Data-Driven Safety Analysis – Nominal vs. Substantive Safety.

Integrating Safety Performance into ALL Highway Investment Decisions

Efficiency through technology and collaboration

Every Day Counts

innovation ingenuity imagination invention

U.S. Department of Transportation
Federal Highway Administration

"Safety"

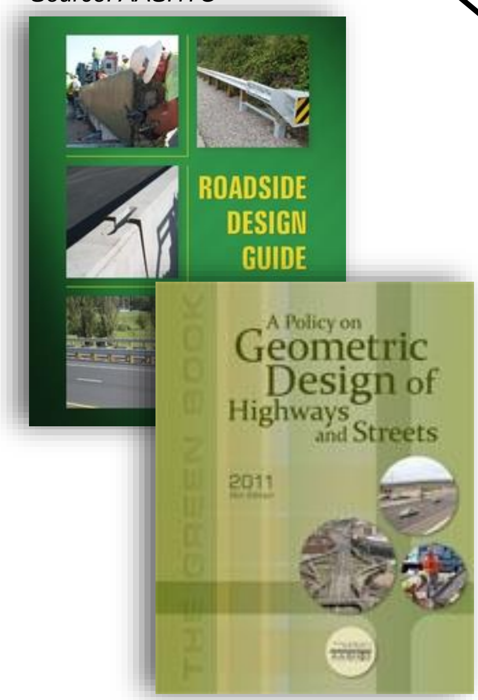
- A core value for all transportation agencies
- Our customers have been assured that maintaining and improving safety is a top priority
- Much of an agency's investments are intended to produce a "safe" highway or system
- "Safety" has traditionally been incorporated in highway programs and projects within a standards-based framework

Approaches for Considering Safety

Nominal Safety

Substantive Safety

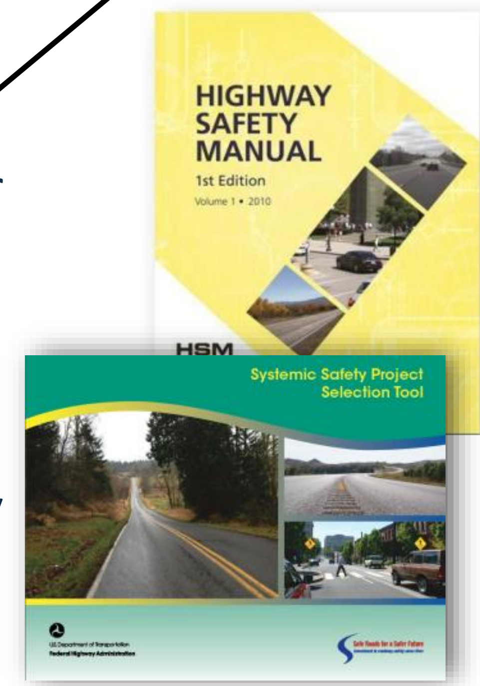
Source: AASHTO



Examined in reference to compliance with standards, warrants, guidelines and sanctioned design procedures

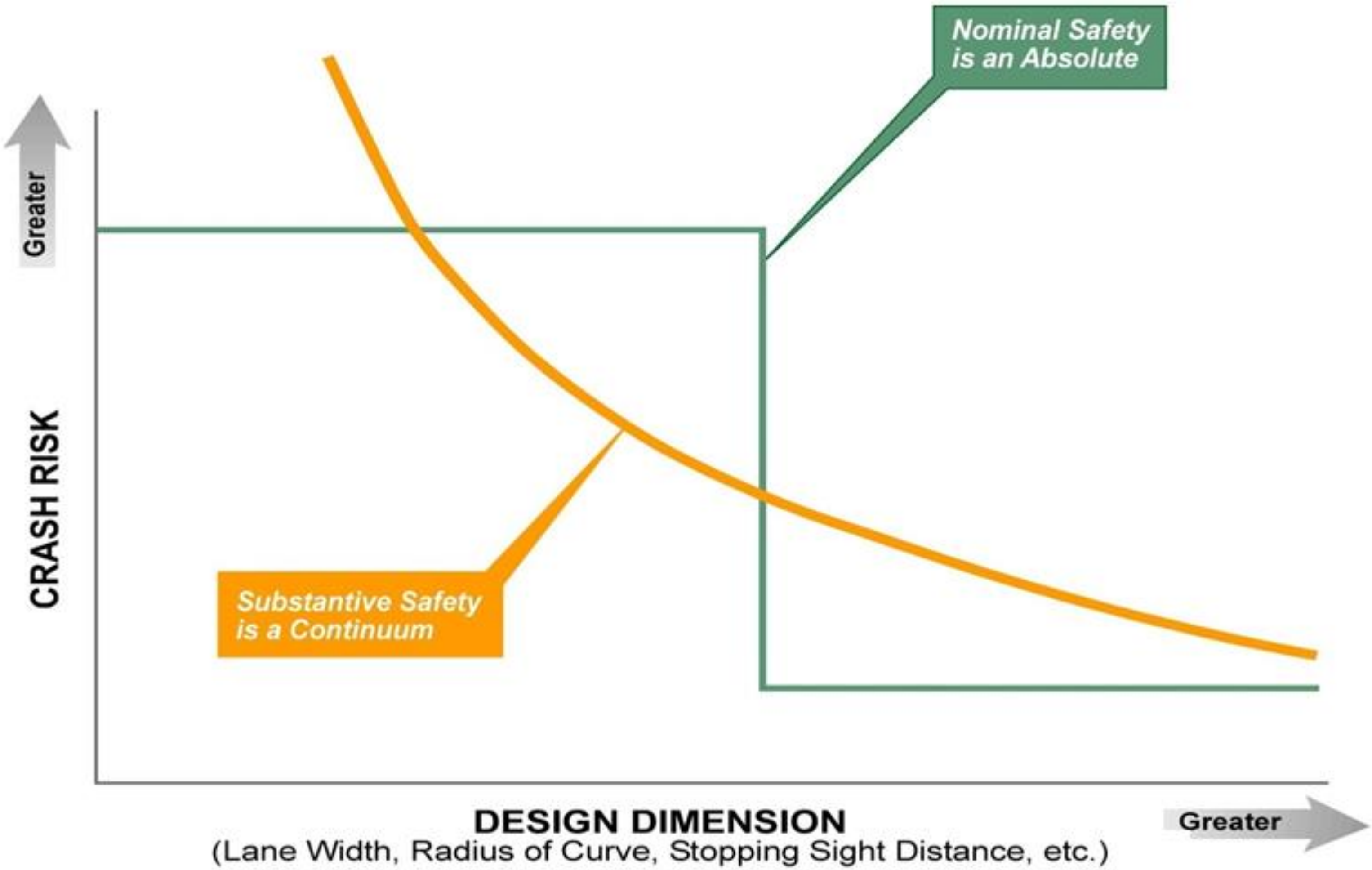
The actual or expected performance in terms of crash frequency and severity

Source: AASHTO



**Adapted from Ezra Hauer, ITE Traffic Safety Toolbox Introduction, 1999*

Nominal vs Substantive Safety



Hwy Design Standards in the U.S.

Initially, AASHO's Committee on Standards confined itself to disseminating information on design to its members, but in 1928 it proposed that the Association adopt "standards of practice" to guide the member States in technical matters in which some uniformity from State to State was urgently needed. As a result, on March 1, 1928, AASHO approved its first four standards which read as follows:

- That wherever practicable shoulders along the edges of pavements shall have a standard width of not less than 8 feet.
- That on pavements 10 feet shall be considered as the standard width for each traffic lane.
- That the crown of a two-lane concrete pavement shall be 1 inch.
- That no part of a concrete pavement shall have a thickness of less than 6 inches, and that all unsupported edges shall be strengthened. (6)

Hwy Design Standards in the U.S.

TABLE 1-1
Evolution of AASHTO (AASHO) Design Policies in the United States[1]

A Policy on Highway Classification, September 16, 1938
A Policy on Highway Types (Geometric), February 13, 1940
A Policy on Sight Distance for Highways, February 17, 1940
A Policy on Criteria for Marking and Signing No-Passing Zones for Two and Three-Lane Roads, February 17, 1940
A Policy on Intersections at Grade, October 7, 1940
A Policy on Rotary Intersections, September 26, 1941
A Policy on Grade Separations for Intersecting Highways, June 19, 1944
A Policy on Design Standards-Interstate, Primary and Secondary Systems, 1945
Policies on Geometric Highway Design, 1950
A Policy on Geometric Design of Rural Highways, 1954
A Policy on Arterial Highways in Urban Areas, 1957
A Policy on Geometric Design of Rural Highways, 1965
A Policy on Design of Urban Highways and Arterial Streets, 1973
A Policy on Geometric Design of Highways and Streets, 1984
A Policy on Geometric Design of Highways and Streets, 1990
A Policy on Geometric Design of Highways and Streets, 1994
A Policy on Geometric Design of Highways and Streets, 2001

Hwy Design Standards in the U.S.

TITLE 23 - HIGHWAYS
CHAPTER 1 - FEDERAL-AID HIGHWAYS

§ 109. Standards

(a) In General.— The Secretary shall ensure that the plans and specifications for each proposed highway project under this chapter provide for a facility that will—

(1) adequately serve the existing and planned future traffic of the highway in a manner that is conducive to safety, durability, and economy of maintenance; and

(2) be designed and constructed in accordance with criteria best suited to accomplish the objectives described in paragraph (1) and to conform to the particular needs of each locality.

Federal Highway Administration, DOT

in the geometric and structural design of highways.

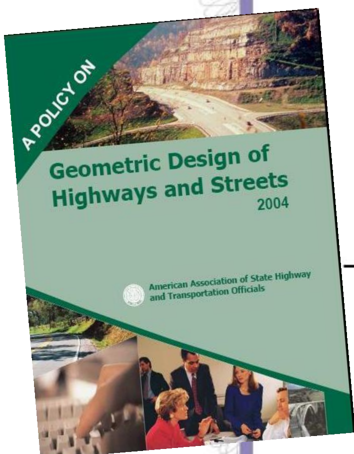
§ 625.2 Policy.

(a) Plans and specifications for proposed National Highway System (NHS) projects shall provide for a facility that will—

(1) Adequately serve the existing and planned future traffic of the highway in a manner that is conducive to safety, durability, and economy of maintenance; and

(2) Be designed and constructed in accordance with criteria best suited to accomplish the objectives described in paragraph (a)(1) of this section and to conform to the particular needs of each locality.

FHWA Adopts AASHTO for NHS



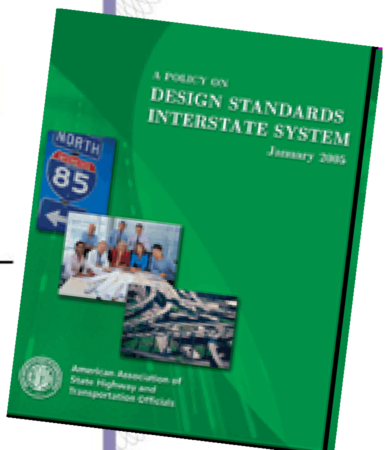
AASHTO Policies on Geometric Design

§ 625.4 Standards, policies, and standard specifications.

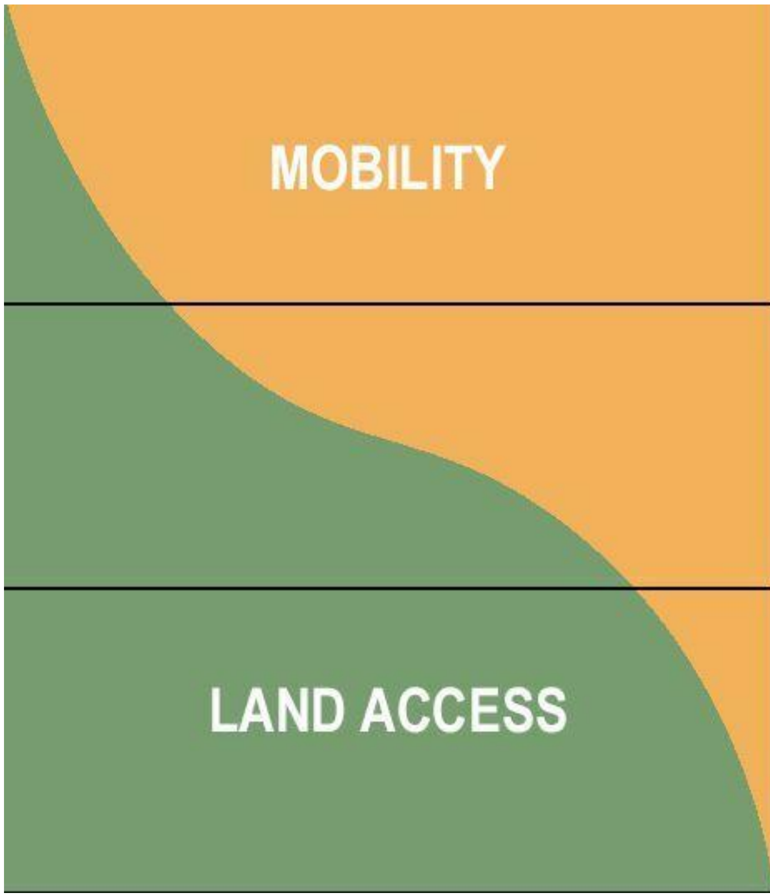
The documents listed in this section are incorporated by reference with the approval of the Director of the Federal Register in accordance with 5 U.S.C. 552(a) and 1 CFR part 51 and are on file at the Office of the Federal Register in Washington, DC. They are available as noted in paragraph (d) of this section. The other CFR references listed in this section are included for cross-reference purposes only.

(a) *Roadway and appurtenances.* (1) A Policy on Geometric Design of Highways and Streets, AASHTO 2001. [See § 625.4(d)(1)]

(2) A Policy on Design Standards Interstate System, AASHTO, January 2005. [See § 625.4(d)(1)]



Defining the Function



Arterials

- higher mobility
- low degree of access

Collectors

- balance between mobility and access

Locals

- lower mobility
- high degree of access

Functional Classification

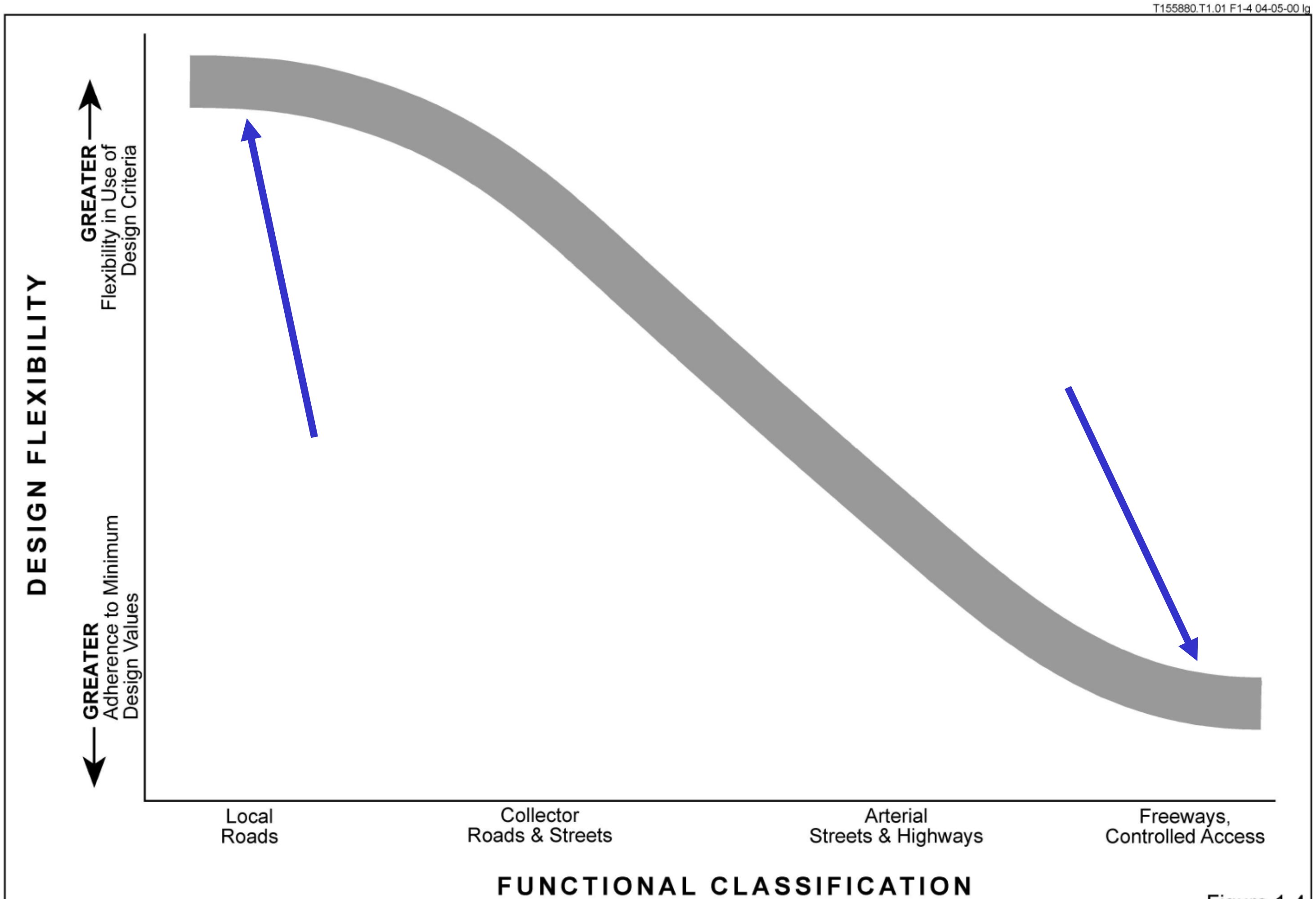
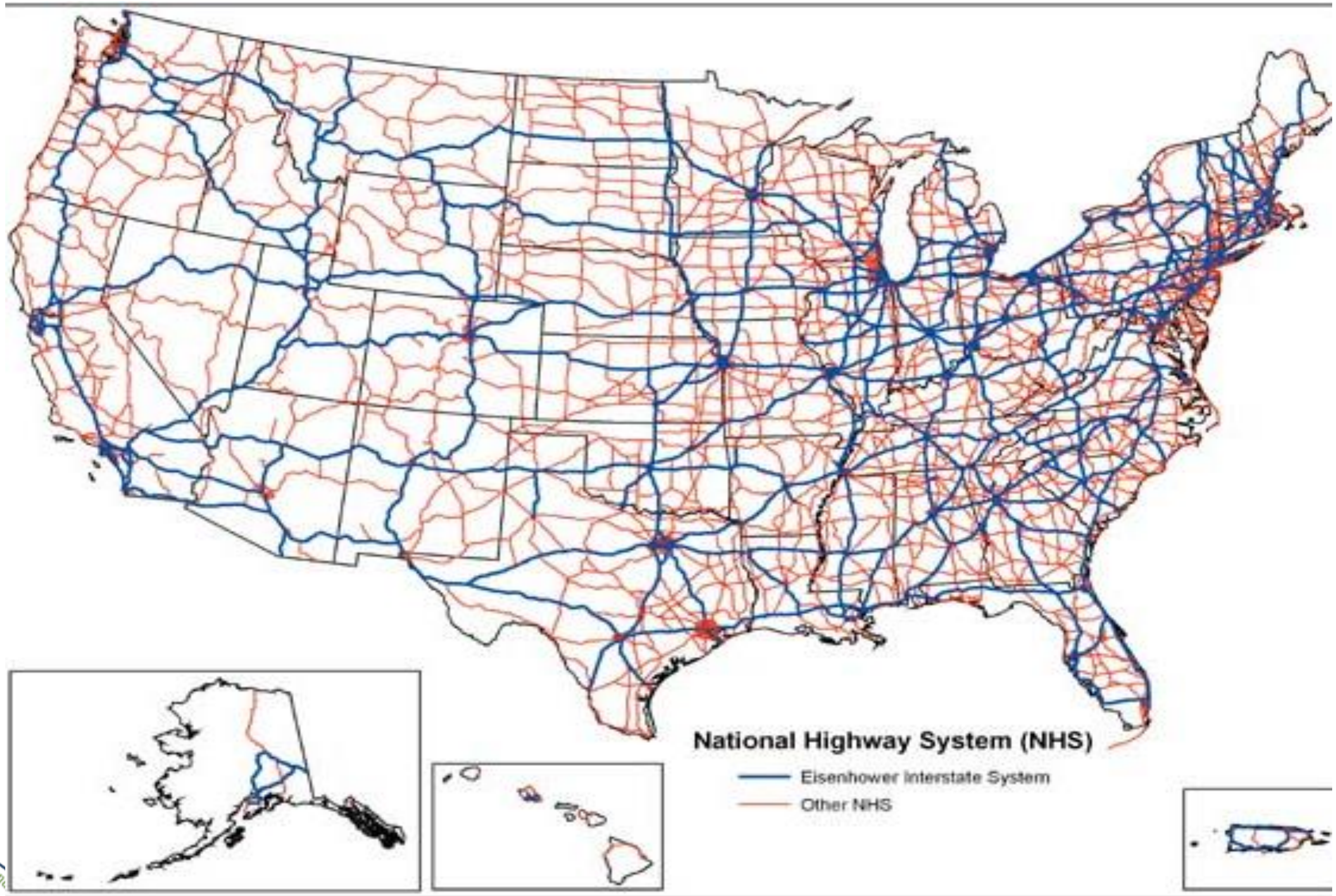


Figure 1-4
Functional Classification Versus Flexibility in Design

FHWA Standards Only for NHS

(o) **Compliance With State Laws for Non-NHS Projects.—** Projects (other than highway projects on the National Highway System) shall be designed, constructed, operated, and maintained in accordance with State laws, regulations, directives, safety standards, design standards, and construction standards.

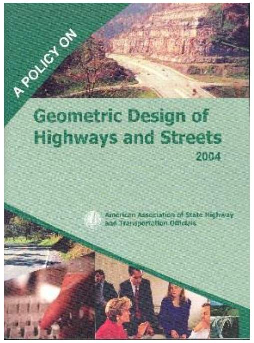


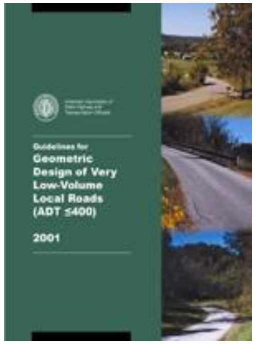
States Designate Standards Off NHS

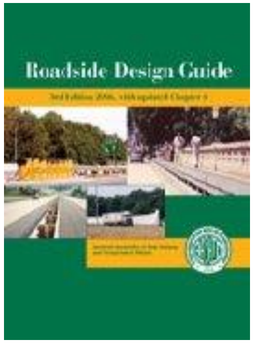
State Roadway Design Manuals

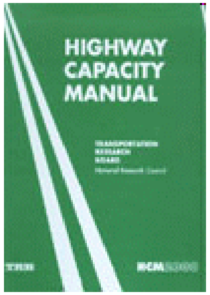
The table below indicates the online location of State highway agency roadway design manuals, when available. If the design manual is not available online the URL listed is the State web site with other design information. If you are just looking for State Standard Drawings, see http://www.fhwa.dot.gov /programadmin/statestandards.cfm

State	URL
AL	Design Bureau's Engineering Support Section
AK	Standard Specs
AZ	Engineering Records Publications
AR	Arkansas State Highway & Transporation Department Info
CA	Highway Design Manual
CO	CDOT Design Guide 2005
CT	Division of State Design
DE	Road Design Manual
DC	Design and Engineering Manual
FL	Designer Manuals
GA	GDOT Construction Standards & Details
HI	Highways - Design Branch
ID	Design Manual
IL	Bureau of Design & Environment Manual - 2002 Edition
IN	Design Manual
IA	Office of Design - Design Manual (.pdf)
KS	Standard Specifications for State Road and Bridge Construction
KY	Highway Design Manual
LA	Road Design Manual
ME	Contractor Information
MD	Business Standards and Specifications









A Predictive Illustration…

All three of these meet design standards…

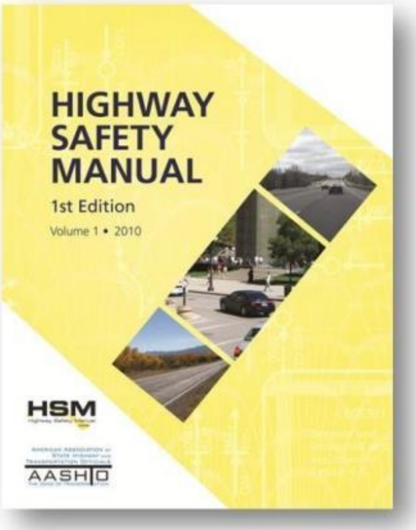
Source: CH2MHILL

but predictive analysis tells us they would perform very differently from a safety perspective.

The EDC Data-Driven Safety Analysis Initiative…

- Goal: Integrate **safety performance** into **ALL** highway investment decisions

What is the HSM?

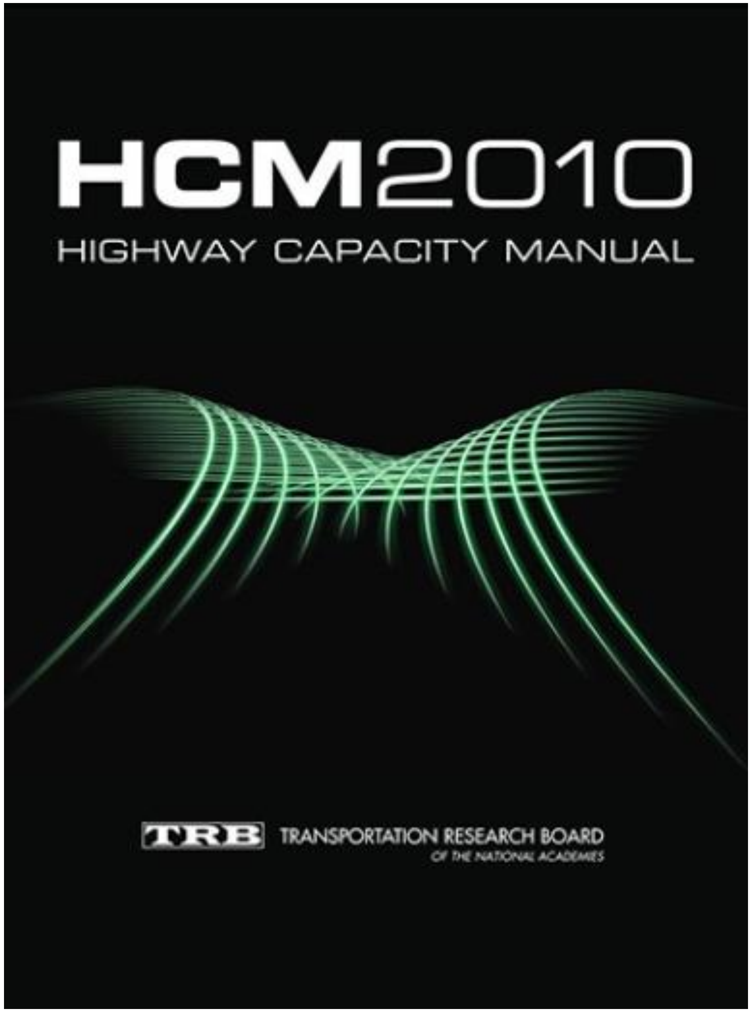


- A tool that applies an **evidence-based** technical approach to safety
- Provides reliable **estimates** of an existing or proposed roadway's **expected safety performance**.
- Helps agencies **quantify** the **safety impacts** of transportation decisions, similar to the way agencies quantify:
  - traffic growth
  - environmental impacts
  - traffic operations
  - pavement life
  - construction costs

The Vision for the HSM

A Document Akin To the HCM…

1. Definitive; represents quantitative 'state-of-the-art' information
2. Widely accepted within professional practice of transportation engineering
3. Science-based; updated regularly to reflect research



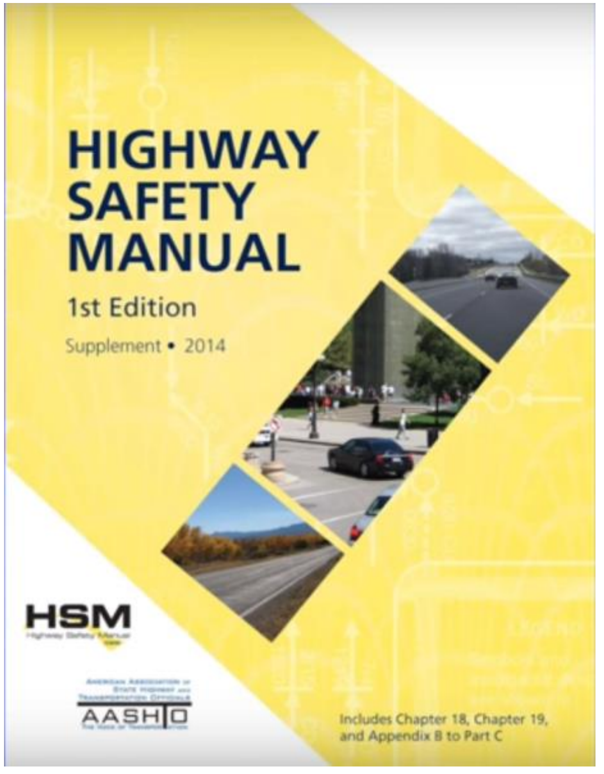
AASHTO Highway Safety Manual, First Edition

2010 Release:

- Rural Two-Lane Roads
- Multilane Rural Highways
- Urban/Suburban Arterials

2014 Supplement:

- Freeway Segments
- Ramps
- Ramp Terminals



Highway Safety Manual Organization

Part A	Introduction, Human Factors & Fundamentals
Part B	Safety Management Process
Part C	Predictive Methods
Part D	Crash Modification Factors

HSM Companion Software

HSM Part	Supporting Tool
PART B: Roadway Safety Management Process	AASHTOWare SafetyAnalyst Agile Assets Safety Analyst CARE Numetric usRAP Vision Zero Suite Other commercial… State-Developed
PART C: Predictive Methods	HSM & ISATe Spreadsheets IHSDM
PART D: CMFs	FHWA CMF Clearinghouse

Design Practice Involves Risk

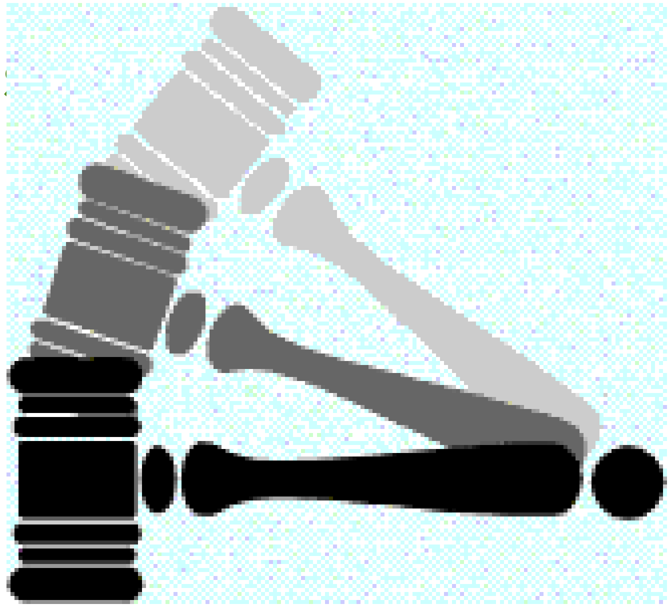
- Two fundamental types of risk:
  - Risk of tort lawsuits arising from crashes alleged to be associated with a design ("Tort Risk")
  - Risk of the solution not performing as expected in terms of safety and operations ("Engineering Risk")

Tort Risk

- Adherence to criteria does not automatically prove <u>*reasonable care*</u>
- Deviation from criteria does not automatically prove <u>*negligence*</u>

Tort Risk

- In most jurisdictions, the Court does not have authority to rule that the design decision was the "correct" choice
- The Court can only render judgment on whether the process was complete and whether the outcome was reasonable given the process



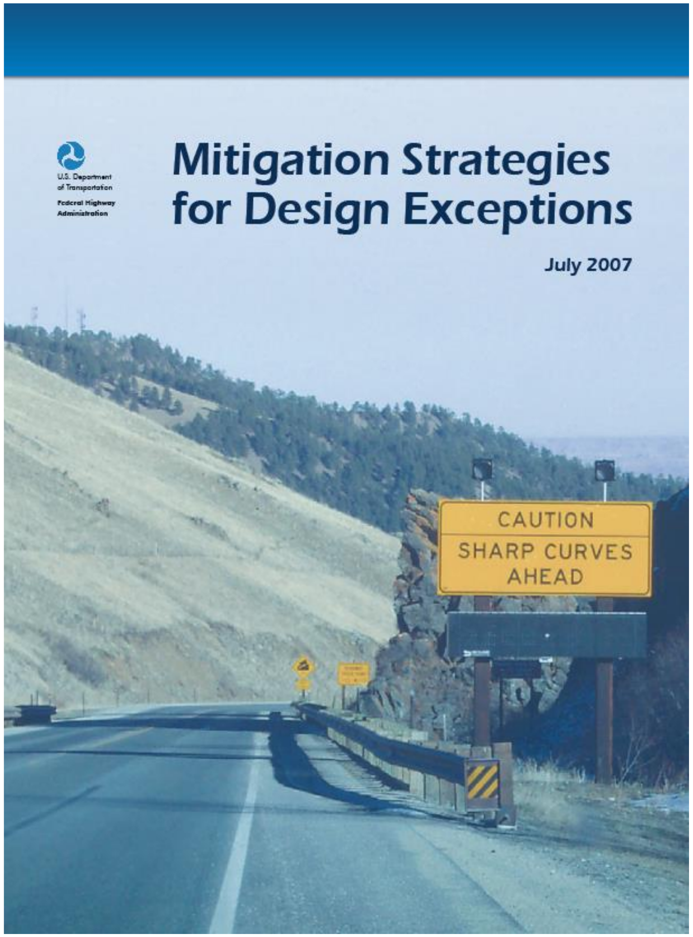
Meeting Design Criteria Important

- "Transportation agencies limit greatly the risk of a successful tort suit by focusing on design solutions that are proven, i.e., that are within current design guidelines and criteria".
- "Providing a nominally safe design is the first and major step toward minimizing tort risk".

Engineering Risk

- How good (or poor) is the existing substantive safety performance?
- What should the long term safety performance of the roadway be?
- What is the difference in expected substantive safety if the exception is implemented?

Engineering Risk



- What is the degree to which a standard is being reduced?
- Will the exception affect other geometric elements?
- What additional features will be introduced, (e.g., signing or delineation) that would mitigate the potential adverse effects of the exception?

CSS Approach Helps Minimize Risk

- It is an unavoidable fact that DOTs face public and legal scrutiny for virtually all their actions.
- However, if a design team works closely with stakeholders, is creative within the bounds of good engineering practice, and fully documents all decisions, they will have gone a long way toward minimizing the risk associated with a future tort action should that occur

Case Study – Arizona DOT

Parameters for Existing & Proposed Conditions:

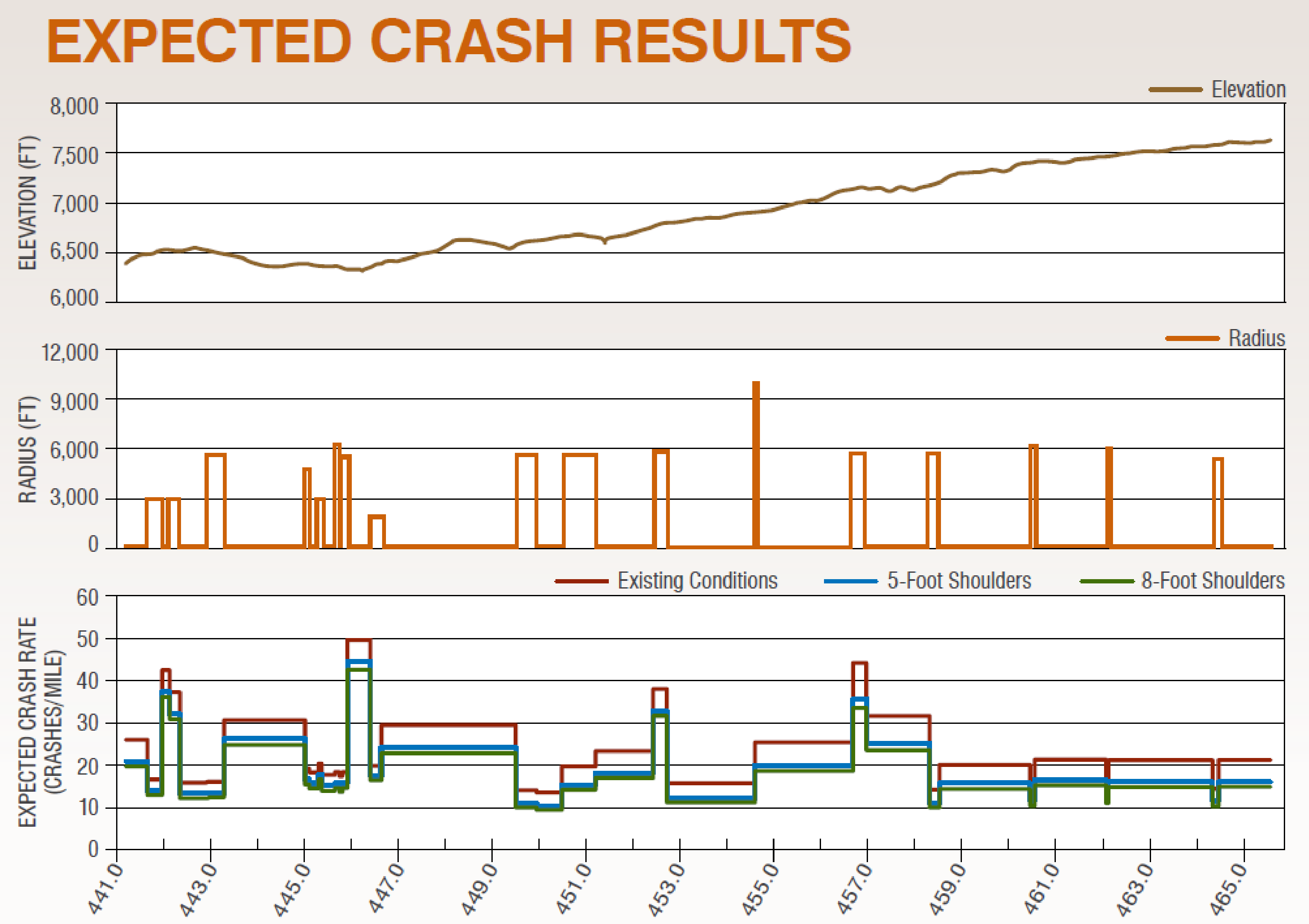
- Used IHSDM to perform safety analysis

ROADWAY ELEMENT	HSM Base Condition	Existing SR 264 (1-Foot Shoulders)	Alternative A (5-Foot Shoulders)	Alternative B (8-Foot Shoulders)
Lane width	12-Foot	12-Foot	12-Foot	12-Foot
Shoulder width	6-Foot	1-Foot	5-Foot	8-Foot
Shoulder type	Paved	Paved	Paved	Paved
Roadside hazard rating	3	Varies (6 or 7 most frequent)	Varies (1 or 2 most frequent)	Varies (1 or 2 most frequent)
Driveway density	≤ 5 per mile	Per survey & Holbrook District turnout database	Per survey & Holbrook District turnout database	Per survey & Holbrook District turnout database
Horizontal curves: length, radius, and presence or absence of spiral transitions	None	Per best fit alignment	Per best fit alignment (match existing)	Per best fit alignment (match existing)
Horizontal curves: Superelevation	None	Per as-builts & survey	Per as-builts & survey (match existing)	Per as-builts & survey (match existing)
Grades	≤ 3%	Per as-builts & survey	Per as-builts & survey (match existing)	Per as-builts & survey (match existing)
Centerline rumble strips	None	None	Present	Present
Passing lanes	None	Per survey	Per survey (match existing)	Per survey (match existing)
Two-way left-turn lanes	None	Per survey	Per survey (match existing)	Per survey (match existing)
Lighting	None	Present @ US 191 Intersection	Present @ US 191 Intersection (match existing)	Present @ US 191 Intersection (match existing)
Automated speed enforcement	None	None	None	None

Source: Arizona DOT

Case Study – Arizona DOT

Plot of Geometric Features and Expected Crashes



Source: Arizona DOT

Case Study – Arizona DOT

Crash Prediction Results

Expected Crash Frequency by Severity: 2016–2036

Source: Arizona Department of Transportation, Traffic Safety Evaluation Report

Alternative	Total Crashes	Fatal and Injury Crashes	Property Damage Only Crashes	Reduction in Total Crashes over Existing Conditions	Percent Reduction
No Build	636.4	283.4	353.0	—	—
Alternative A	531.6	230.5	301.1	104.8	16.5
Alternative B	504.2	216.8	287.4	132.2	20.8
Only Superelevation Improvements	635.3	282.7	352.6	1.1	0.2

- **IHSDM Safety Analysis:**
  - Model was un-calibrated as used (not necessary for comparative alternatives analysis)
  - **Alternative B** (8-ft shoulders) **would reduce crashes by 4 percent more** than Alternative A (5-ft shoulders)

IHSDM "Safer Roads Through Better Design"

Case Study – Arizona DOT

Benefit to Cost Ratio: Design Alternatives

Alternative	Annual Benefit	Annual Cost	Benefit/Cost Ratio
Alternative A	$3,873,681	$1,680,561	2.30
Alternative B	$5,084,207	$2,678,713	1.90
Superelevation Improvements	$41,807	$135,464	0.31

Source: Arizona Department of Transportation, Traffic Safety Evaluation Report

- **Economic analysis:**
  - Although Alternative B (8-ft shoulders) could provide the greater benefit in reduction in fatal and injury crashes, **Alternative A** (5-ft shoulders) would provide the **greater return on investment** and was selected as the preferred alternative.

IHSDM
"Safer Roads Through Better Design"

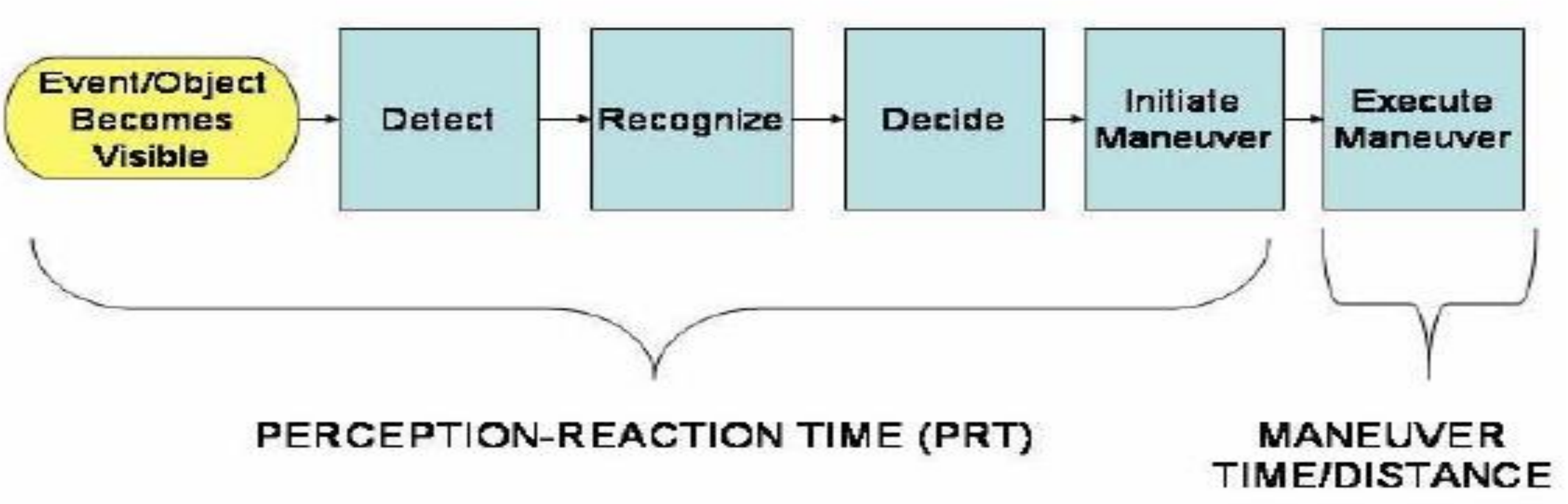
Example – Stopping Sight Distance (SSD)

Distance required to perceive an object in roadway and bring vehicle to a stop

"… the sight distance at every point along a roadway should be at least that needed for a below-average driver or vehicle to stop."

AASHTO Green Book Chapter 3

SSD Conceptual Model



SSD = perception reaction distance + braking distance

$SSD = 1.47\ V\ t + (1.075\ V^2 / a)$

V = design speed in mph

t = percept reaction time (2.5 sec)

a = deceleration rate (11.2 ft/sec^2)

SSD Conceptual Model

SCHEMATIC SHOWING THE PERCEPTION-REACTION TIME AND MANEUVER TIME COMPONENTS OF SIGHT DISTANCE

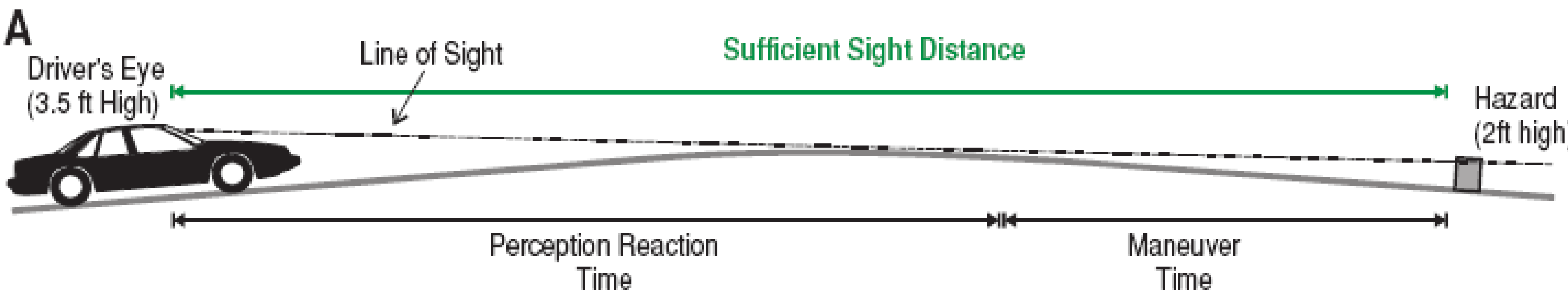


Diagram A: The hazard is visible to the driver far enough away that there is sufficient distance for the driver to recognize and react to the hazard and to complete the maneuver necessary to avoid it.

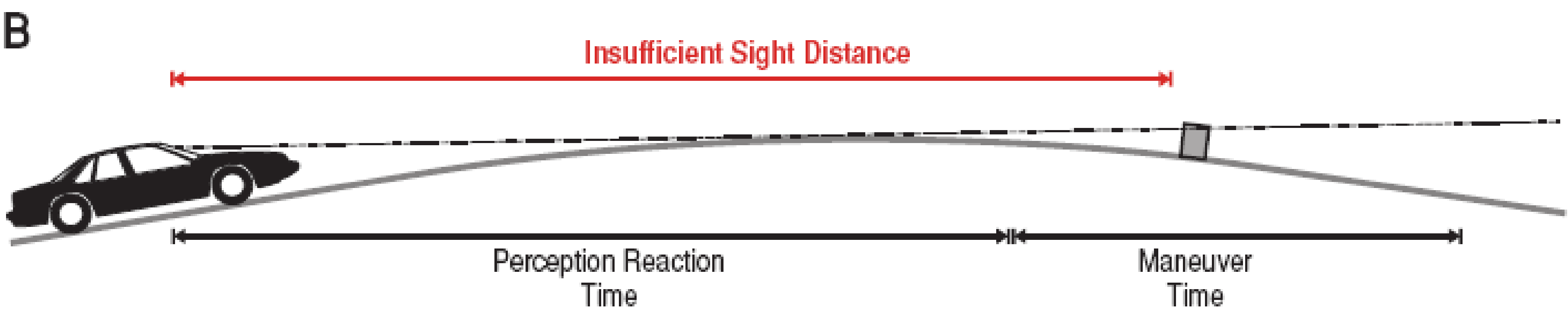


Diagram B: Because of the steeper vertical crest, the driver's sight distance is shorter than in Diagram A making it possible for a hazard to be hidden from sight until there is *insufficient distance to avoid it.*

**Note: distances not to scale*

SSD Design Values

Design speed (mph)	Stopping sight distance: Calculated (ft)	Stopping sight distance: Design (ft)
15	76.7	80
20	111.9	115
25	151.9	155
30	196.7	200
35	246.2	250
40	300.6	305
45	359.8	360
50	423.8	425
55	492.4	495
60	566.0	570
65	644.4	645
70	727.6	730
75	815.5	820
80	908.3	910

From Exhibit 3-1, AASHTO Green Book

Level Terrain

US Customary						
Design speed (mph)	Stopping sight distance (ft)					
	Downgrades			Upgrades		
	3 %	6 %	9 %	3 %	6 %	9 %
15	80	82	85	75	74	73
20	116	120	126	109	107	104
25	158	165	173	147	143	140
30	205	215	227	200	184	179
35	257	271	287	237	229	222
40	315	333	354	289	278	269
45	378	400	427	344	331	320
50	446	474	507	405	388	375
55	520	553	593	469	450	433
60	598	638	686	538	515	495
65	682	728	785	612	584	561
70	771	825	891	690	658	631
75	866	927	1003	772	736	704
80	965	1035	1121	859	817	782

From Exhibit 3-2, AASHTO Green Book

SSD on Grades

SSD Design Values

Design speed (mph)	Stopping sight distance: Calculated (ft)	Stopping sight distance: Design (ft)
15	76.7	80
20	111.9	115
25	151.9	155
30	196.7	200
35	246.2	250
40	300.6	305
45	359.8	360
50	423.8	425
55	492.4	495
60	566.0	570
65	644.4	645
70	727.6	730
75	815.5	820
80	908.3	910

From Exhibit 3-1, AASHTO Green Book

Level Terrain

US Customary						
Design speed (mph)	Stopping sight distance (ft)					
	Downgrades			Upgrades		
	3 %	6 %	9 %	3 %	6 %	9 %
15	80	82	85	75	74	73
20	116	120	126	109	107	104
25	158	165	173	147	143	140
30	205	215	227	200	184	179
35	257	271	287	237	229	222
40	315	333	354	289	278	269
45	378	400	427	344	331	320
50	446	474	507	405	388	375
55	520	553	593	469	450	433
60	598	638	686	538	515	495
65	682	728	785	612	584	561
70	771	825	891	690	658	631
75	866	927	1003	772	736	704
80	965	1035	1121	859	817	782

From Exhibit 3-2, AASHTO Green Book

SSD on Grades

SSD Design Recommendations

"Stopping sight distances exceeding those shown in Exhibit 3-1 should be used as the basis for design wherever practical. Use of longer stopping sight distances increases the margin of safety for all drivers …"

"The recommended stopping sight distances are based on passenger car operations and do not explicitly consider design for truck operation."

AASHTO Green Book

Conceptual Safety Relationship?

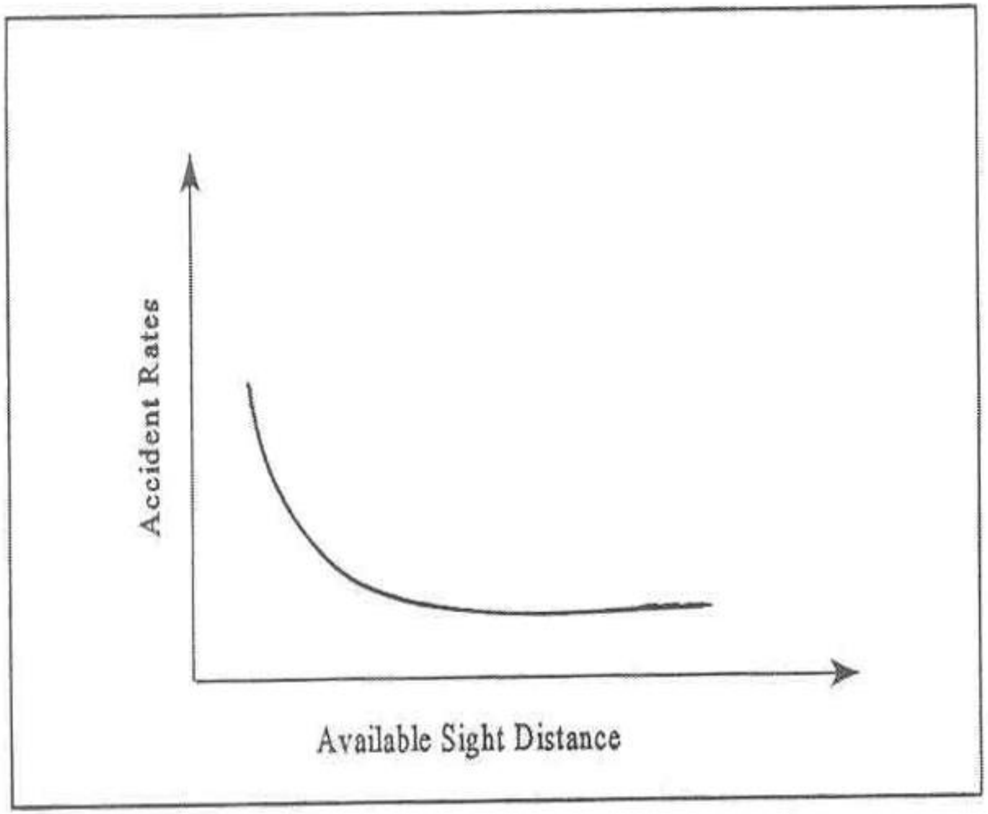


Figure 4. Conceptual Relationship Between Available Sight Distance and Safety at Crest Vertical Curves

Past studies that examined the relationship between SSD and safety have been inconsistent and inconclusive

NCHRP 400

Conceptual Safety Relationship?

Parameters	1940 A Policy on Sight Distance for Highways	1954 A Policy on Geometric Design - Rural Highways	1965 A Policy on Geometric Design - Rural Highways	1971 A Policy on Geometric Design of Highways and Streets	1984 and 1990 A Policy on Geometric Design Highways and Streets
Design Speed	Design Speed	85 to 95 percent of design speed.	80 to 93 percent of design speed.	Min. - 80 to 93 percent of design speed. Des. - design speed.	Min. - 80 to 93 percent of design speed. Des. - design speed.
Perception - Reaction Time	Variable: 3.0 sec at 30 mph 2.0 sec at 70 mph	2.5 sec	2.5 sec	2.5 sec	2.5 sec
Design Pavement/ Stop	Dry Pavement Locked-wheel Stop	Wet Pavement Locked-wheel Stop	Wet Pavement Locked-wheel Stop	Wet Pavement Locked-wheel Stop	Wet Pavement Locked-wheel Stop
Friction Factors	Ranges from 0.50 at 30 mph to 0.40 at 70 mph	Ranges from 0.36 to 30 mph to 0.29 to 70 mph	Ranges from 0.36 to 30 mph to 0.27 at 70 mph	Ranges from 0.35 at 0.30 mph to 0.27 at 70 mph	Slightly higher at higher speeds than 1970 values
Eye Height	4.5 ft	4.5 ft	3.75 ft	3.75 ft	3.5 ft
Object Height	4.0 in	4.0 in	6.0 in	6.0 in	6.0 in

Conceptual Safety Relationship?

There are a number of factors or conditions associated with driver responses to a hazardous event or object that are not reflected in the basic sight distance model, but nonetheless can have a profound effect on driver behavior and overall roadway safety:

- Conditions or events that occur prior to a hazardous event/object becoming visible to the driver
- How and when the driver processes relevant information
- Driving as an "episodic" activity versus driving as a "smooth and continuous" activity
- The nature of the hazardous object or event
- The nature of the driver's response
- Individual differences across drivers
- The quality and applicability of the empirical research used to develop the driver models

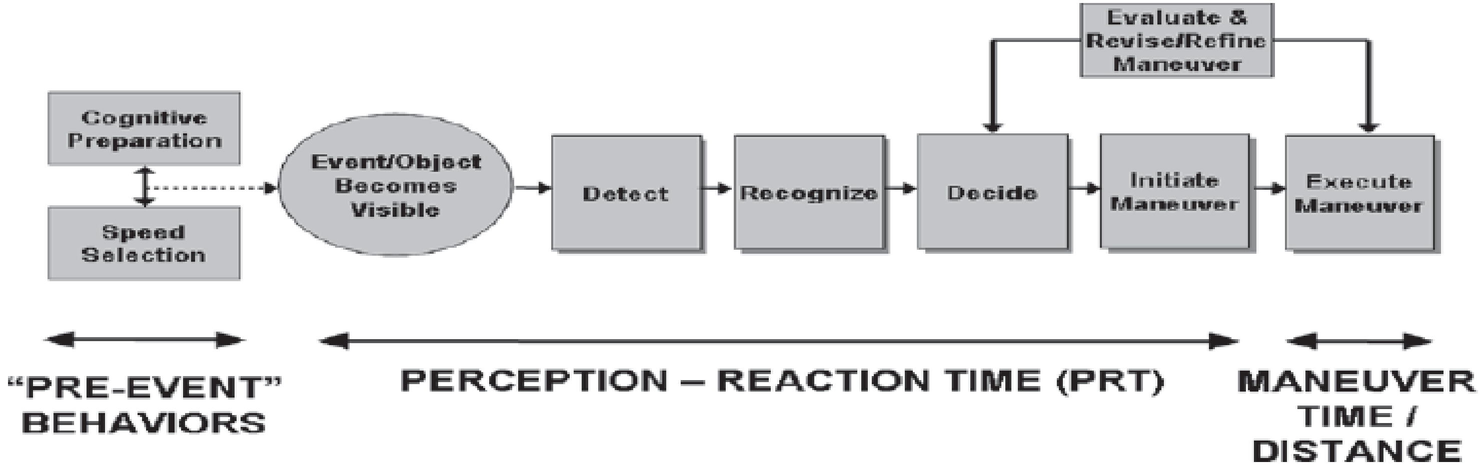


Figure 22-2. Added elements to basic sight distance behavioral model.

Risk Assessment Guidelines

- Assess the risk of a location with SSD below current criteria. Risk is related to traffic volume (exposure) and other features within the sight restriction (intersections, narrow bridges, high-volume driveways, sharp curvature)
- "Where no high-risk features exist within the sight restriction, nominal deficiencies as great as 5-10 mph may not create an undue risk of increased crashes."

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Guide for Achieving Flexibility in Highway Design AASHTO

Questions & Answers

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