are the ISD models presented in Sections 3.1 through 3.4 , with additional time, Δt_c, being added to the time gaps.

Evaluation Variable

The variable used to evaluate ISD for a multileg intersection is V_{eff}, the effective speed for which ISD is provided.

Another variable used to evaluate ISD for a multileg intersection is the user's response (YES/NO) to the question concerning whether the sight triangles shown in Figure 3 in Section 3.1 are clear.

Evaluation Procedure

The procedure presented here should be applied to both vertical and horizontal sight obstructions for each ISD case listed below in the section entitled "Concern Statement Message." The models used for these checks are those presented in Sections 3.1 through 3.4.

1. Compute the threshold ISD for a Level 1 advisory condition (ISD_1) as:

$$ISD_1 = 0.278(V_{act} - X)(t_c + \Delta t) \quad \text{Equation 4.5.1}$$

where:

X = 10 km/h (if ADT ≥ 5,000 veh/day) or 25 km/h (if ADT < 5,000 veh/day)
Δt = __ [to be determined]

2. Compute the threshold for an ISD Level 2 advisory condition (ISD_2) as:

$$ISD_2 = 0.278(V_{act} - X)(t_c + \Delta t) \quad \text{Equation 4.5.2}$$

where:

X = 0 km/h (independent of ADT)
Δt = __ [to be determined]

3. If $ISD_{vert} \le ISD_1$, then LEVEL 1 ADVISORY applies for vertical sight obstructions.

If $ISD_{vert} > ISD_1$ and $ISD_{vert} \le ISD_2$, then LEVEL 2 ADVISORY applies for vertical sight obstructions.

4. The following checks should be applied for horizontal sight obstructions:

- Is Region 1 clear of roadside sight obstructions?
    - If response is NO, then LEVEL 1 ADVISORY applies for horizontal sight obstructions. Proceed to Step 5.
    - If response is YES and $ISD_{vert} < ISD_1$, then LEVEL 2 ADVISORY applies.
    - If response is YES, then proceed to the next question.
- Is Region 2 clear of roadside sight obstructions?
    - If response is NO, then LEVEL 2 ADVISORY applies. Proceed to Step 5.
    - If response is YES, proceed to Step 5.

5. The more critical of the results from Steps 3 and 4 should be selected as follows:

- If either Step 3 or Step 4 indicates a LEVEL 1 ADVISORY, then a LEVEL 1 ADVISORY applies.
- If neither Step 3 nor Step 4 indicates a LEVEL 1 ADVISORY, but either Step 3 or Step 4 indicates a LEVEL 2 ADVISORY, then a LEVEL 2 ADVISORY applies.
- If neither Step 3 nor Step 4 indicates any advisory, then no advisory applies.

6. If either a LEVEL 1 ADVISORY or a LEVEL 2 ADVISORY is triggered based on Step 3, then the postscripts "- crest vertical curve" and "- multileg intersection" should be included after the advisory message.

7. If either a LEVEL 1 ADVISORY or a LEVEL 2 ADVISORY is triggered based on Step 4 and a horizontal curve is present within the applicable distance to the left or right of the intersection, as appropriate to the ISD case being evaluated, then the postscripts "- crest vertical curve" and "- multileg intersection" should be included after the advisory message.

8. If either a LEVEL 1 ADVISORY or a LEVEL 2 ADVISORY is triggered based on Step 4, but no horizontal curve is present within the applicable distance to the left or right of the intersection, as appropriate to the ISD case being evaluated, then the postscript "- multileg intersection" should be included after the advisory message.

9. Display and/or record the appropriate safety advisory message.

Threshold Values

Threshold values can be found in Table 20 in Section 4.1 .

Concern Statement Message

Insufficient ISD to right (Case B1) for ___ leg
- multileg intersection

Insufficient ISD to left (Case B2) for ___ leg
- multileg intersection

Insufficient ISD to right (Case B3) for ___ leg
- multileg intersection

Insufficient ISD to left (Case B3) for ___ leg
- multileg intersection

Insufficient ISD for left turn from major road (Case F) for ___ leg
- multileg intersection

These concerns may include other hyphenated postscripts as noted in Steps 6 and 7 above.

Basis

The thresholds are based on the judgment of the expert team.

Supplementary Information for the User

None known at this time.

References

1. Harwood, D.W., J. Mason, R. Brydia, M. Pietrucha, and G. Gittings. *Intersection Sight Distance*, NCHRP Report 383. Transportation Research Board, Washington, DC, 1996.
2. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 2001.

4.6 Insufficient Intersection Sight Distance For Intersections With More Than One Minor-Road Approach On The Same Side Of The Major Road

Description

Intersections with more than one minor-road approach on the same side of the major road represent an additional risk beyond that of a typical four-leg intersection. The additional minor-road approach may be confusing to some drivers. For example, the priority of movements is unclear for minor-road approaches and drivers may have difficulty perceiving the correct route to follow.

Concern Type

Leg concern

Geometric Elements Involved

- Local grade.
- Length of vertical curve.
- Length of horizontal curve.
- Radius of horizontal curve.
- Lane width.
- Clear sight width available on the inside of the horizontal curve.

Associated Accident Types

The following accident types are associated with insufficient ISD for intersections with more than one minor-road approach:

- Rear-end collision.
- Head-on collision.
- Angle collision.

Model(s) Used

The models used to determine if there is sufficient ISD for intersections with more than one minor-road approach on the same side of the major road are the ISD models presented in Sections 3.1 through 3.4, with additional time, Δt_c, being added to the time gaps.

Evaluation Variable

The variable used to evaluate ISD for intersections with more than one minor-road approach on the same side of the major road is V_{eff}, the effective speed for which ISD is provided.

Another variable used to evaluate ISD for this scenario is the user's response (YES/NO) to the question concerning whether the sight triangles shown in Figure 3 in Section 3.1 are clear.

Evaluation Procedure

The procedure presented here should be applied to both vertical and horizontal sight obstructions for each ISD case listed below in the section entitled "Concern Statement Message." The models used for these checks are those presented in Sections 3.1 through 3.4.

1. Compute the threshold ISD for a Level 1 advisory condition (ISD_1) as:

$$ISD_1 = 0.278\left(V_{act} - X\right)\left(t_c + \Delta t\right) \qquad \text{Equation 4.6.1}$$

where:

X = 10 km/h (if ADT ≥ 5,000 veh/day) or 25 km/h (if ADT < 5,000 veh/day)
Δt = __ [to be determined]

2. Compute the threshold for an ISD Level 2 advisory condition (ISD_2) as:

$$ISD_2 = 0.278\left(V_{act} - X\right)\left(t_c + \Delta t\right) \qquad \text{Equation 4.6.2}$$

where:

X = 0 km/h (independent of ADT)
Δt = __ [to be determined]

3. If $ISD_{vert} \le ISD_1$, then LEVEL 1 ADVISORY applies for vertical sight obstructions.

4. If $ISD_{vert} > ISD_1$ and $ISD_{vert} \le$ □ ISD_2, then LEVEL 2 ADVISORY applies for vertical sight obstructions.

- Is Region 1 clear of roadside sight obstructions?

- If response is NO, then LEVEL 1 ADVISORY applies for horizontal sight obstructions. Proceed to Step 5.
- If response is YES and $ISD_{vert} < ISD_1$, then LEVEL 2 ADVISORY applies.
- If response is YES, then proceed to the next question.

- Is Region 2 clear of roadside sight obstructions?
  - If response is NO, then LEVEL 2 ADVISORY applies. Proceed to Step 5.
  - If response is YES, proceed to Step 5.

5. The more critical of the results from Steps 3 and 4 should be selected, as follows:

- If either Step 3 or 4 indicates a LEVEL 1 ADVISORY, then a LEVEL 1 ADVISORY applies.
- If neither Step 3 nor Step 4 indicates a LEVEL 1 ADVISORY, but either Step 3 or Step 4 indicates a LEVEL 2 ADVISORY, then a LEVEL 2 ADVISORY applies.
- If neither Step 3 nor Step 4 indicates any advisory, then no advisory applies.

6. If either a LEVEL 1 ADVISORY or LEVEL 2 ADVISORY is triggered based on Step 3, then the postscripts "- crest vertical curve" and "- more than one minor-road approach on the same side of the major road" should be included after the advisory message.

7. If either a LEVEL 1 ADVISORY or LEVEL 2 ADVISORY is triggered based on Step 4, and a horizontal curve is present within the applicable distance to the left or right of the intersection, as appropriate to the ISD case being evaluated, then the postscripts "- horizontal curve" and "- more than one minor-road approach on the same side of the major road" should be included after the advisory message.

8. If either a LEVEL 1 ADVISORY or LEVEL 2 ADVISORY is triggered based on Step 4, but no horizontal curve is present within the applicable distance to the left or right of the intersection, as appropriate to the ISD case being evaluated, then the postscript "- more than one minor-road approach on the same side of the major road" should be included after the advisory message.

9. Display and/or record the appropriate safety advisory messages.

Threshold Values

Threshold values can be found in Table 20 in Section 4.1.

Concern Statement Message

Insufficient ISD to right (Case B1) for ___ leg
- more than one minor-road approach on the same side of the major road

Insufficient ISD to left (Case B2) for ___ leg
- more than one minor-road approach on the same side of the major road

Insufficient ISD to right (Case B3) for ___ leg
- more than one minor-road approach on the same side of the major road

Insufficient ISD to left (Case B3) for ___ leg
- more than one minor-road approach on the same side of the major road

Insufficient ISD for left turn from major road (Case F) for ___ leg
- more than one minor-road approach on the same side of the major road

Basis

The thresholds are based on the judgment of the expert team.

Supplementary Information for the User

None known at this time.

References

Harwood, D.W., J. Mason, R. Brydia, M. Pietrucha, and G. Gittings. *Intersection Sight Distance*, NCHRP Report 383. Transportation Research Board, Washington, DC, 1996.

A Policy on Geometric Design of Highways and Streets (Green Book). American Association of State Highway and Transportation Officials, Washington, DC, 2001.

4.7 Insufficient Intersection Sight Distance For Skewed Intersections

Description

When two highways intersect at an angle of less than 90 degrees, some of the factors for determination of intersection sight distance may need adjustment. For skewed intersections, the ISD model should be used to determine whether through traffic on the major road would be hidden from the view of a driver stopped on the minor-road approach at a skewed intersection.

Concern Type

Leg concern

Geometric Elements Involved

- Cross-slope of the major-road pavement.
- Lane width of major road.
- Grade of minor road.
- Approach grade.
- Traffic volume levels.

Associated Accident Types

The following accident types are associated with insufficient ISD for skewed intersections:

- Rear-end collision.
- Head-on collision.
- Angle collision.

Model(s) Used

The models used to determine if there is sufficient ISD for skewed intersections are the ISD models presented in Sections 3.1 through 3.4 , with additional time, Δt_c, being added to the time gaps.

The legs of the sight triangles will lie along the intersection approaches and each sight triangle will be larger or smaller than the corresponding sight triangle would be at a right-angle intersection. The area within each sight triangle should be clear of potential sight obstructions. At an oblique-angle intersection, the length of the travel paths for some turning and crossing maneuvers will be increased and additional time to assess a turning maneuver may be required.

In the obtuse-angle quadrant of an oblique-angle intersection, the angle between the approach leg and the sight line is often so small that drivers can look across the full sight triangle with only a small head movement. However, in the acute-angle quadrant, drivers are often required to turn their heads considerably to see across the entire clear sight triangle.

Evaluation Variable

The variable used to evaluate ISD for skewed intersections is V_{eff}, the effective speed for which ISD is provided.

Another variable used to evaluate ISD for skewed intersections is the user's response (YES/NO) to the question concerning whether the sight triangles shown in Figure 3 in Section 3.1 are clear.

Evaluation Procedure

The procedure presented here should be applied to both vertical and horizontal sight obstructions for each ISD case listed below in the section entitled "Concern Statement Message." The models used for these checks are those presented in Sections 3.1 through 3.4.

1. Compute the threshold ISD for a Level 1 advisory condition (ISD_1) as:

$$ISD_1 = 0.278\left(V_{act} - X\right)\left(t_c + \Delta t\right) \quad \text{Equation 4.7.1}$$

where:

X = 10 km/h (if ADT ≥ 5,000 veh/day) or 25 km/h (if ADT < 5,000 veh/day)
Δt = __ [to be determined]

2. Compute the threshold for an ISD Level 2 advisory condition (ISD_2) as:

$$ISD_2 = 0.278\left(V_{act} - X\right)\left(t_c + \Delta t\right) \quad \text{Equation 4.7.2}$$

where:

X = 0 km/h (independent of ADT)
Δt = __ [to be determined]

3. If $ISD_{vert} \le ISD_1$, then LEVEL 1 ADVISORY applies for vertical sight obstructions.

If $ISD_{vert} > ISD_1$ and $ISD_{vert} \le ISD_2$, then LEVEL 2 ADVISORY applies for vertical sight obstructions.

4. The following checks should be applied for horizontal sight obstructions:

- Is Region 1 clear of roadside sight obstructions?
  - If response is NO, then LEVEL 1 ADVISORY applies for horizontal sight obstructions. Proceed to Step 5.
  - If response is YES, then proceed to the next question.
- Is Region 2 clear of roadside sight obstructions?
  - – If response is NO, then LEVEL 2 ADVISORY applies. Proceed to Step 5.
  - – If response is YES, proceed to Step 5.

5. The more critical of the results from Steps 3 and 4 should be selected as follows:

- If either Step 3 or Step 4 indicates a LEVEL 1 ADVISORY, then a LEVEL 1 ADVISORY applies.
- If neither Step 3 nor Step 4 indicates a LEVEL 1 ADVISORY, but either Step 3 or Step 4 indicates a LEVEL 2 ADVISORY, then a LEVEL 2 ADVISORY applies.
- If neither Step 3 nor Step 4 indicates any advisory, then no advisory applies.

6. If either a LEVEL 1 ADVISORY or a LEVEL 2 ADVISORY is triggered based on Step 3, then the postscripts "- crest vertical curve" and "- multileg intersection" should be included after the advisory message.

7. If either a LEVEL 1 ADVISORY or a LEVEL 2 ADVISORY is triggered based on Step 4 and a horizontal curve is present within the applicable distance to the left or right of the intersection, as appropriate to the ISD case being evaluated, then the postscripts "- crest vertical curve" and "- multileg intersection" should be included after the advisory message.

8. If either a LEVEL 1 ADVISORY or a LEVEL 2 ADVISORY is triggered based on Step 4, but no horizontal curve is present within the applicable distance to the left or right of the intersection, as appropriate to the ISD case being evaluated, then the postscript "- multileg intersection" should be included after the advisory message.

9. Display and/or record the appropriate safety advisory message.

Threshold Values

Threshold values can be found in Table 20 in Section 4.1.

Concern Statement Message

Insufficient ISD to right (Case B1) for ___ leg
- skewed intersection

Insufficient ISD to left (Case B2) for ___ leg
- skewed intersection

Insufficient ISD to right (Case B3) for ___ leg
- skewed intersection

Insufficient ISD to left (Case B3) for ___ l
- skewed intersection

Insufficient ISD for left turn from major road (Case F) for ___ leg
- skewed intersection

Basis

The thresholds are based on the judgment of the expert team.

Supplementary Information for the User

None known at this time.

References

1. Harwood, D.W., J. Mason, R. Brydia, M. Pietrucha, and G. Gittings. *Intersection Sight Distance*, NCHRP Report 383. Transportation Research Board, Washington, DC, 1996.
2. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 2001.

4.8 Insufficient Stopping Sight Distance For A Crest Vertical Curve On An Intersection Approach

Description

The presence of a crest vertical curve on an intersection approach represents an additional risk beyond that of a typical intersection. The crest vertical curve may hide the intersection or vehicles at the intersection from the driver's view.

Concern Type

Leg concern

Geometric Elements Involved

- Local grade.
- Length of vertical curve.

Associated Accident Types

The following accident types are associated with insufficient SSD for a crest vertical curve on an intersection approach:

- Rear-end collision.
- Head-on collision.
- Angle collision.

Model(s) Used

The model used to determine if there is sufficient SSD for a crest vertical curve is the SSD model presented in Section 3.5.

Evaluation Variable

The variable used to evaluate SSD for a crest vertical curve on an intersection approach is V_{eff}, the effective speed for which SSD is provided.

Evaluation Procedure

Assess the criticality of any SSD deficiency by the difference between V_{act} and V_{eff}. If the intersection in question is a multileg intersection or has more than one minor-road leg on the same side of the major road, and if these conditions have led to advisory messages based on other models, then use an appropriate value of Δt in the determination of V_{eff}. Table 21 presents the recommended threshold values and the types of safety advisory messages to be issued.

Threshold Values

Threshold values can be found in Table 21 in Section 4.9.

Concern Statement Message

Insufficient SSD for ___ leg
- crest vertical curve

If the above message is triggered and the intersection in question is a multileg intersection or has more than one minor-road approach on the same side of the major road, then add the appropriate postscript(s) to the advisory:

- multileg intersection
- more than one minor-road approach on the same side of the major road

Basis

The thresholds are based on the judgment of the expert team.

Supplementary Information for the User

None known at this time.

References

1. Fambro, D.B., R. Koppa, and K. Fitzpatrick. *Determination of Stopping Sight Distances*, NCHRP Report 400. Transportation Research Board, Washington, DC, 1997.
2. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994.

4.9 Insufficient Stopping Sight Distance For A Horizontal Curve On An Intersection Approach

Description

The presence of a horizontal curve on an intersection approach represents an additional risk beyond that of a typical intersection. The horizontal curve presents an increased probability of roadside sight obstructions that hide the intersection or vehicles at the intersection from the driver's view.

Concern Type

Leg concern

Geometric Elements Involved

- Local grade.
- Length of horizontal curve.
- Radius of horizontal curve.
- Lane width.
- Clear sight width available on the inside of the horizontal curve.

Associated Accident Types

The following accident types are associated with insufficient SSD for a horizontal curve on an intersection approach:

- Rear-end collision.
- Head-on collision.
- Angle collision.

Model(s) Used

The model used to determine if there is sufficient SSD for a horizontal curve is the SSD model presented in Section 3.6.

Evaluation Variable

The variable used to evaluate SSD for a horizontal curve on an intersection approach is V_{eff}, the effective speed for which SSD is provided.

Evaluation Procedure

1. Assess the criticality of any SSD deficiency by comparing V_{eff} and V_{act}. If the intersection in question is a multileg intersection or has more than one minor-road leg on the same side of the major road, and if these conditions have led to advisory messages based on other models, then use an appropriate value of Δt in the determination of V_{eff}. Table 21 presents the recommended threshold values and the types of safety advisory messages to be issued.
2. Display and/or record the appropriate safety advisory message.

Threshold Values

Table 21. Tentative Threshold Values and Types of Safety Advisory Messages for Evaluation of SSD

Traffic Volume Level	**$SSD_{act} < SSD_{des}$**			**$SSD_{act} \geq SSD_{des}$**
	$V_{eff} \leq V_{act} - 10$	**$V_{act} - 10 < V_{eff} \leq V_{act} - 5$**	**$V_{act} - 5 < V_{eff} < V_{act}$**	
≥ 5,000 veh/day	Level 1 advisory	Level 1 advisory	Level 2 advisory	OK
< 5,000 veh/day	Level 1 advisory	Level 2 advisory	Level 2 advisory	OK

Concern Statement Message

Insufficient SSD for ___ leg
- horizontal curve

If the above message is triggered and the intersection in question is a multileg intersection or has more than one minor-road approach on the same side of major road, then add the appropriate postscript(s) to the advisory:

- multileg intersection
- more than one minor-road approach on the same side of the major road

Basis

The thresholds are based on the judgment of the expert team.

Supplementary Information for the User

None known at this time.

References

1. Fambro, D.B., R. Koppa, and K. Fitzpatrick. *Determination of Stopping Sight Distances*, NCHRP Report 400. Transportation Research Board, Washington, DC, 1997.
2. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994.

4.10 Insufficient Visibility Of Traffic Signal

Description

The presence of a horizontal curve, vertical curve, or any other physical sight obstruction within the intersection area can reduce the visibility distance to the traffic signal, thus affecting the driver's ability to stop in time.

Concern Type

Leg concern

Geometric Elements Involved

- Horizontal curve.
- Vertical curve.
- Grade.

Associated Accident Types

The following accident types are associated with insufficient visibility distance to a traffic signal for signalized intersections:

- Rear-end collision.
- Angle collision.

Model(s) Used

The model used to determine if there is sufficient visibility distance to a traffic signal is the SSD model presented in Section 3.7.

Evaluation Variable

The variable used to evaluate the visibility distance to a traffic signal, considering vertical sight restrictions, is V_{eff}, the effective speed, for which visibility distance, VD_{avail}, is provided. The variable used for evaluation of horizontal sight restrictions is the user's YES/NO response to the questions concerning a clear sight area.

Evaluation Procedure

The following evaluation procedure is used for vertical and horizontal sight obstructions:

1. For vertical sight obstructions, assess the criticality of any deficiency in visibility distance by computing the difference between V_{act} and V_{eff}. Table 22 presents the recommended threshold values and the types of safety advisory messages to be issued.
2. For horizontal sight obstructions, if the user's response to the question concerning clear sight area is YES, then no advisory is needed. If the answer to the first question is NO, display a Level 2 advisory, unless the answer to the second question is NO as well, in which case a Level 1 advisory should be displayed.

Threshold Values

Table 22. Tentative Threshold Values and Types of Safety Advisory Messages for Evaluation of Visibility to Traffic Signals

ADT Level (veh/day)	**$VD_{avail} < VD_{des}$**			
	$V_{eff} \le V_{act} - 10$	**$V_{act} - 10 < V_{eff} \le V_{act} - 5$**	**$V_{act} - 5 < V_{eff} < V_{act}$**	**$VD_{avail} \ge VD_{des}$**
≥ 5,000	Level 1 advisory	Level 1 advisory	Level 2 advisory	OK
< 5,000	Level 1 advisory	Level 2 advisory	Level 2 advisory	OK

Concern Statement Message

Insufficient visibility to signal for ____ leg

Basis

The thresholds are based on the judgment of the expert team.

Supplementary Information for the User

None known at this time.

References

1. *Manual on Uniform Traffic Control Devices.* U.S. Department of Transportation, Federal Highway Administration, Washington, DC, 1988.

2. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994.

4.11 Insufficient Visibility Of Stop Sign

Description

The presence of a horizontal curve, vertical curve, or any other physical sight obstruction within the intersection area can reduce the visibility distance to a stop sign, thus affecting the driver's ability to stop in time.

Concern Type

Leg concern

Geometric Elements Involved

- Horizontal curve.
- Vertical curve.
- Grade.

Associated Accident Types

The following accident types are associated with insufficient visibility distance to a stop sign for stop-controlled intersections:

- Rear-end collision.
- Angle collision.

Model(s) Used

The model used to determine if there is sufficient visibility distance to a stop sign is the SSD model presented in Section 3.8.

Evaluation Variable

The variable used to evaluate the visibility distance to a stop sign, considering vertical sight restriction, is V_{eff}, the effective speed, for which visibility distance, VD_{avail},is provided. The variable used for evaluation of horizontal sight restrictions is the user's YES/NO response to the questions concerning a clear sight area.

Evaluation Procedure

The following evaluation procedure is used for vertical and horizontal sight obstructions:

1. For vertical sight obstructions, assess the criticality of any deficiency in visibility distance by computing the difference between V_{act} and V_{eff}. Table 23 presents the recommended threshold values and the types of safety advisory messages to be issued.
2. For horizontal sight obstructions, if the user's response to the question concerning clear sight area is YES, then no advisory is needed. If the answer to the first question is NO, display a Level

2 advisory, unless the answer to the second question is NO as well, in which case a Level 1 advisory should be displayed.

Threshold Values

Table 23. Tentative Threshold Values and Types of Safety Advisory Messages for Evaluation of Visibility to Stop Signs

ADT Level (veh/day)	$VD_{avail} < VD_{des}$			$VD_{avail} \geq VD_{des}$
	$V_{eff} \leq V_{act} - 10$	$V_{act} - 10 < V_{eff} \leq V_{act} - 5$	$V_{act} - 5 < V_{eff} < V_{act}$	
≥ 5,000	Level 1 advisory	Level 1 advisory	Level 2 advisory	OK
< 5,000	Level 1 advisory	Level 2 advisory	Level 2 advisory	OK

Concern Statement Message

Insufficient visibility to stop sign for ___ leg

Basis

The thresholds are based on the judgment of the expert team.

Supplementary Information for the User

None known at this time.

References

1. *Manual on Uniform Traffic Control Devices.* U.S. Department of Transportation, Federal Highway Administration, Washington, DC, 1988.
2. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994.

4.12 Insufficient Visibility Of Yield Sign

Description

The presence of a horizontal curve, vertical curve, or any other physical sight obstruction within the intersection area can reduce the visibility distance to a yield sign, thus affecting the driver's ability to react appropriately.

Concern Type

Leg concern

Geometric Elements Involved

- Horizontal curve.

- Vertical curve.
- Grade.

Associated Accident Types

The following accident types are associated with insufficient visibility distance to a yield sign for yield-controlled intersections:

- Rear-end collision.
- Angle collision.

Model(s) Used

The model used to determine if there is sufficient visibility distance to a yield sign is the SSD model presented in Section 3.9.

Evaluation Variable

The variable used to evaluate the visibility distance to a yield sign, considering vertical sight restrictions, is V_{eff}, the effective speed, for which visibility distance, VD_{avail},is provided. The variable used for evaluation of horizontal sight restrictions is the user's YES/NO response to the questions concerning a clear sight area.

Evaluation Procedure

The following evaluation procedure is used for vertical and horizontal sight obstructions:

1. For vertical sight obstructions, assess the criticality of any deficiency visibility distance by computing the difference between V_{act} and V_{eff}. Table 24 presents the recommended threshold values and the types of safety advisory messages to be issued.
2. For horizontal sight obstructions, if the user's response to the question concerning clear sight area is YES, then no advisory is needed. If the answer to the first question is NO, display a Level 2 advisory, unless the answer to the second question is NO as well, in which case a Level 1 advisory should be displayed.

Threshold Values

Table 24. Tentative Threshold Values and Types of Safety Advisory Messages for Evaluation of Visibility to Yield Signs

ADT Level (veh/day)	$VD_{avail} < VD_{des}$			$VD_{avail} \geq VD_{des}$
	$V_{eff} \leq V_{act} - 10$	$V_{act} - 10 < V_{eff} \leq V_{act} - 5$	$V_{act} - 5 < V_{eff} < V_{act}$	
≥ 5,000	Level 1 advisory	Level 1 advisory	Level 2 advisory	OK
< 5,000	Level 1 advisory	Level 2 advisory	Level 2 advisory	OK

Concern Statement Message

Insufficient visibility of yield sign for ____ leg

Basis

The thresholds are based on the judgment of the expert team.

Supplementary Information for the User

None known at this time.

References

1. *Manual on Uniform Traffic Control Devices.* U.S. Department of Transportation, Federal Highway Administration, Washington, DC, 1988.
2. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994.

4.13 Insufficient Decision Sight Distance For A Crest Vertical Curve On An Intersection Approach

Description

The presence of a crest vertical curve on an intersection approach represents an additional risk beyond that of a typical intersection. The crest vertical curve may hide the intersection or vehicles at the intersection from the driver's view.

Concern Type

Leg concern

Geometric Elements Involved

- Local grade.
- Length of crest vertical curve.

Associated Accident Types

The following accident types are associated with insufficient DSD for a crest vertical curve on an intersection approach:

- Rear-end collision.
- Head-on collision.
- Angle collision.

Model(s) Used

The model used to determine if there is sufficient DSD for vertical curves is the DSD model presented in Section 3.10.

Evaluation Variable

The variable used to evaluate DSD for a crest vertical curve on an intersection approach is V_{eff}, the effective speed for which DSD is provided.

Evaluation Procedure

1. The criticality of any DSD deficiency ($V_{eff} < V_{act}$) would be represented as a Level 2 advisory. Intersections with severely limited DSD will also trigger Level 1 or Level 2 advisories, as appropriate, for SSD and ISD.

   Consideration should be given to the concept of having a more stringent threshold for DSD problems when no turn lanes are present on an uncontrolled approach to an intersection than when left- and/or right-turn lanes are present.

2. Display and/or record the appropriate safety advisory message.

Threshold Values

The threshold value for a Level 2 advisory is $V_{eff} - V_{act} < 0$.

Concern Statement Message

Insufficient DSD for ___ leg
- crest vertical curve

Basis

The thresholds are based on the judgment of the expert team.

Supplementary Information for the User

None known at this time.

References

1. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994.
2. McGee, H.W., W. Moore, B.G. Knapp, and J.H. Sanders. *Decision Sight Distance for Highway Design and Traffic Control Requirements*, Report No. FHWA-RD-78-078. Federal Highway Administration, Washington, DC, 1978.

4.14 Insufficient Decision Sight Distance For A Horizontal Curve On An Intersection Approach

Description

The presence of a horizontal curve on an intersection approach represents an additional risk beyond that of a typical intersection. The horizontal curve presents an increased probability of roadside sight obstructions that hide the intersection or vehicles at the intersection from the driver's view. The DSD model for horizontal curves is applied in IDRM wherever the driver's view of an intersection or potentially conflicting vehicle is limited by an obstruction on the inside of a horizontal curve.

Concern Type

Leg concern

Geometric Elements Involved

- Length of horizontal curve.
- Radius of horizontal curve.
- Lane width.
- Clear sight width available on the inside of the horizontal curve.

Associated Accident Types

The following accident types are associated with insufficient DSD for a horizontal curve on an intersection approach:

- Rear-end collision.
- Head-on collision.
- Angle collision.

Model(s) Used

The model used to determine if there is sufficient DSD for horizontal curves is the DSD model presented in Section 3.11.

Evaluation Variable

The variable used to evaluate DSD for a horizontal curve on an intersection approach is V_{eff}, the effective speed for which DSD is provided.

Evaluation Procedure

1. Assess the criticality of any DSD deficiency by comparing V_{eff} and V_{act}.

   If $V_{eff} < V_{act}$, then the criticality of DSD should be represented as a Level 2 advisory. Intersections with severely limited DSD will also trigger Level 1 or Level 2 advisories, as appropriate, for SSD and ISD.

   Consideration should be given to the concept of having a more stringent threshold for DSD problems when no turn lanes are present on an uncontrolled approach to an intersection than when left- and/or right-turn lanes are present.

2. Incorporate consideration of roadside obstructions for sight triangles within $DSD_{des}/2$ outside the point of curvature (PC) and point of tangent (PT), analogous to SSD.

3. Display and/or record the appropriate safety advisory message.

Threshold Values

The threshold value for a Level 2 advisory is $V_{eff} - V_{act} < 0$.

Concern Statement Message

Insufficient DSD for ___ leg

- horizontal curve

Basis

The thresholds are based on the judgment of the expert team.

Supplementary Information for the User

None known at this time.

References

1. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994.
2. McGee, H.W., W. Moore, B.G. Knapp, and J.H. Sanders. *Decision Sight Distance for Highway Design and Traffic Control Requirements*, Report No. FHWA-RD-78-078. Federal Highway Administration, Washington, DC, 1978.

4.15 Insufficient Decision Sight Distance For Multileg Intersection

Description

Multileg intersections are those with five or more intersection legs. The inclusion of additional approach(es) to an intersection represents an additional risk beyond that of a typical four-leg intersection. A multileg intersection may violate driver expectancy and present an additional burden to the driver's decision-making process. For example, drivers may have difficulty perceiving the correct route to follow.

Concern Type

Leg concern

Geometric Elements Involved

- Local grade.
- Length of vertical curve.
- Length of horizontal curve.
- Radius of horizontal curve.
- Lane width.
- Clear sight width available on the inside of the horizontal curve.

Associated Accident Types

The following accident types are associated with insufficient DSD for a multileg intersection:

- Rear-end collision.
- Head-on collision.
- Angle collision.

Model(s) Used

It is recommended that a model of driver navigational decisions that is sensitive to the number of intersection legs (i.e., the number of potential paths through the intersection) be developed. This model should be based on a synthesis of human factors literature related to driver navigational decisions. It is expected that the results of this human factors evaluation will indicate that an additional increment of time (Δt) is required for a driver to perceive and react to a multileg intersection over and above that required at a four-leg intersection. This $\Delta\tau$ would be added to the DSD value from Table 10 for a speed equal to V_{act}, both for horizontal curves as well as for vertical curves:

$$DSD = DSD_{table} + V_{act}\Delta t$$ Equation 4.15.1

Evaluation Variable

The variable used to evaluate DSD for a multileg intersection is V_{eff}, the effective speed for which DSD is provided.

Evaluation Procedure

Assess the criticality of any DSD deficiency by the difference between V_{act} and V_{eff}.

Threshold Values

The threshold value for a Level 2 advisory is $V_{eff} - V_{act} < 0$.

Concern Statement Message

Insufficient DSD for ___ leg
- multileg intersection

Basis

The thresholds are based on the judgment of the expert team.

Supplementary Information for the User

None known at this time.

References

1. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994.
2. McGee, H.W., W. Moore, B.G. Knapp, and J.H. Sanders. *Decision Sight Distance for Highway Design and Traffic Control Requirements*, Report No. FHWA-RD-78-078. Federal Highway Administration, Washington, DC, 1978.

4.16 Insufficient Decision Sight Distance For Intersections With More Than One Minor-Road Approach On The Same Side Of The Major Road

Description

Intersections with more than one minor-road approach on the same side of the major road represent an additional risk beyond that of a typical four-leg intersection. The additional minor-road approach may be confusing to some drivers. For example, the priority of movements is unclear for minor-road approaches and drivers may have difficulty perceiving the correct route to follow.

Concern Type

Leg concern

Geometric Elements Involved

- Local grade.
- Length of vertical curve.
- Length of horizontal curve.
- Radius of horizontal curve.
- Lane width.
- Clear sight width available on the inside of the horizontal curve.

Associated Accident Types

The following accident types are associated with insufficient SSD for intersections with more than one minor-road approach:

- Rear-end collision.
- Head-on collision.
- Angle collision.

Model(s) Used

It is recommended that a human factors evaluation be performed to determine what effect the additional minor-road approach on one side of the major road has on the driver. It is expected that the results of this human factors evaluation will indicate that an additional increment of time (Dt) is required for a driver to perceive and react to this type of intersection over and above that required at a standard four-leg intersection. This Dt would be added to the DSD value from Table 10 for a speed equal to V_{act}, both for horizontal curves as well as for vertical curves:

$$DSD = DSD_{table} + V_{act}\Delta t$$ Equation 4.16.1

Evaluation Variable

The variable used to evaluate DSD for an intersection with more than one minor-road approach is V_{eff}, the effective speed for which DSD is provided.

Evaluation Procedure

Assess the criticality of any DSD deficiency by the difference between V_{act} and V_{eff}.

Threshold Values

The threshold value for a Level 2 advisory is $V_{eff} - V_{act} < 0$.

Concern Statement Message

Insufficient DSD for ___ leg - more than one minor-road approach on the same side of the major road

Basis

The thresholds are based on the judgment of the expert team.

Supplementary Information for the User

None known at this time.

References

1. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994.
2. McGee, H.W., W. Moore, B.G. Knapp, and J.H. Sanders. *Decision Sight Distance for Highway Design and Traffic Control Requirements*, Report No. FHWA-RD-78-078. Federal Highway Administration, Washington, DC, 1978.

4.17 Increased Crossing Distance

Description

A clearance time model is required to address safety and operational issues that arise from the additional distance (and time) that vehicles require to cross skewed intersections versus right-angle intersections.

At unsignalized intersections, the need for additional clearance time is safety-related. Additional clearance time is required for stopped vehicles on the minor approach to cross the intersection, resulting in greater exposure of the vehicle to conflict. The sight distance for a crossing maneuver from one minor-road leg to the other is based on the time it takes for the stopped vehicle to clear the intersection. The time gap for ISD for crossing the major road at an unsignalized intersection should thus be increased by Δt at a skewed intersection.

At signalized intersections, the additional time needed to cross the skewed intersection is more of an operational issue than a safety issue. Increased crossing time at a skewed intersection will have a negative effect on the operational efficiency of a signalized intersection by requiring an increase in the all-red clearance time. The function of the all-red clearance time is to allow the vehicle that has entered the intersection to safely clear the intersection before the conflicting movement is released.

Concern Type

Leg concern

Geometric Elements Involved

- Multileg intersection.
- Intersection skew angle.

Associated Accident Types

The following accident type is associated with increased crossing distance:

- Angle collision.

Model(s) Used

The model used to determine if increased crossing distance is a concern is the clearance time model presented in Section 3.12.

Evaluation Variable

The variable used to evaluate this concern is the additional time needed for vehicles to cross a skewed intersection relative to a right-angle intersection.

Evaluation Procedure

The following steps are required to evaluate the clearance time model:

1. From data provided by the designer, determine intersection skew angle.
2. Display the appropriate message to the designer.

The evaluation procedure is the same for both signalized and unsignalized intersections.

Threshold Values

Unsignalized Intersections

- Level 2 warning issued if intersection angle is between 50 degrees and 60 degrees.
- Level 1 warning issued if intersection angle is less than or equal to 50 degrees.

Signalized Intersections Concern Statement Message

Increased crossing distance for ____ leg - skewed intersection

Basis

At signalized intersections, the key issue is providing increased clearance intervals. The researchers feel that the increased clearance times at skewed intersections are not substantial enough to affect the overall operation of the intersections; thus, only a Level 2 advisory message is issued for intersections with a skew angle of 45 degrees or less.

Supplementary Information for the User

No additional information is expected to be made available to the user through the help system.

References

1. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994 (Table II-1, Design Vehicle Dimensions, p. 21).
2. Harwood, D.W., J. Mason, R. Brydia, M. Pietrucha, and G. Gittings. *Intersection Sight Distance*, NCHRP Report 383. Transportation Research Board, Washington, DC, 1996 (acceleration rate from a stop).

3.

4.18 Warranted Left-Turn Lane Is Not Present

Description

A model is required to identify the need for left-turn lanes at intersections and to highlight locations where lack of a left-turn lane presents a potential safety concern. For rural, unsignalized intersections along the through or unstopped approach, left-turn lanes serve a safety and operational efficiency function by removing decelerating and stopped vehicles waiting to turn from the higher speed through lanes.

Concern Type

Leg concern

Geometric Elements Involved

- Crest vertical curve on an intersection approach.
- Operational inefficiency/delay.
- Ability to perceive an intersection.
- Separate turn lane not present.

Associated Accident Types

The following accident types are associated with a warranted left-turn lane:

- Rear-end collision.
- Angle collision.

Model(s) Used

The model used to determine if a left-turn lane is warranted is the left-turn lane warrants model presented in Section 3.13 .

Evaluation Variable

The variables used to evaluate this concern are the peak- or design-hour volume for the left turn in question and the peak- or design-hour volume for the opposing approach for the major, unstopped approach at the intersection.

Evaluation Procedure

The following steps are required to evaluate the left-turn lane warrant model:

1. For each unstopped approach to an intersection, determine whether a left-turn lane is present or not.
2. From data provided by the designer, determine the peak-hour volume of the approach. If peak-hour volume is not available, use design-hour volume. Hourly volumes are required for both directions of travel on the unstopped approaches.

3. Determine the 85th percentile speed. The speed can be determined from actual data, from a speed-prediction model like those developed for the IHSDM design consistency module, or from engineering judgment by the user. (Note that both directions of travel need to be evaluated.)
4. Look up the appropriate warranting condition and display an appropriate message.

Threshold Values

A Level 2 warning would be displayed if the design year forecast warranting left-turn volume is within 10 percent of the value indicated in Table 15, Section 3.13 Left-Turn Lane Warrants (i.e., 0.9 * volume from look-up table < design year volume < volume from look-up table). A Level 1 warning would be displayed where the left-turn volume exceeds the warranting volume given in Table 15 .

Concern Statement Message

Warranted left-turn lane is not present on ____ leg

Basis

The basis for the Level 2 warning is that the designer should be alerted to the fact that the respective traffic volume is approaching a threshold value. This is especially true given the uncertainty of typical traffic forecasts. When threshold values are exceeded, a Level 1 warning is generated to instruct the designer to include a left-turn lane in the design.

Given the use of actual speed and considering the potential variations in left-turn volumes, it is possible that one approach may indicate the need for a left-turn lane, but the other may not show the need. IDRM will consider a warranting condition as applying to both directions of travel if warrants are met for either unstopped approach.

In most cases, an identified non-warranting condition will be associated with the lack of a turn lane where one should exist. Where a turning lane exists, but is not "warranted," this is not considered a problem and no message would be displayed.

Supplementary Information for the User

No additional information is expected to be made available to the user through the help system.

References

1. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994 (Table II-1, Design Vehicle Dimensions, p. 21).
2. *Intersection Channelization Design Guide*, NCHRP Report 279. Transportation Research Board, Washington, DC (Figure 4-12 [Harmelink study]).

4.19 Warranted Right-Turn Lane Is Not Present

Description

A model is required to identify the need for right-turn lanes at intersections and to highlight locations where lack of a right-turn lane presents a potential safety concern. For rural, unsignalized intersections along the through or unstopped approach, right-turn lanes serve a safety and operational efficiency function by removing decelerating and stopped vehicles waiting to turn from the higher speed through lanes.

Concern Type

Leg concern

Geometric Elements Involved

- Crest vertical curve on an intersection approach.
- Operational inefficiency/delay.
- Ability to perceive an intersection.
- Separate turn lane not present.

Associated Accident Types

The following accident type is associated with a warranted right-turn lane:

- Rear-end collision.

Model(s) Used

The model used to determine if a right-turn lane is warranted is the right-turn lane warrants model presented in Section 3.14.

Evaluation Variable

The variables used to evaluate this concern are the peak- or design-hour volume for the right turn in question and the peak- or design-hour volume for the total approach on which the right-turn lane warrant is being investigated.

Evaluation Procedure

The following steps are required to evaluate the right-turn lane warrant model:

1. For each unstopped approach to an intersection, determine whether a right-turn lane is present or not.
2. From data provided by the designer, determine the peak-hour volume of the right turn and the total approach in question. If peak-hour volume is not available, use design-hour volume.
3. Look up the appropriate warranting condition and display an appropriate message.

Threshold Values

A Level 2 warning would be displayed if the design year forecast warranting right-turn volume is within 10 percent of the value indicated in Table 16, Section 3.14, Right-Turn Lane Warrants. A Level 1 warning would be displayed where the right-turn volume exceeds the warranting volume given in Table 16.

Concern Statement Message

Warranted right-turn lane is not present on ____ leg

Basis

The basis for the Level 2 warning is that the designer should be alerted to the fact that the respective traffic volume is approaching a threshold value. This is especially true given the uncertainty of typical traffic forecasts. When threshold values are exceeded, a Level 1 warning is generated to instruct the designer to include a right-turn lane in the design.

In most cases, an identified non-warranting condition will be associated with the lack of a turn lane where one should exist. Where a turning lane exists, but is not "warranted," this is not considered a problem and no message would be displayed.

Supplementary Information for the User

No additional information is expected to be made available to the user through the help system.

References

1. *The Development of Criteria for the Treatment of Right-Turn Movements on Rural Roads*. Virginia Highway and Transportation Council, March 1981.

4.20 Insufficient Left-Turn Bay Storage And Deceleration Length Between Closely Spaced Intersections

Description

A model is required to address safety and operational issues that arise from the often-restricted dimension along a major road between closely spaced intersections. A function of auxiliary lanes is to store vehicles waiting to turn off a major roadway. Intersections with high turning-traffic volumes and/or opposing traffic volumes generally require greater storage lengths.

Concern Type

Intersection concern

Geometric Elements Involved

- Back-to-back left-turn lanes at closely spaced intersections.
- Left-turn lane length.

Associated Accident Types

The following accident type is associated with insufficient storage and deceleration length for back-to-back left-turn lanes between closely spaced intersections:

- Rear-end collision.

Model(s) Used

The models used to determine if there is sufficient storage and deceleration length for left-turn lanes between closely spaced intersections are left-turn lane length for closely spaced intersections model (Section 3.15) and queue length prediction model (Section 3.20).

Evaluation Variable

The variable used to evaluate this concern is the left-turn lane storage and deceleration length.

Evaluation Procedure

The following steps are required to evaluate the storage and deceleration length model for left turns at an intersection:

1. Obtain design-hour volume for all movements on the major, unstopped approaches.
2. Obtain the percentage of large vehicles turning on each major, unstopped approach.
3. Obtain the anticipated left-turn queue from the queue-prediction model. Calculate the required length using the queue-prediction output and the assumed vehicle dimension. If the percentage of heavy vehicles is less than 10 percent, use a vehicle dimension of 8 m. If the percentage is more than 10 percent, use a vehicle dimension of 10 m.
4. Obtain the required deceleration length from the left-turn length for closely spaced intersection model.
5. Compare available storage length (full-width portion of the lane) to required length based on the queue-prediction model and the required deceleration length model. (Required length = deceleration length + queue storage length.)
6. Display the appropriate message.

Threshold Values

Threshold values for storage and deceleration are based on the queue-prediction model output and the required deceleration length. These values may vary substantially based on existing or forecast volume conditions at an intersection and the anticipated vehicle speed. Guidance on required length may also be available in the PRM.

Level 2 messages will be issued when the required storage and deceleration lane length is within 10 percent of the actual full-width lane length. Level 1 messages will be issued when the required storage and deceleration lane length is greater than the actual length provided.

Concern Statement Message

Insufficient storage and deceleration length for left-turn lanes between closely spaced intersections
- back-to-back left-turn lanes

Basis

The basis of the thresholds is that providing full turn-bay storage and deceleration length at an intersection is critical to avoiding backing up traffic into the through lane.

Supplementary Information for the User

No additional information is expected to be made available to the user through the help system.

References

1. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994 (deceleration length requirements, p. 780).

2. *Manual on Uniform Traffic Control Devices.* U.S. Department of Transportation, Federal Highway Administration, Washington, DC, 1988 (Figure 3-10, Typical Lane Transition Markings, p. 3B-13).
3. *Highway Capacity Manual*. Transportation Research Board, 1997 (Chapter 10, Unsignalized Intersections).

4.21 Insufficient Taper Length For Left-Turn Lanes Between Closely Spaced Intersections

Description

A model is required to address safety and operational issues that arise from the often-restricted dimension along a major road between closely spaced intersections. Drivers turning off a highway at an intersection are usually required to reduce their speed before turning. When undue deceleration takes place directly on the highway through lanes, it disrupts the flow of through lane traffic. Providing an adequate taper length for vehicles entering a left-turn bay helps remove decelerating vehicles from the through-traffic stream.

Concern Type

Intersection concern

Geometric Elements Involved

- Back-to-back left-turn lanes at closely spaced intersections.
- Taper length.

Associated Accident Types

The following accident types are associated with insufficient taper length for left-turn lanes between closely spaced intersections:

- Rear-end collision.
- Sideswipe collision.

Model(s) Used

The model used to determine if there is sufficient taper length for left-turn lanes between closely spaced intersections is the left-turn lane length for closely spaced intersections model presented in Section 3.15.

Evaluation Variable

The variable used to evaluate this concern is the left-turn lane taper length.

Evaluation Procedure

The following steps are required to evaluate the taper length model:

1. Determine the 85th percentile speed. The speed can be determined from actual data, from a speed-prediction model like those developed for the IHSDM design consistency module, or from engineering judgment by the user.
2. Obtain the left-turn lane width.
3. Calculate required taper length using the *Manual on Uniform Traffic Control Devices* (MUTCD) equation.

4. Compare available taper length to required taper length.
5. Display the appropriate message.

Threshold Values

Level 2 messages will be issued when the required taper length is within 10 percent of the actual taper length. Level 1 messages will be issued when the required taper length is greater than the actual taper length provided.

Concern Statement Message

Insufficient taper length for left-turn lanes between closely spaced intersections
- back-to-back left-turn lanes

Basis

The basis of the thresholds is that providing adequate taper lengths for left-turn lanes is critical to removing slow-moving vehicles from the through-traffic stream.

Supplementary Information for the User

No additional information is expected to be made available to the user through the help system.

References

1. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994 (deceleration length requirements, p. 780).
2. *Manual on Uniform Traffic Control Devices.* U.S. Department of Transportation, Federal Highway Administration, Washington, DC, 1988 (Figure 3-10, Typical Lane Transition Markings, p. 3B-13).
3. *Highway Capacity Manual*. Transportation Research Board, 1997 (Chapter 10, Unsignalized Intersections).

4.22 High Traffic Conflict Index

Description

The intersection conflict index is used to measure the relative safety of an intersection configuration as a function of the number and types of intersection conflicts. Intersection conflict analysis is a well-understood means of addressing intersection safety. It has long been known that three-leg intersections operate more safely than four-leg intersections because three-leg intersections have fewer conflict points at which conflicting traffic streams cross, merge, or diverge. Intersection conflicts reflect the crossing or conflicting paths of vehicles moving from one leg to another. Depending on the type of movement (right or left turn, or crossing the intersection), any one vehicle can encounter or create one or more different conflicts. The different types of conflicts include diverging, merging, or crossing conflicts.

It is proposed to extend the same concept to the evaluation of multileg intersections. The intersection conflict index proposed for IDRM recognizes two principles of intersection conflicts and accidents. First, conflicts (and the associated risk of a particular type of accident) are related to the traffic volume of the conflicting movements. Second, the different conflicts have differing importance. This is a reflection of the severity of accidents associated with a conflict type.

Concern Type

Intersection concern

Geometric Elements Involved

- Multileg intersection.

Associated Accident Types

The following accident types are associated with a high traffic conflict index:

- Rear-end collision.
- Sideswipe collision.
- Angle collision.

Model(s) Used

The model used to determine if the intersection has a high traffic conflict index is the intersection conflict index model presented in Section 3.16.

Evaluation Variable

The variable used to evaluate this concern is the intersection conflict index.

Evaluation Procedure

The following steps are required to evaluate the intersection conflict index (ICI) model at an intersection:

1. Record or compute turning-movement volumes from all approaches.
2. Determine (input or read from file) type of traffic control.
3. Compute ICI for a comparable four-leg intersection based on intersection geometry, design or peak-hour traffic volume, and type of traffic control. Obtain the comparable four-leg intersection by dropping the lowest volume approach and reallocating the turning volumes associated with the leg to the remaining legs of the intersection. Engineering judgment should be used to allocate the dropped leg volumes to approaches/movements that result in similar conflicts to those expected on the dropped intersection leg.
4. Compare ICI computed in Step 3 to threshold values of the ICI for multileg intersection; display and/or record appropriate safety advisory message.

Threshold Values

The following thresholds are proposed for the intersection conflict index of a four-leg intersection:

ICI < 600,000 Reasonable level of conflict at an intersection.

ICI > 600,000 Investigate signalization to minimize conflicts and serve traffic volumes.

Based on the judgment of the researchers, the following threshold values of the ICI for multileg intersections are recommended:

ICI ≤ 660,000	Limited potential problem.
660,000 < ICI ≤ 900,000	Suggest reevaluation of intersection configuration or type of traffic control (Level 2 message).
900,000 < ICI	Strongly suggest reevaluation of intersection configuration or type of traffic control (Level 1 message).

Concern Statement Message

High traffic conflict interest

- multileg intersection

Basis

MUTCD warrants for all-way stop and signalized intersection control offer a means of determining reasonable thresholds for critical values of ICI as an absolute measure of intersection safety. The warrants are based on the same general principles of conflict and traffic volume. To establish reasonable thresholds, a series of calculations were performed for a range of typical traffic volumes based on the following MUTCD warrants:

- All-Way Stop Warrant.
- Signalized Intersection Warrants.
- Warrant No. 1 – Minimum Vehicular Volume (based on 8-h volumes).
- Warrant No. 2 – Interruption of Continuous Traffic (based on 8-h volumes).
- Warrant No. 9 – Four-Hour Volume.
- Warrant No. 11 – Peak-Hour Volume.

Conversion of peak-hour volumes to 4-h and 8-h volumes was based on typical 24-h volume distributions. The distribution of ICI values is relatively uniform for each signal warrant investigated. ICI values for the all-way stop condition are approximately one-half of those computed for the signal warrants.

Supplementary Information for the User

No additional information is expected to be made available to the user through the help system.

References

1. *Manual on Uniform Traffic Control Devices.* U.S. Department of Transportation, Federal Highway Administration, Washington, DC, 1988 (traffic signal warrants, pp. 4C-1 to 4C-12).

4.23 Uneven, Discontinuous Minor-Road Profile Through Intersection

Description

The profile of minor roads at intersections can present operational problems if not properly de4signed. Issues of concern where there is not continuity of the minor-road profile through an intersection include:

- Pavement elevations and drainage patterns across the intersection result in flat spots at corners or through intersection.
- Amount of grade change from the minor road to the major road may result in an alignment that is uncomfortable to drive, necessitating lower speeds.
- Presence of a reasonable platform for drivers stopped on the minor approach.

- Presence of vertical curves connecting significantly different grades that may result in vehicles "bottoming out."

Concern Type

Leg concern

Geometric Elements Involved

Discontinuous minor-road profile through intersection.

Associated Accident Types

No particular crash types are associated with this concern.

Model(s) Used

The model used to determine if the minor-road profile through the intersection is a concern is the minor-road profile model presented in Section 3.17.

Evaluation Variable

The variables used to evaluate this concern are:

- Presence of a 2-percent platform in the vehicle queuing area for the minor, stopped approach.
- Difference between the major- and minor-road cross-slopes.
- Intersection profiles.

Evaluation Procedure

1. Determine each minor, stopped approach:

- Based on user input, which leg(s) of the intersection are stopped approaches.

2. Determine the grade within 100 m of the centerline intersection of the two roadways on each minor approach. The intent is to provide information on the full vertical profile within 100 m on each side of the intersection.

3. Refer to the traffic volume and determine the desirability or need for a "platform" for drivers stopped on the minor approach. The criteria for a platform is considered to be any local grade of ± 2 percent. Display appropriate message (see below).

- A platform is required on each stopped approach if the design-hour volume (DHV) for the minor road is greater than 100 vehicles or the DHV of the major road is greater that 300 vehicles.
- Traffic volumes should be measured as the total approach DHV at the start of the intersection influence area (300 m).

4. Determine the cross-slope (or slope if superelevated) of the major road through the intersection.

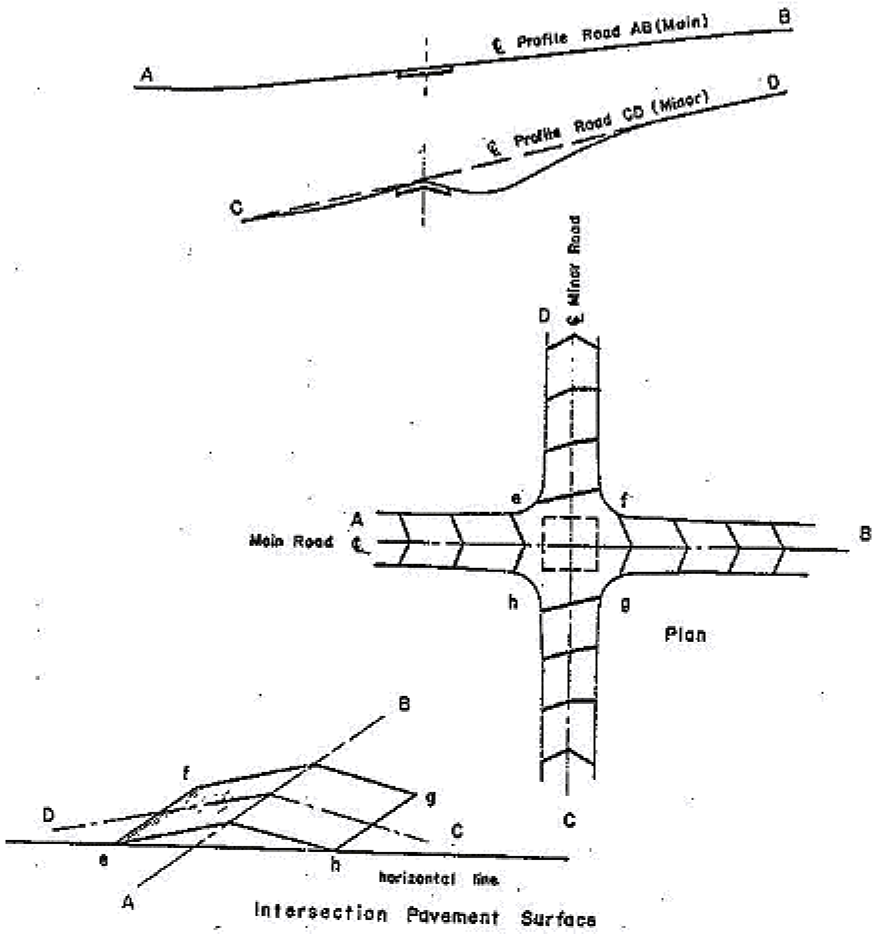
- Obtain information by user input or from a typical section of the major road.

- Cross-slope of major road should be measured at the intersection of the major-road and minor-road centerlines.
- Cross-slope needs to be measured from the centerline of the major road toward each stopped approach at the intersection.

5. For each minor road, determine the relative difference in grades between the cross-slope of the major road and the minor road. Refer to the table that relates to design controls on grade; produce message as appropriate.

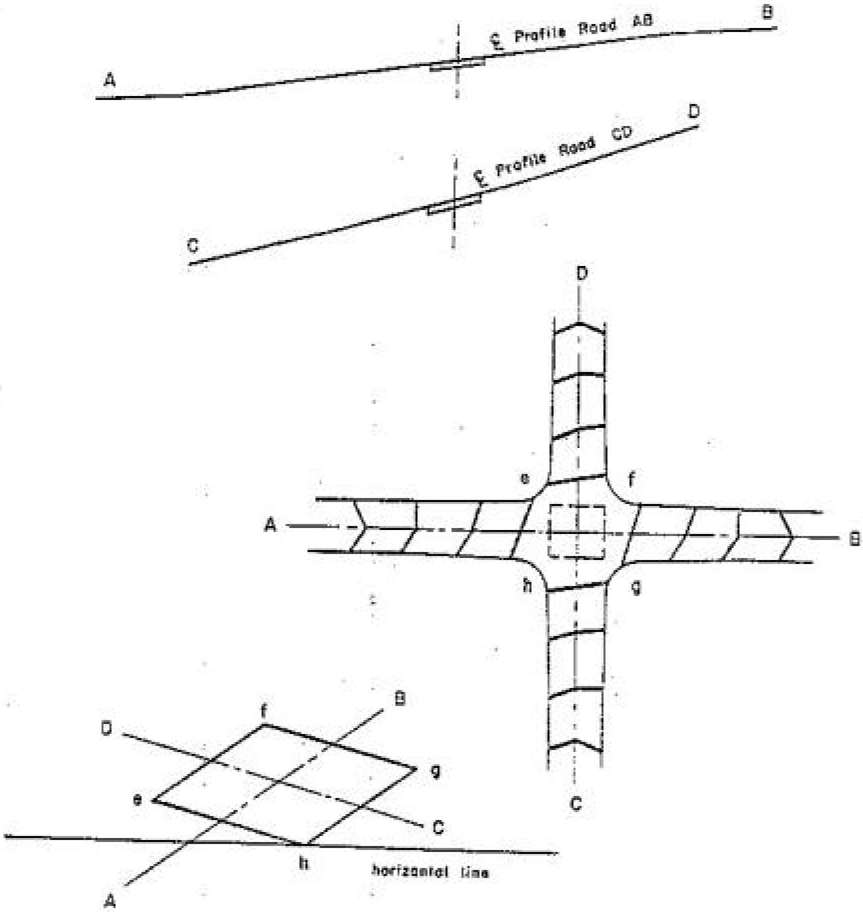
6. Check the presence of a vertical curve where grade changes are significant (see table notes); produce message as appropriate.

Referring to Figure 9 through Figure 11 below, the user can note the type of drainage and edge warping planned. Check the operating speeds of both roads and the type of traffic control. Case A (Figure 9), in which the major-road profile dictates and the minor-road profile fits the cross-slope of the major road, is preferred. Case B (Figure 10), presents a case in which the entire intersection drains to one corner. This is not desirable and should be avoided, particularly if the pavement area is large and/or the local grades through the intersection are very mild. Case C (Figure 11), in which the pavement edges are warped so that water drains to all four corners, is to be avoided on higher speed, unstopped approaches. It may be suitable where speeds are low, both facilities are similar in nature, and where all four approaches are stop-controlled.



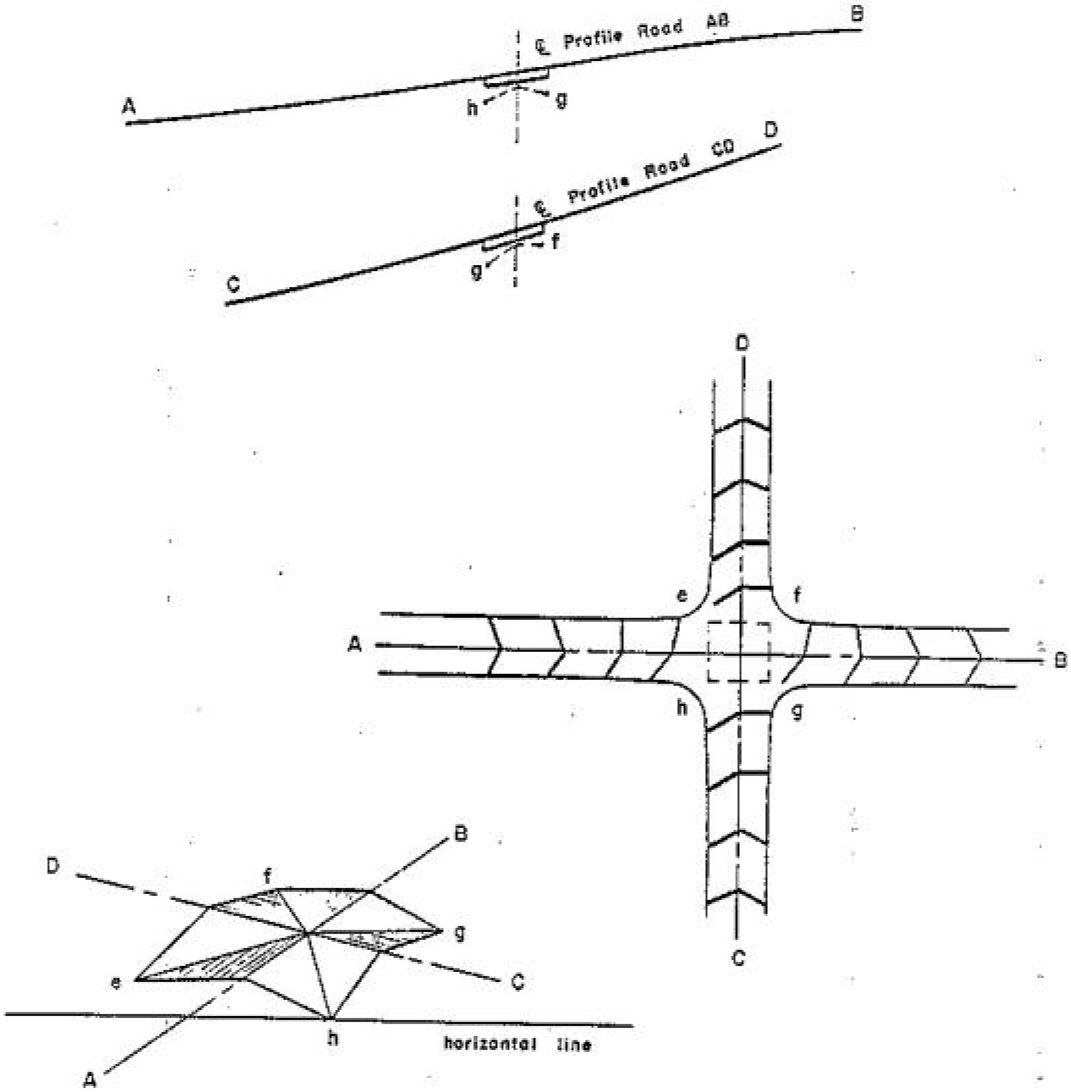
INTERSECTION PROFILES – CASE "A"
FIGURE 4.14

Figure 9. Intersection Profile Case A



INTERSECTION PROFILES – CASE "B"
FIGURE 4.15

Figure 10. Intersection Profile Case B



INTERSECTION PROFILES – CASE "C"
FIGURE 4.16

Figure 11. Intersection Profile Case C

Threshold Values

The threshold value for the profile on the minor, stopped approach is 2 percent. Areas not meeting this criterion would be given a Level 2 warning. Threshold values for cross-slope differential between the major and minor road are shown in Table 19 , which can be found in Section 3.17, Minor-Road Profile.

A Level 2 warning would be displayed for intersections exceeding the maximum criteria above.

Concern Statement Message

Uneven, discontinuous minor-road profile through intersection for ____ leg

Basis

The threshold values are based on operational and geometric principles as well as the judgment of the researchers.

Supplementary Information for the User

Reference to Figures illustrating Cases A, B, and C intersection profiles will be made available to the user via the concern background.

References

Planning and Design Guide for At-Grade Intersection (Course workbook), Jack E. Leisch and Associates, 1990.

4.24 Large Intersection Pavement Area

Description

Intersections with large, open pavement areas can produce operational problems. Large, open pavement areas generally occur at multileg intersections, skewed intersections, and intersections on a horizontal curve. Larger intersections are more costly to construct and maintain. The open pavement areas can be more difficult to drain, which may create icing or other vehicle control problems. In addition, large, open pavement areas at intersections may also be difficult for unfamiliar drivers to navigate.

The need to accommodate the operation of long and wide vehicles also produces special problems at intersections. Vehicle turning paths, which are a function of the characteristics of the vehicles, take up considerable space as the vehicle makes either a right or left turn. The amount of space and potential impacts on the operation and safety of the intersection are influenced by the type of large vehicle and the angle of the intersection. The types and severity of the potential for turning path problems are based on the frequency of large vehicle turns and which approach legs (i.e., stopped or unstopped) are skewed. Turning-path requirements are a concern at all intersections, but are particularly important at skewed and multileg intersections. An intersection on a relatively sharp horizontal curve will also result in one or more turning movements occurring through a skew.

Concern Type

Intersection concern

Geometric Elements Involved

- Multileg intersection.
- Intersection skew angle.
- Intersection on horizontal curve.

Associated Accident Types

The following accident types are associated with a large intersection pavement area:

- Rear-end collision.
- Sideswipe collision.
- Angle collision.

Model(s) Used

The model used to determine if the pavement area is a concern is the intersection pavement area model presented in Section 3.18.

Evaluation Variable

The variables used to evaluate this concern are number of intersection legs, skew angle, type of design vehicle, and percentage of heavy vehicles in the traffic stream.

Evaluation Procedure

The following steps are required to evaluate the pavement area model:

1. Check if the intersection is a multileg intersection; display appropriate message to the designer.
2. Compute the intersection skew angle and compare to threshold value; display appropriate message to the designer.
3. Check the intersection design vehicle and compare to threshold design vehicle; display appropriate message to the designer.
4. Compute the percentage of heavy vehicles on each approach leg and compare to threshold values; display appropriate message to the designer.

Threshold Values

A Level 2 warning would be displayed for multileg intersections and intersections with skew angles less than 60 degrees. Level 1 warnings will not be issued for this concern.

A Level 2 warning would be displayed for multileg intersections and intersections with skew angles less than 80 degrees if the design vehicle is larger than a WB-15 and if the percentage of heavy vehicles in the traffic stream is greater than 5 percent.

Concern Statement Message

Large intersection pavement area
- multileg intersection

Large intersection pavement area
- skewed intersection

Large intersection pavement area
- large-vehicle turn path

Basis

The basis for the Level 2 warning is that the designer should be alerted to the fact that intersections with large, open pavement areas can produce operational problems and are more costly to construct and maintain. The threshold intersection skew angle of 60 degrees is recommended based on the judgment of the researchers. A 60-degree skew angle is approximately the intersection angle where intersection pavement area for a skewed intersection doubles relative to a 90-degree intersection. This is thought to be a reasonable threshold upon which the designer should be alerted to issues associated with large pavement areas at intersections.

The Level 2 warning for vehicle turn path is based on the presence of large vehicles in the traffic stream and the likelihood that the intersection skew angle will present turning-path issues for large vehicles. When these conditions exist, the user should be prompted to confirm the proposed geometry using turning-vehicle templates or a software package.

Supplementary Information for the User

No additional information is expected to be made available to the user through the help system.

References

1. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994 (Table IX-1, Minimum Edge of Traveled Way Designs for Turns at Intersections, pp. 648-649).

4.25 Approach Alignment Differs Between Opposing Approaches

Description

The change in approach alignment model is proposed for use in IDRM to deal with forced directional changes for through vehicles as they proceed through an intersection. Forced directional changes may be difficult for unfamiliar drivers to navigate.

Concern Type

Leg concern

Geometric Elements Involved

- General intersection.

Associated Accident Types

The following accident types are associated with a change in alignment between opposing intersection approaches:

- Head-on collision.
- Sideswipe collision.

Model(s) Used

The models used to check the opposing approach is the change in approach alignment between opposing approaches model (Section 3.19).

Evaluation Variable

The variable used to evaluate this concern is the change in approach alignment between intersection legs (degrees).

Evaluation Procedure

The following general steps would be undertaken by IDRM to utilize the change in approach alignment model:

1. Obtain the design speed or 85th percentile speed for the approach leg(s) being examined.
2. Compute the deflection angle between intersection legs for each direction of travel.
3. Compare the angle with the threshold values; display appropriate message to the designer.

Threshold Values

Threshold values are established on the basis of design speed for an approach leg to the intersection. For design speeds less than or equal to 70 km/h (40 mi/h):

- Level 2 warning is generated for an intersection approach leg when the deflection angle for the through movement is ≥ 3 degrees and ≤ 5 degrees.
- Level 1 warning is generated for an intersection approach leg when the deflection angle for the through movement is > 5 degrees.

For design speeds greater than 70 km/h (40 mi/h):

- Level 2 warning is generated for an intersection approach leg when the deflection angle for the through movement ≥ 2 degrees and ≤ 4 degrees.
- Level 1 warning is generated for an intersection approach leg when the deflection angle for the through movement is > 4 degrees.

Concern Statement Message

Approach alignment differs between opposing approaches on ____ leg

Basis

The basis for the warnings is that the designer should be alerted to the fact that intersections with substantial changes between approach alignments can produce operational and safety problems. Thresholds are based on the judgment of the researchers. The degree of acceptable deflection is related to the potential speed of a vehicle. A 2-degree deflection angle between approach alignments approximates a 70-km/h (40-mi/h) design speed for a through roadway and a 5-degree deflection angle is approximately a 40-km/h (25-mi/h) design speed for the through roadway.

Supplementary Information for the User

No additional information is expected to be made available to the user through the help system.

References

1. *A Policy on Geometric Design of Highways and Streets (Green Book)*. American Association of State Highway and Transportation Officials, Washington, DC, 1994.

4.26 Insufficient Queue Storage

Description

A traffic operational model is needed to identify situations in which expected queues of vehicles will pose an unusual hazard because of the presence of a particular geometric condition or feature. A queue-prediction model would estimate a level of queuing for a given approach-traffic volume and translate that volume to a design dimension.

Concern Type

Leg concern

Geometric Elements Involved

- Turn-bay length.
- Offset T intersections.

Associated Accident Types

The following accident type is associated with insufficient queue storage:

- Rear-end collision.

Model(s) Used

The model used to determine if there is sufficient queue storage is the queue length prediction model presented in Section 3.20.

Evaluation Variable

The variable used to evaluate this concern is the length of the queue.

Evaluation Procedure

The following steps are required to evaluate the queue storage model:

1. Obtain the percentage of large vehicles turning left on the unstopped approaches.

2. Obtain design-hour traffic volumes for both directions of travel on the unstopped approaches:

– Design-hour traffic volume information obtained for each unstopped intersection approach.

– Design-hour traffic volume information needed for left turns and the sum of through and right-turning vehicles for each unstopped approach.

3. Obtain the expected number of queued left-turning vehicles based on the volume conditions from Figure 8 :

– Chart can be shown to the user or answer can be selected by the program.

– Chart inputs are left turns on major, unstopped approach vs. through/right-turning vehicles on opposite major, unstopped approach.

4. Translate the expected number of queued vehicles obtained from the look-up table into a predicted queue dimension:

– Dimension calculated will be based on the truck percentage from Step 1. If the percentage of trucks turning left is less than 10 percent, use a vehicle length of 8 m. If the percentage of trucks turning left is 10 percent or more, use a vehicle length of 10 m.

– Total queue length is the number of queued vehicles multiplied by the vehicle length.

5. Get the actual storage length for the left-turn lane. This will be the full-width portion of the turn lane.

6. Compare the predicted queue dimension to the actual storage length and generate the appropriate message based on the thresholds noted below.

Threshold Values

A Level 2 advisory is generated if the predicted queue dimension is greater than 75 percent of the available queue storage dimension.

A Level 1 advisory is generated if the predicted queue dimension exceeds the available queue storage dimension.

Concern Statement Message

Insufficient queue storage for left-turn lane for __ leg

Basis

The basis for establishing queue lengths are *Highway Capacity Manual* procedures for unsignalized intersections.

Supplementary Information for the User

No additional information is expected to be made available to the user through the help system.

References

1. *Highway Capacity Manual* . Transportation Research Board, 1997 (Chapter 10, Unsignalized Intersections).

4.27 Loss Of Control Potential Due To Frequent Braking

Description

At intersections on horizontal curves and intersections with horizontal curves on the intersection approach, the driver's capacity to brake may be limited because the vehicle is simultaneously braking and cornering. The purpose of this procedure is to determine whether the combination of braking and cornering that may occur when an intersection is on or near a curve is likely to result in vehicle loss of control due to skidding.

Concern Type

Leg concern

Geometric Elements Involved

- Superelevation rate for horizontal curve.
- Radius.

Associated Accident Types

The following accident types are associated with skidding on horizontal curves:

- Single-vehicle run-off-road collisions.
- Rear-end collisions.
- Head-on collisions.
- Angle collisions.

Model(s) Used

The model used to determine if there is a sufficient margin of safety against skidding due to combined braking and cornering is presented in Section 3.21.

Evaluation Variable

The evaluation variable is the speed margin of safety (V_{ms}) against skidding due to combined braking and cornering.

Evaluation Procedure

The evaluation procedure is to determine the value of V_{ms} and compare it to the threshold values given below.

Threshold Values

If $V_{ms} \leq 20$ km/h and $V_{ms} > 10$ km/h, then display a Level 2 advisory. If $V_{ms} \leq 10$ km/h, then display a Level 1 advisory.

Concern Statement Message

Loss of control potential due to frequent braking for __leg
- horizontal curve

Basis

The thresholds are based on the judgment of the expert team.

Supplementary Information for the User

None known at this time.

References

1. *A Policy on Geometric Design of Highways and Streets (Green Book)* . American Association of State Highway and Transportation Officials, Washington, DC, 1994.

USE OF ACCIDENT HISTORY DATA TO HIGHLIGHT PARTICULAR INTERSECTION-LEG CONCERNS

Accident history data are used in IDRM to highlight or call special attention to concerns that are accompanied by a related accident pattern, as defined by specific traffic movements. Accident history data are considered for intersection-leg concerns, but not for general intersection concerns (see Table 3), which are not necessarily associated with particular traffic movements. The following discussion indicates how this is done.

5.1 Role Of Site-Specific Accident History Data In IDRM

FHWA's original concept, at the outset of this project, was to have a separate expert system to evaluate the accident history at an intersection, identify accident patterns, and recommend appropriate treatments. The research team recommended, and FHWA agreed, that it would be better to have a single expert system that integrated both the diagnostic review of a design and the consideration of accident history data. A geometric and operational diagnostic review of an intersection can be performed alone when no accident history data are available. However, when accident history data are available, those data should be used to enhance the diagnostic review of the intersection.

IDRM will be used primarily by highway agency engineers and their consultants. It is assumed that, in at least some cases, IDRM can be implemented in an environment where the agency's accident history data are available online. In other cases, accident history data may need to be obtained from an external system and entered manually by the user.

5.2 Conceptual Approach To Use Of Site-Specific Accident History Data In IDRM

The conceptual approach to consideration of accident history data in IDRM is based on recognition that most of the concerns identified in a diagnostic review are associated with the risk of potential collisions involving specific pairs of vehicle movements. For example, the concern *Insufficient ISD to right (Case B1) for NB leg* is intended as an indicator of the potential risk of collisions between northbound (NB) left-turning vehicles and westbound (WB) through vehicles. While less common, there is also a risk of collision between NB left-turning vehicles and WB left-turning vehicles. Therefore, when this concern is identified, it makes sense to check the accident history data to determine whether there is a pattern of collisions involving these two pairs of through or turning movements. If a pattern of related crashes is evident, this indicates a need for heightened interest in improving ISD at the intersection because the ISD concern identified in the diagnostic review is supported by an existing accident pattern. It should be noted that the conceptual approach, in effect, places primary emphasis on the geometric and operational reviews, using accident data in an important but supporting (not primary) role. A designer need not abandon IDRM because she or he is lacking accident data of sufficient quality; on the other hand, having such data makes an enhanced and "richer" review possible.

The heightened interest in concerns that are accompanied by related accident patterns should be communicated to the IDRM user in the list of concerns identified by the diagnostic review either by presenting the ISD concern in a contrasting color, in a bold font, or perhaps with a special message. This would contrast with other concerns, not confirmed by accident patterns, which would be presented in a normal color or font.

5.3 Identification Of Patterns Of Specific Collision Types

A key issue for implementation of this approach is the decision of how to identify accident patterns. This will be accomplished with a matrix of collision types and a threshold value for the minimum number of accidents that constitutes an accident pattern.

Classification of Collision Types

The concerns identified by IDRM are related primarily to the risk of multiple-vehicle collisions (i.e., collisions involving two or more motor vehicles). The traffic movement (or intended movement) being made by each vehicle will be used in classifying the collision types, just as an analyst does in preparing a collision diagram. At a four-leg intersection, there are 12 possible traffic movements:

- Northbound (NB) leg (left turn, through, and right turn).
- Eastbound (EB) leg (left turn, through, and right turn).
- Southbound (SB) leg (left turn, through, and right turn).
- Westbound (WB) leg (left turn, through, and right turn).

Thus, for any accident involving two vehicles, there are a total of 12 x 12 = 144 possible combinations of traffic movements. Each multiple-vehicle accident at the intersection being evaluated will be classified into one of these 144 cells. At a three-leg intersection, there are only 6 x 6 = 36 combinations of traffic movements, so 108 of the 144 cells do not exist. At multileg intersections, there are more than 144 combinations of movements, so specific procedures for handling multileg intersections will need to be developed.

In the case of one concern, *Loss of control potential due to frequent braking for NB leg*, single-vehicle accidents are also relevant. This creates 12 new classifications of interest – single-vehicle accidents involving each of the 12 traffic movements at a four-leg intersection. Thus, there are a total of 12 x 13 = 156 accident categories of interest, including single-vehicle accidents.

Some IDRM concerns are associated with only 1 of the 156 combinations of traffic movements. For example, the concern *Insufficient ISD to right (Case B1) for NB leg* is associated specifically with the NB left-turn and WB through movement. Other IDRM concerns are associated with multiple combinations of movements. For example, the concern *Increased crossing distance for NB leg* deals with potential conflicts between a NB through vehicle and the following six traffic movements:

- EB through movement.
- EB left-turn movement.
- SB left-turn movement.
- WB through movement.
- WB left-turn movement.
- WB right-turn movement.

Thus, in assessing the presence of an accident pattern for this concern, the accident frequencies for 6 of the 156 cells should be combined (i.e., summed). These are the six cells that represent the combination of the NB through movement with each of the six other movements identified above.

Accidents will be classified by the direction of travel and intended movement of the one vehicle for single-vehicle accidents and of the two vehicles for two-vehicle collisions. For collisions involving more than two vehicles, the movements associated with Vehicles 1 and 2 in the accident data will be used to classify the accident. Some States always put the offending vehicle first; others number vehicles in the order in which they became involved in the accident. In either of these cases, the use of Vehicles 1 and 2 would appear to be appropriate.

IDRM will recommend that accident patterns be identified from 3 to 5 years of accident history data. Most analysts agree that 3 years is a desirable minimum for an intersection analysis. Five years is a practical maximum because data are often not available for longer periods and, in many cases, modifications to the intersection make it inappropriate to use accident history data older than 5 years.

Threshold Number of Accidents to Constitute an Accident Pattern

A threshold value will be used to determine what minimum number of accidents constitutes an "accident pattern." Clearly, the term "accident pattern" implies that the threshold value should be greater than one accident. One accident, by itself, can hardly constitute a "pattern." An appropriate threshold would relate to the overall expected accident frequency given traffic volume, location, type of traffic control, etc. The current application of IDRM is for intersections on rural two-lane highways, which experience relatively few accidents. The threshold value, therefore, cannot be substantially greater than one, or very few "accident patterns" would be identified for normal conditions.

A review of expected accident rates at signalized and unsignalized intersections on two-lane highways was undertaken using the safety prediction models in Report No. FHWA-RD-99-207. This review found that very few two-lane highway intersections, even those with relatively high volumes, are likely to have three or more accidents during a 3- to 5-year period in a pattern associated with a specific IDRM concern. Therefore, for application to intersections on two-lane rural highways, the threshold number of accidents to identify an accident pattern should be two. (NOTE: If the IDRM concept should, at some future time be applied to higher volume roadways, such as multilane urban/suburban arterials, a threshold higher than two accidents will be appropriate. Furthermore, a threshold that varies with traffic volume level might also be appropriate in that situation.)

5.4 Algorithm For Use In IDRM

1. Standard IHSDM crash data capabilities are available to IDRM if the user elects to consider actual history data for a particular intersection.
2. As IDRM evaluates the intersection, each time an intersection-leg-related concern is identified based on the geometric design review, check the associated accident data as follows:
    - Consult Table 25 to determine the specific accident classifications associated with that concern. Use of Table 25 is described in more detail below.
    - Sum the number of accidents for all classifications shown in Table 25 for the concern in question.
    - If the total number of accidents for all classifications associated with the concern in question is two or more, then highlight the concern to indicate that it has been confirmed from accident data. If the total number of accidents is zero or one, then do not highlight the concern.

5.5 Use Of Table 25 To Identify Accident Patterns Of Interest

Table 25 presents the following data for each IDRM intersection-leg concern:

- Description of concern.
- Type of leg to which the concern applies.
- List of traffic movement pairs to which the concern applies (i.e., accident patterns).
- Number of traffic movement pairs to which the concern applies.

The table, as presented, applies to four-leg unsignalized intersections, but it can be readily adapted to signalized and three-leg intersections.

The type of leg column indicates the type of leg to which specific concerns apply at unsignalized intersections. For example, the table shows that, for the concern *Insufficient ISD to right (Case B1) for Leg A*, Leg A would normally be a minor approach. At signalized intersections, all approaches are major approaches, so if this concern is identified, it must pertain to a major approach (probably for the case of flashing operation of a signal).

The traffic movement pairs column lists the traffic movement pairs that should be considered in assessing the concern. The number of traffic movement pairs to be considered for particular concerns ranges from 1 to 23, out of the 156 combinations of interest. The intersection legs for a four-leg intersection are read as follows:

- Leg A is the leg for which the concern in question was identified.
- Leg A+1 is the next leg clockwise from Leg A (i.e., the roadway to the left of Leg A).
- Leg A+2 is the second leg clockwise from Leg A (i.e., the roadway opposite Leg A).
- Leg A+3 is the third leg clockwise from Leg A (i.e., the roadway to the right of Leg A).

Thus, if Leg A were the NB leg, then Legs A+1, A+2, and A+3 are the EB, SB, and WB legs, respectively.

At a three-leg intersection, the same rules apply, except that in applying the rules, the "missing" minor-road leg must be counted. For example, if Leg A is the minor-road leg at a three-leg intersection, then:

- Leg A+1 is the major-road leg to the left.
- Leg A+2 is the non-existent minor-road leg opposite Leg A.
- Leg A+3 is the major-road leg to the right.

Thus, if Leg A were the NB leg, then Legs A+1 and A+3 are the EB and WB legs, respectively, and Leg A+2, the SB leg, does not exist.

By contrast, if the concern applied to the major-road leg to the left of the minor-road leg at a three-leg intersection, then Leg A is a major-road leg and the movement pairs in the table would be interpreted as follows:

- Leg A+1 is the non-existent major-road leg.
- Leg A+2 is the major-road leg to the right.
- Leg A+3 is the minor-road leg.

In this situation, if Leg A were the EB leg, then Legs A+2 and A+3 would be the WB and NB legs, respectively, and the SB leg would not exist.

When applied to three-leg intersections, Table 25 includes some traffic movement pairs that do not exist. However, this should not cause any problem because, by definition, the number of accidents classified for each of these traffic movement pairs should be zero.

5.6 Summary

In summary, the approach to using site-specific accident history data in IDRM is as follows:

- Accident history data for 3 to 5 years at each intersection evaluated will be used whenever available. It is desirable, but not essential, that the accident data should be accessible to IDRM in electronic form.
- Only accidents that occur within 76 m (250 ft) of the intersection and are classified as "at intersection" or "intersection-related" are considered.

- The evaluation will focus on single- and multiple-vehicle collisions, each of which will be classified into one of 156 cells based on the movements of the involved vehicles.
- Whenever an intersection-leg concern is identified in the diagnostic review, IDRM will check the accident history for collisions involving traffic movements related to that concern. If the number of total collisions for those related traffic movements is two or more, greater attention will be directed toward that concern by presenting it in the list of concerns in a contrasting color, or a bold font, or with a special message.
- Table 25 defines which traffic movement pairs are associated with each intersection-leg concern.
- For four-leg unsignalized intersections, all concerns shown in Table 25 are considered. For signalized intersections, only the concerns for which Leg A Type is "major" or " either" are considered. For three-leg intersections, any traffic movement pair that involves a non-existent traffic movement should be ignored. However, if an approach has flashing red operation at night, while a conflicting approach has flashing yellow operation at night, the concerns for which Leg A Type is "minor" should also be considered.

Table 25. Accident Patterns for Increased Emphasis on Particular Intersection-Leg Concerns at Four-Leg Intersections

Concern	Leg A Type	Traffic Movement Pairs	No.
Insufficient ISD to right (Case B1) for Leg A	Minor	Leg A left turn vs. • Leg A+3 through • Leg A+3 left turn	2
Insufficient ISD to left (Case B2) for Leg A	Minor	Leg A right turn vs. • Leg A+1 through	1
Insufficient ISD to right (Case B3) for Leg A	Minor	Leg A through vs. • Leg A+3 through • Leg A+3 left turn • Leg A+3 right turn	3
Insufficient ISD to left (Case B3) for Leg A	Minor	Leg A through vs. • Leg A+1 through • Leg A+1 left turn	2
Insufficient ISD for left turn from major road (Case F) for Leg A	Major	Leg A left turn vs. • Leg A+2 through • Leg A+2 left turn • Leg A+2 right turn	3
Insufficient SSD for Leg A	Either	Leg A through vs. • Leg A through • Leg A left turn • Leg A right turn	9

		Leg A left turn vs. • Leg A through • Leg A left turn • Leg A right turn Leg A right turn vs. • Leg A through • Leg A left turn • Leg A right turn	

Table 25. Accident Patterns for Increased Emphasis on Particular Intersection-Leg Concerns at Four-Leg Intersections (continued)

Concern	Leg A Type	Traffic Movement Pairs	No.
Insufficient visibility of signal for Leg A	Either (if signalized)	Leg A through vs. • Leg A through • Leg A left turn • Leg A right turn • Leg A+1 through • Leg A+1 left turn • Leg A+2 left turn • Leg A+3 through • Leg A+3 left turn • Leg A+3 right turn Leg A left turn vs. • Leg A through • Leg A left turn • Leg A right turn • Leg A+1 through • Leg A+1 left turn • Leg A+2 through • Leg A+2 right turn • Leg A+2 left turn • Leg A+3 through • Leg A+3 left turn Leg A right turn vs. • Leg A through • Leg A left turn • Leg A right turn • Leg A+1 through • Leg A+2 left turn	24

Table 25. Accident Patterns for Increased Emphasis on Particular Intersection-Leg Concerns at Four-Leg Intersections (continued)

Concern	Leg A Type	Traffic Movement Pairs	No.
Insufficient visibility of stop sign for Leg A	Minor	Leg A through vs. • Leg A through • Leg A left turn • Leg A right turn • Leg A+1 through • Leg A+1 left turn • Leg A+2 left turn • Leg A+3 through • Leg A+3 left turn • Leg A+3 right turn Leg A left turn vs. • Leg A through • Leg A left turn • Leg A right turn • Leg A+1 through • Leg A+1 left turn • Leg A+2 through • Leg A+2 right turn • Leg A+2 left turn • Leg A+3 through • Leg A+3 left turn Leg A right turn vs. • Leg A through • Leg A left turn • Leg A right turn • Leg A+1 through • Leg A+2 left turn	24

Table 25. Accident Patterns for Increased Emphasis on Particular Intersection-Leg Concerns at Four-Leg Intersections (continued)

Concern	Leg A Type	Traffic Movement Pairs	No.
Insufficient visibility of yield sign for Leg A	Minor	Leg A through vs. • Leg A through • Leg A left turn • Leg A right turn • Leg A+1 through • Leg A+1 left turn • Leg A+2 left turn • Leg A+3 through • Leg A+3 left turn • Leg A+3 right turn Leg A left turn vs. • Leg A through • Leg A left turn • Leg A right turn • Leg A+1 through • Leg A+1 left turn • Leg A+2 through • Leg A+2 right turn • Leg A+2 left turn • Leg A+3 through • Leg A+3 left turn Leg A right turn vs. • Leg A through • Leg A left turn • Leg A right turn • Leg A+1 through • Leg A+2 left turn	24
Increased crossing distance for Leg A	Minor	Leg A through vs. • Leg A+1 through • Leg A+1 left turn • Leg A+2 left turn • Leg A+3 through • Leg A+3 left • Leg A+3 right	6

Warranted left-turn lane not present for Leg A	Major	Leg A left turn vs. • Leg A through • Leg A right turn • Leg A+1 through • Leg A+1 left turn • Leg A+2 through • Leg A+2 right turn • Leg A+3 through • Leg A+3 left turn	8

Table 25. Accident Patterns for Increased Emphasis on Particular Intersection-Leg Concerns at Four-Leg Intersections (continued)

Concern	Leg A Type	Traffic Movement Pairs	No.
Warranted right-turn lane not present for Leg A	Major	Leg A right turn vs. • Leg A through • Leg A left turn • Leg A+1 through • Leg A+2 left turn	4
Insufficient queue storage	Either	Leg A left turn vs. • Leg A through • Leg A left turn • Leg A right turn	3
Loss of control potential due to frequent braking for Leg A	Either	Leg A through vs. • No other vehicle (e.g., SV[1] accident) • Leg A through • Leg A left turn • Leg A right turn Leg A left turn vs. • No other vehicle (e.g., SV accident) • Leg A through • Leg A left turn • Leg A right turn • Leg A right turn vs. • No other vehicle (e.g., SV accident) • Leg A through • Leg A left turn • Leg A right turn	12

[1]SV – single-vehicle

IDRM TREATMENT RECOMMENDATIONS

When IDRM identifies a potential intersection design concern, it also identifies design changes and other measures that could eliminate or mitigate the concern. These are referred to as "treatments." Treatments that could mitigate each identified concern are presented to the user through the IDRM user interface.

The IDRM knowledge base relates concerns to the applicable treatments by means of the treatment recommendation matrix. A row in this matrix is specified by a concern, a specific geometric condition or other design element related to the concern, and a treatment that addresses that condition. For some treatments, the design element is designated as "general," indicating that the treatment is potentially applicable to the concern, regardless of the specific design element related to the concern.

Each treatment is categorized as either a "design improvement" (generally higher cost) or a "mitigation measure" (generally lower cost).

Table 26 and Table 27 present the IDRM treatment recommendation matrix for intersection concerns and intersection-leg concerns, respectively.

Table 26. List of Treatments (Design Improvements and Mitigation Measures) for Intersection Concerns

Concern Messages	Design Improvements	Mitigation Measures
4.20 Insufficient Left-Turn Bay Storage and Deceleration Length Between Closely Spaced Intersections		
- back-to-back left-turn lanes	• Relocate one or both minor-road legs • Close one minor-road leg • Provide an alternative path around the intersection for minor-road vehicles • Convert to back-to-back parallel left-turn lanes	• Prohibit left turns • Restrict left turns • Signalize intersection (*if unsignalized*) • Convert to all-way stop • Restripe with shorter taper
4.21 Insufficient Taper Length for Left-Turn Lanes Between Closely Spaced Intersections		
- back-to-back left-turn lanes	• Convert back-to-back to parallel left-turn lanes • Relocate one or both minor-road legs • Close one minor-road leg • Provide an alternative path around the intersection for minor-road vehicles	• Prohibit turns • Convert to all-way stop (*if unsignalized*) • Restripe with shorter taper

Table 26. List of Treatments (Design Improvements and Mitigation Measures) for Intersection Concerns (continued)

Concern Messages	Design Improvements	Mitigation Measures
4.22 High Traffic Conflict Index		
- multileg intersection	• Relocate one or more legs • Make one or more legs one-way • Close one or more legs	• Signalize (*if unsignalized*) • Prohibit turns • Restrict turns
4.24 Large Intersection Pavement Area		
- multileg intersection	• Add channelizing islands • Relocate one or more legs • Close one or more legs • Consider smaller design vehicle • Improve drainage • Consider roundabout	• Supplemental dotted line • Add painted channelization
- skewed intersection	• Realign one or more legs (consider offset T) • Add channelizing islands • Relocate one or more legs • Close one or more legs • Consider smaller design vehicle • Improve drainage	• Supplemental dotted line • Add painted channelization
- large vehicle turn path	• Realign approach • Rechannelize turn to accommodate design vehicle (*if channelization present*) • Increase throat width • Remove unnecessary channelization (*if channelization present*) • Consider smaller design vehicle	• Move stop bar

Table 27. List of Treatments (Design Improvements and Mitigation Measures) for Intersection-Leg Concerns

Concern Messages	Design Improvements	Mitigation Measures
4.1 - 4.7 Insufficient ISD to right (Case B1) for ___ leg		
- general	• Remove roadside obstacles within sight triangle • Close approach • Relocate approach • Make leg one-way away from intersection • Reduce upgrade on approach (*if upgrade is present*)	• Remove roadside obstacles within sight triangle • Signalize intersection (*if unsignalized*) • Convert to all-way stop (*if unsignalized*) • Convert yield control to stop control (*if yield-controlled*) • Post advisory speed on major road • Review speed limit on major road • Install warning sign on major road • Install flashing beacons (*if unsignalized*) • Prohibit left turn • Provide intersection lighting
- multileg intersection	• Close one or more legs • Relocate one or more legs	
- skewed intersection	• Realign one or more legs • Relocate one or more legs • Close one or more legs	
- more than one minor-road approach on the same side of the major road	• Close one or more legs • Relocate one or more legs • Make one or more legs one-way	
- horizontal curve	• Increase curve radius • Remove roadside obstacles on inside of curve	
- crest vertical curve	• Lengthen vertical curve	

Table 27. List of Treatments (Design Improvements and Mitigation Measures) for Intersection-Leg Concerns (continued)

Concern Messages	Design Improvements	Mitigation Measures
4.1 - 4.7 Insufficient ISD to left (Case B2) for ___ leg		
- general	• Remove roadside obstacles within sight triangle • Close approach • Relocate approach • Make leg one-way away from intersection • Reduce upgrade on approach (*if upgrade is present*) • Install channelized right-turn roadway • Provide right-turn acceleration lane	• Remove roadside obstacles within sight triangle • Signalize intersection (*if unsignalized*) • Convert to all-way stop (*if unsignalized*) • Convert yield control to stop control (*if yield-controlled*) • Post advisory speed on major road • Review speed limit on major road • Install warning sign on major road • Install flashing beacons (*if unsignalized*) • Prohibit right turn • Provide intersection lighting • Restripe shoulder as right-turn acceleration lane
- multileg intersection	• Close one or more legs • Relocate one or more legs	
- skewed intersection	• Realign one or more legs • Close one or more legs • Relocate one or more legs	
- more than one minor-road approach on the same side of the major road	• Close one or more legs • Relocate one or more legs	
- horizontal curve	• Increase curve radius • Remove roadside obstacles on inside of curve	
- crest vertical curve	• Lengthen vertical curve	

Table 27. List of Treatments (Design Improvements and Mitigation Measures) forIntersection-Leg Concerns (continued)

Concern Messages	Design Improvements	Mitigation Measures
4.1 - 4.7 Insufficient ISD to right (Case B3) for ___ leg		
- general	• Remove roadside obstacles within sight triangle • Close approach • Relocate approach • Make leg one-way away from intersection • Reduce upgrade on approach (*if upgrade is present*)	• Remove roadside obstacles within sight triangle • Signalize intersection (*if unsignalized*) • Convert to all-way stop (*if unsignalized*) • Convert yield control to stop control (*if yield-controlled*) • Post advisory speed on major road • Review speed limit on major road • Install warning sign on major road • Install flashing beacons (*if unsignalized*) • Prohibit left turn • Channelize to prohibit left turns and through movements • Provide intersection lighting
- multileg intersection	• Close one or more legs • Relocate one or more legs	
- skewed intersection	• Realign one or more legs • Relocate one or more legs • Close one or more legs	
- more than one minor-road approach on the same side of the major road	• Close one or more legs • Relocate one or more legs • Make one or more legs one-way	
- horizontal curve	• Increase curve radius • Remove roadside obstacles on inside of curve	
- crest vertical curve	• Lengthen vertical curve	

Table 27. List of Treatments (Design Improvements and Mitigation Measures) for Intersection-Leg Concerns (continued)

Concern Messages	Design Improvements	Mitigation Measures
4.1 - 4.7 Insufficient ISD to left (Case B3) for ___ leg		
- general	• Remove roadside obstacles within sight triangle • Close approach • Relocate approach • Make leg one-way away from intersection • Reduce upgrade on approach (*if upgrade is present*) • Install channelized right-turn roadway • Provide right-turn acceleration lane	• Remove roadside obstacles within sight triangle • Signalize intersection (*if unsignalized*) • Convert to all-way stop (*if unsignalized*) • Convert yield control to stop control (*if yield-controlled*) • Post advisory speed on major road • Review speed limit on major road • Install warning sign on major road • Install flashing beacons (*if unsignalized*) • Prohibit right turn • Channelize to prohibit through movements • Provide intersection lighting • Restripe shoulder as right-turn acceleration lane
- multileg intersection	• Close one or more legs • Relocate one or more legs	
- skewed intersection	• Realign one or more legs • Close one or more legs • Relocate one or more legs	
- more than one minor-road approach on the same side of the major road	• Close one or more legs • Relocate one or more legs	
- horizontal curve	• Increase curve radius • Remove roadside obstacles on inside of curve	
- crest vertical curve	• Lengthen vertical curve	

Table 27. List of Treatments (Design Improvements and Mitigation Measures) for Intersection-Leg Concerns (continued)

Concern Messages	Design Improvements	Mitigation Measures
4.1 - 4.7 Insufficient ISD for left turn from major road (Case F) for ___ leg		
- general	• Close departure roadway • Relocate departure roadway • Make departure roadway one-way toward intersection • Provide left-turn lane on major road • Provide left-turn lanes with positive offset	• Prohibit left turns • Restrict left turns • Signalize and provide exclusive left-turn lane signal phase (*if unsignalized*) • Provide exclusive left-turn signal phase • Post advisory speed on major road • Review speed limit on major road • Install warning sign on major road • Install flashing beacons (*if unsignalized*) • Provide intersection lighting
- multileg intersection	• Close one or more legs • Relocate one or more legs	
- skewed intersection	• Realign one or more legs • Relocate one or more legs • Close one or more legs	
- more than one minor-road approach on the same side of the major road	• Close one or more legs • Relocate one or more legs • Make one or more legs one-way	
- horizontal curve	• Increase curve radius • Remove roadside obstacles on inside of curve	
- crest vertical curve	• Lengthen vertical curve	

Table 27. List of Treatments (Design Improvements and Mitigation Measures) for Intersection-Leg Concerns (continued)

Concern Messages	Design Improvements	Mitigation Measures
4.8 - 4.9 Insufficient SSD for ___ leg		
- horizontal curve	• Increase curve radius • Remove roadside obstacles on inside of curve • Close intersection • Relocate intersection • Lengthen intersection approach channelization (*if left-turn lane present*) • Provide left-turn lane (*if no left-turn lane present*)	• Post advisory speed on curve • Reduce speed limit • Install warning sign • Prohibit turns • Install advance warning beacon and sign
- crest vertical curve	• Lengthen vertical curve • Close intersection • Relocate intersection • Lengthen intersection approach channelization (*if left-turn lane present*) • Provide left-turn lane (*if no left-turn lane present*)	• Post advisory speed on curve • Reduce speed limit • Install warning sign • Prohibit turns • Install advance warning beacon and sign
- multileg intersection	• Close one or more legs • Relocate one or more legs	
- more than one minor-road approach on the same side of the major road	• Close one or more legs • Relocate one or more legs • Make one or more legs one-way	
4.10 Insufficient Visibility of Traffic Signal		
- general	• Realign approach • Remove roadside sight obstructions	• Move traffic control device • Install advance warning sign • Provide supplemental traffic control device • Install advance warning beacon and sign
4.11 Insufficient Visibility of Stop Sign		
- general	• Realign approach • Remove roadside sight obstructions	• Move traffic control device • Install advance warning sign

		• Provide supplemental traffic control device • Install advance warning beacon and sign

Table 27. List of Treatments (Design Improvements and Mitigation Measures) for

Intersection-Leg Concerns (continued)

Concern Messages	Design Improvements	Mitigation Measures
4.12 Insufficient Visibility of Yield Sign		
- general	• Realign approach • Remove roadside sight obstructions	• Move traffic control device • Install advance warning sign • Provide supplemental traffic control device • Install advance warning beacon and sign
4.13 - 4.16 Insufficient DSD for ___ leg		
- horizontal curve	• Increase curve radius • Remove roadside obstacles on inside of curve • Close intersection • Relocate intersection • Lengthen intersection approach channelization (*if left-turn lane present*) • Provide left-turn lane (*if no left-turn lane present*)	
- crest vertical curve	• Lengthen vertical curve • Close intersection • Relocate intersection • Lengthen intersection approach channelization (*if left-turn lane present*) • Provide left-turn lane (*if no left-turn lane present*)	
- multileg intersection	• Close one or more legs • Relocate one or more legs	

- more than one minor-road approach on the same side of the major road	• Close one or more legs • Relocate one or more legs • Make one or more legs one-way	

Table 27. List of Treatments (Design Improvements and Mitigation Measures) for Intersection-Leg Concerns (continued)

Concern Messages	Design Improvements	Mitigation Measures
	Increased Crossing Distance	
- skewed intersection	• Realign one or more legs • Relocate one or more legs • Close one or more legs	• Signalize intersection (*if unsignalized*) • Convert to all-way stop (*if unsignalized*) • Convert yield control to stop control (*if yield-controlled*) • Post advisory speed on major road • Reduce speed limit on major road • Install warning sign on major road • Install flashing beacons (*if unsignalized*) • Provide lighting • Increase signal clearance on all-red time (*if signalized*)
	4.18 Warranted Left-Turn Lane Is Not Present	
- general	• Provide left-turn lane	• Provide shoulder bypass lane (*if three-leg intersection and unsignalized*) • Provide warning signs • Prohibit left turns • Restrict left turns • Provide split phasing (*if signalized*) • Restripe or reallocate approach lane configuration
	4.19 Warranted Right-Turn Lane Is Not Present	
- general	• Provide right-turn lane • Provide channelized right-turn roadway	• Restripe or reallocate approach lane configuration

	• Provide right-turn acceleration lane	• Install advance warning sign
4.23 Uneven, Discontinuous Minor-Road Profile Through Intersection		
- general	• Redesign minor-road profile through intersection	• Provide warning signs • Spot resurfacing

Table 27. List of Treatments (Design Improvements and Mitigation Measures) for Intersection-Leg Concerns (continued)

Concern Messages	**Design Improvements**	**Mitigation Measures**
4.25 Approach Alignment Differs Between Opposing Approaches		
- general	• Realign one or more legs • Provide horizontal curve to eliminate deflection angle	• Add painted channelization to delineate vehicle path • Review speed limit on approach legs • Post advisory speed signs on approach legs • Install flashing beacons (*if unsignalized*) • Convert to all-way stop (*if unsignalized*) • Provide intersection lighting
4.26 Insufficient Queue Storage		
- general	• Increase storage-bay length	• Prohibit left turns • Restrict left turns • Signalize intersection • Convert to all-way stop • Restripe turn bay with a shorter taper length
4.27 Loss of Control Potential Due to Frequent Braking		
- horizontal curve	• Relocate intersection • Increase curve radius • Provide left-turn lane • Provide right-turn lane • Increase superelevation • Improve drainage	• Provide more skid-resistant pavement • Post advisory speed • Reduce speed limit • Install warning sign • Increase signal clearance on all-red time (*if signalized*)

APPENDIX A – IDRM TREATMENT DETAILS

When IDRM identifies a potential intersection design concern, it also identifies design changes and other measures that could eliminate or mitigate the concern. These are referred to as "treatments." Treatments that could mitigate each identified concern are presented to the user through the IDRM user interface.

Appendix A is intended to provide additional information on recommended treatment options that are generated by executing IDRM. The information provided in Appendix A is intended to provide a sampling of what types of information may ultimately be provided to the IDRM user. Basic information is expected to be gathered from readily available sources such as AASHTO Policy, State DOT design manuals, the *Highway Capacity Manual*, NCHRP Research Reports, etc.

Information presented in this document is in text form. Eventually, information could be made available within the IHSDM framework to provide online help. Real-time links to key sources of information should be considered as the concept is developed further.

Appendix A highlights information on treatment options for skewed intersections and intersections without turning lanes. Discussion of these topics is not intended to be all-encompassing. Rather, the information presented herein is intended to provide the reader with a sense of the type of information that is expected to be ultimately provided to IDRM users.

Skewed Intersection Treatment Details

Roadways intersecting at acute angles tend to:

- Increase the time required for vehicles to cross the intersection.
- Have large turning roadway areas (increased pavement area).
- Limit the visibility of turning vehicles (sight distance problems).

Geometric design improvements generally focus on realigning, relocating, or closing one or more legs of the intersection to improve the angle of intersection. The reader is directed to two sources highlighting implementation of treatment options:

1. AASHTO Policy (pp. 584-585) - The information from these pages, which pertains to roadway alignment, will be displayed.
2. *Ohio Department of Transportation (ODOT) Location and Design Manual Volume 1: Roadway Design* - The intersection at-grade information from p. 4-1 will be displayed.

(Note: ODOT design manual information can be substituted with any DOT standard practice.)

Turn-Lane Treatment Details

Turn lanes are desirable from both a safety and an operational standpoint. Providing a turn lane allows decelerating and stopped vehicles to remove themselves from the through-traffic stream and can increase the available capacity at an intersection. Desirably, the auxiliary lane should allow for deceleration and storage of turning vehicles.

The reader is directed to two sources highlighting implementation of treatment options:

1. AASHTO Policy (pp. 717-720) - The information from these pages will be displayed.

2. *Ohio Department of Transportation Location and Design Manual Volume 1: Roadway Design* - The information pertaining to turn-lane treatments, pp. 4-3 and 4-4, and the accompanying figures from Sections 401-5 through 401-8, will be displayed.

(Note: ODOT design manual information can be substituted with any DOT standard practice.)