Performance-Based Highway Design

What the heck is it?

We all have a stake in A to B

National Research Scene

Topic (SORTED BY TOTAL VOTES)	AASHTO Votes (22)	TRB Votes (34)	Total Votes
Median Design and Barrier Issues in Urban and Rural Environments (1.1)/Median: Types and Design (Crossover Crashes) (2.1)	13	15	28
Performance-based Geometric Design Analysis (1.3)	7	17	24
Multimodal Highway Design for "Complete Streets" (1.2)/ Determine the primary and secondary users for various functional classes. (2.3)	6	17	23
Investigation of Alternative Geometric Highway Design Processes (Design Decision Support) (1.3)	8	12	20
Horizontal Curve Design Philosophy (Should it be for driver			

TRB research needs workshop – 2004

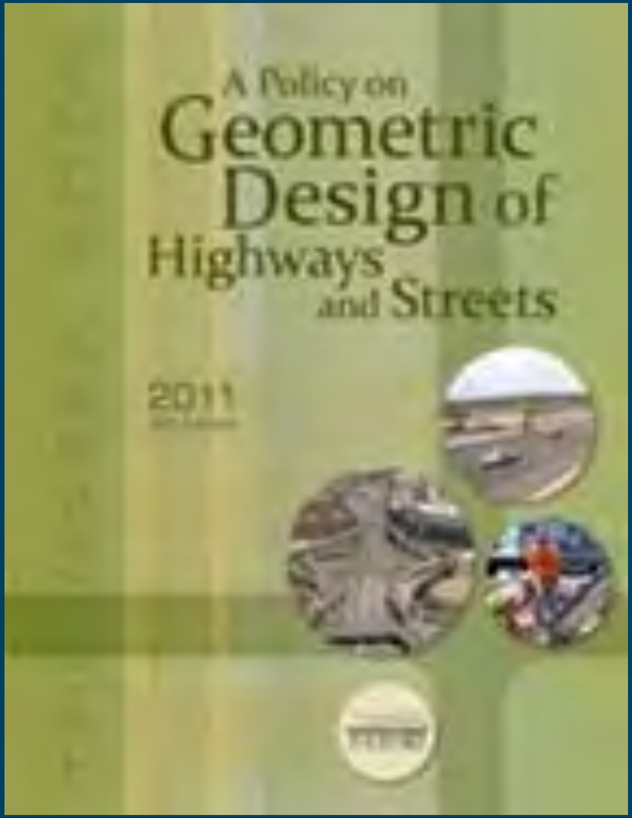
National Research Scene

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

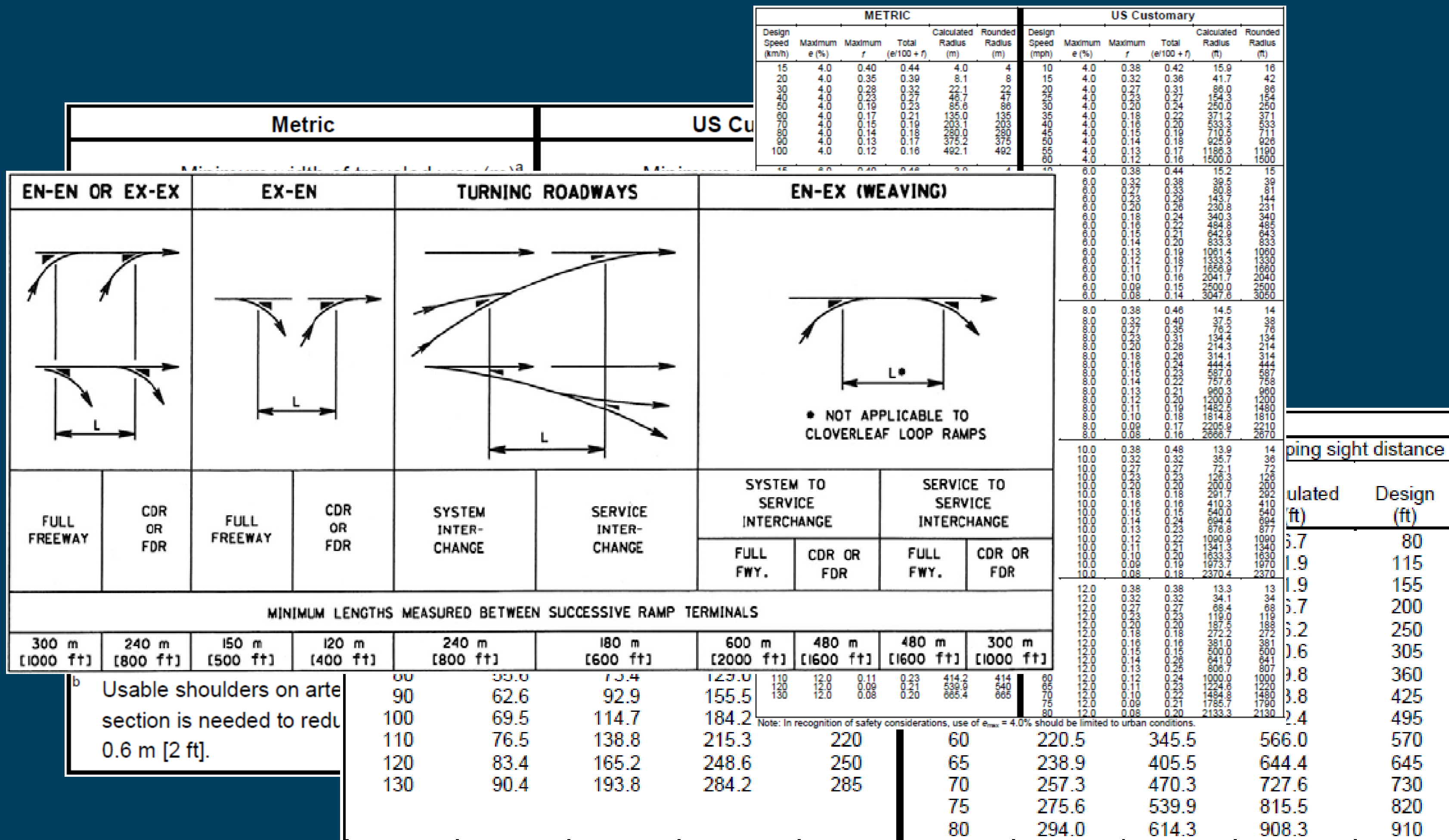
Research Categories	Research Sequence			
	A	B	C	D
Methodology	Performance-based Geometric Design Analysis (2)	Investigation of Alternative Geometric Highway Design Processes (4)	Continued	Continued
Criteria	Superelevation Criteria for Steep Grades on Horizontal Curves (13)	Horizontal Curve Design Philosophy (5)		
Highways	Median Design and Barrier Considerations in Urban and Rural Environments (1)	Transition Zone Design (8)	Accommodating Bicyclists on Rural Highways (21)	

TRB: *Geometric Design Strategic Research* – 2007

"Code-based" road design

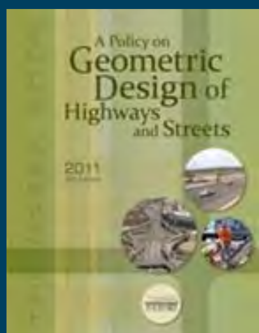


Code-based road design

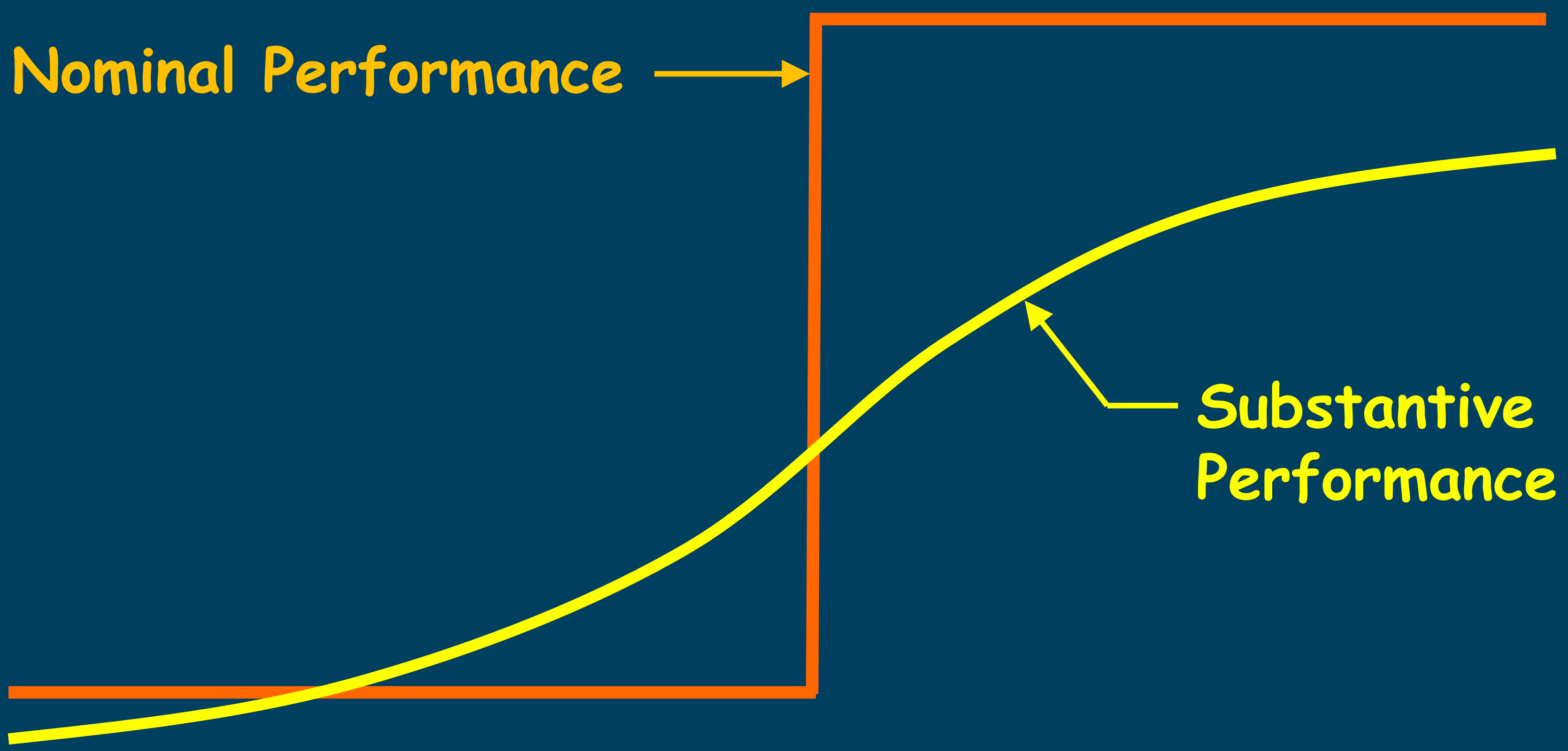


EN-EN OR EX-EX		EX-EN		TURNING ROADWAYS		EN-EX (WEAVING)			
						SYSTEM TO SERVICE INTERCHANGE		SERVICE TO SERVICE INTERCHANGE	
FULL FREEWAY	CDR OR FDR	FULL FREEWAY	CDR OR FDR	SYSTEM INTER-CHANGE	SERVICE INTER-CHANGE	FULL FWY.	CDR OR FDR	FULL FWY.	CDR OR FDR
MINIMUM LENGTHS MEASURED BETWEEN SUCCESSIVE RAMP TERMINALS									
300 m [1000 ft]	240 m [800 ft]	150 m [500 ft]	120 m [400 ft]	240 m [800 ft]	180 m [600 ft]	600 m [2000 ft]	480 m [1600 ft]	480 m [1600 ft]	300 m [1000 ft]

The traditional design process



Performance basis



Performance basis

Metric					US Customary				
Design speed (km/h)	Minimum width of traveled way (m)[a] for specified design volume (veh/day)				Design speed (mph)	Minimum width of traveled way (ft)[a] for specified design volume (veh/day)			
	under 400	400 to 1500	1500 to 2000	over 2000		under 400	400 to 1500	1500 to 2000	over 2000
60	6.6	6.6	6.6	7.2	40	22	22	22	24
70	6.6	6.6	6.6	7.2	45	22	22	22	24
80	6.6	6.6	7.2	7.2	50	22	22	24	24
90	6.6	6.6	7.2	7.2	55	22	22	24	24
100	7.2	7.2	7.2	7.2	60	24	24	24	24
110	7.2	7.2	7.2	7.2	65	24	24	24	24
120	7.2	7.2	7.2	7.2	70	24	24	24	24
130	7.2	7.2	7.2	7.2	75	24	24	24	24
All speeds	Width of usable shoulder (m)[b]				All speeds	Width of usable shoulder (ft)[b]			
	1.2	1.8	1.8	2.4		4	6	6	8

[a] On roadways to be reconstructed, an existing 6.6-m [22-ft] traveled way may be retained where alignment and safety records are satisfactory.

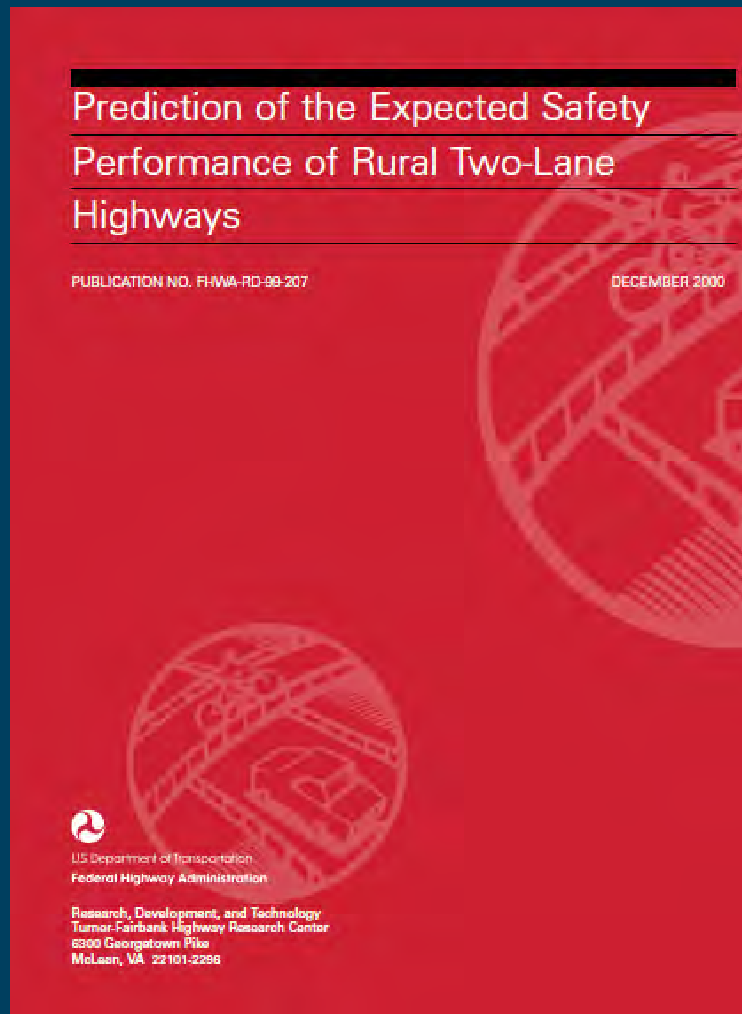
[b] Usable shoulders on arterials should be paved; however, where volumes are low or a narrow section is needed to reduce construction impacts, the paved shoulder may be reduced to 0.6 m [2 ft].

Ongoing research

NCHRP Project 15-47 "An Improved Geometric Design Process"

- Some AASHTO criteria are based on outdated and/or overly simplistic models lacking scientific basis
- Dimensional design criteria should be based only on measurable performance effects

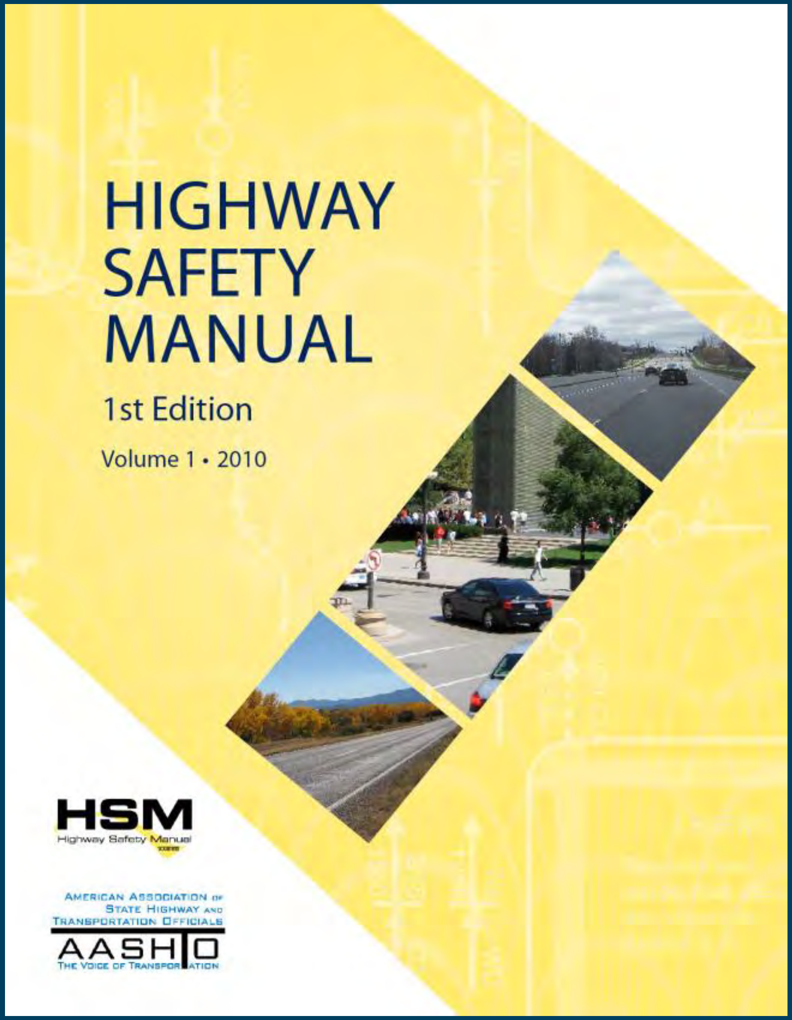
“measurable performance effects”



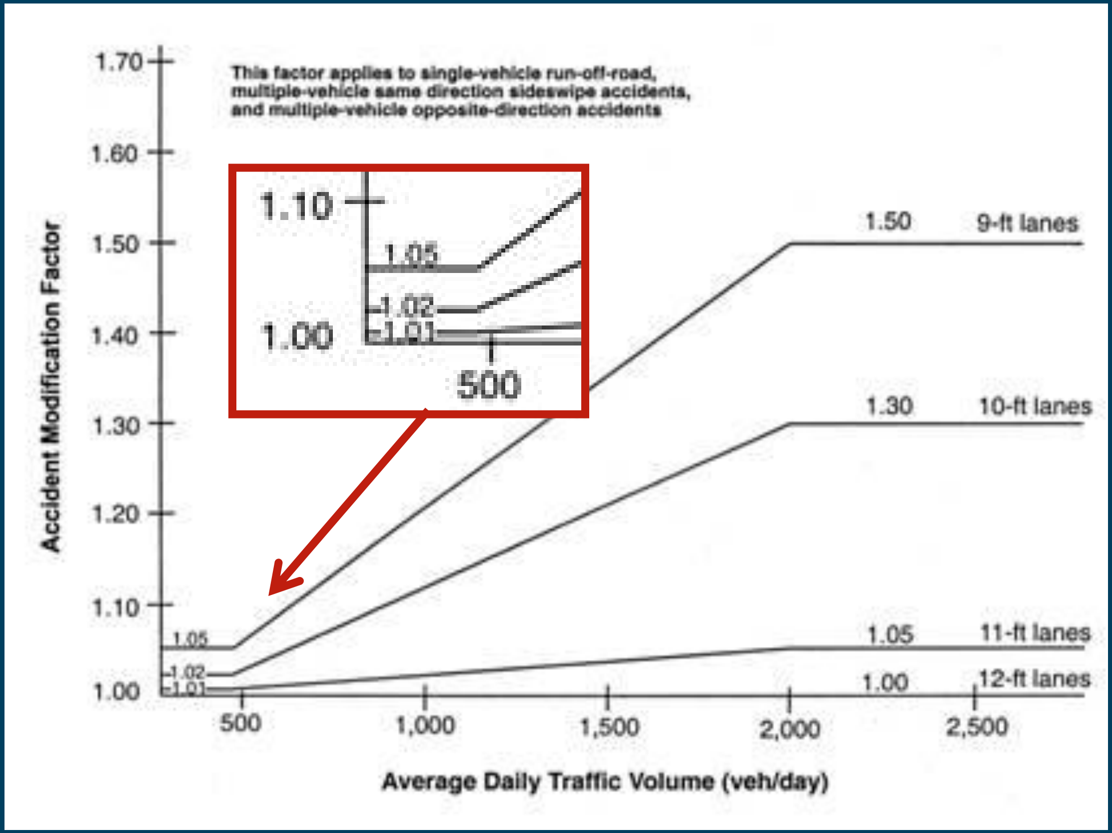
Knowledge!

Unintended consequences

“measurable performance effects”

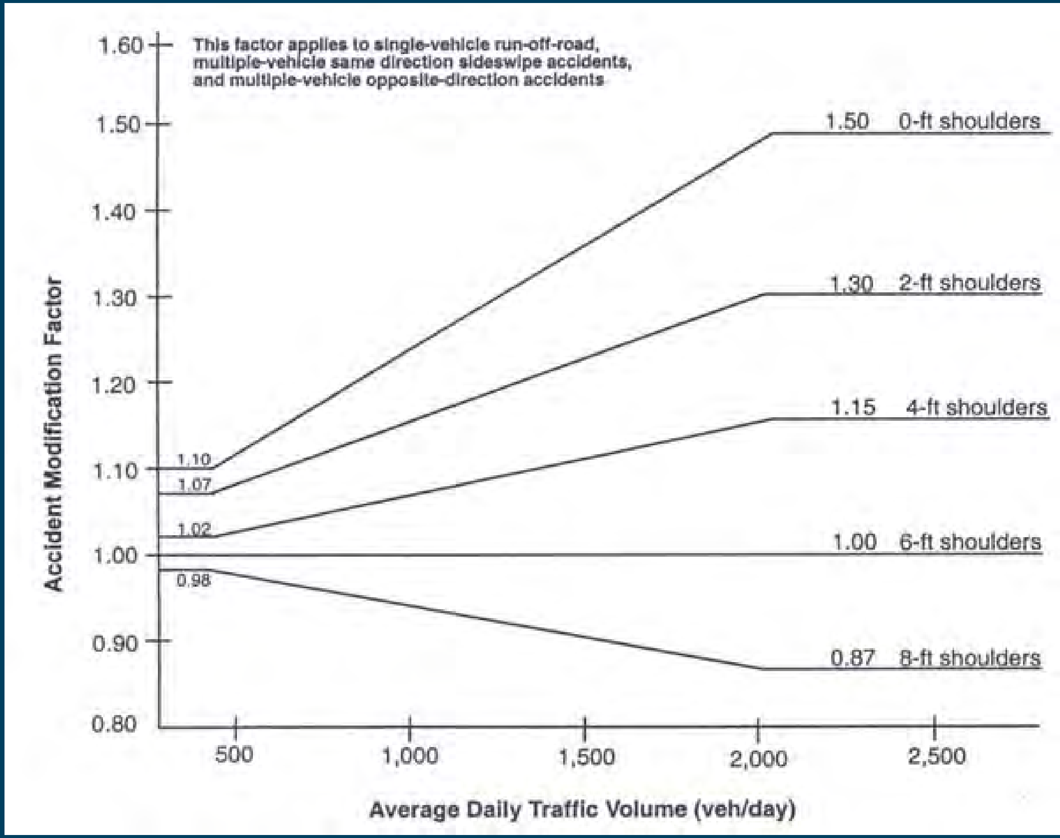


Known safety effects



Travel lane width – rural two-lane

Known safety effects

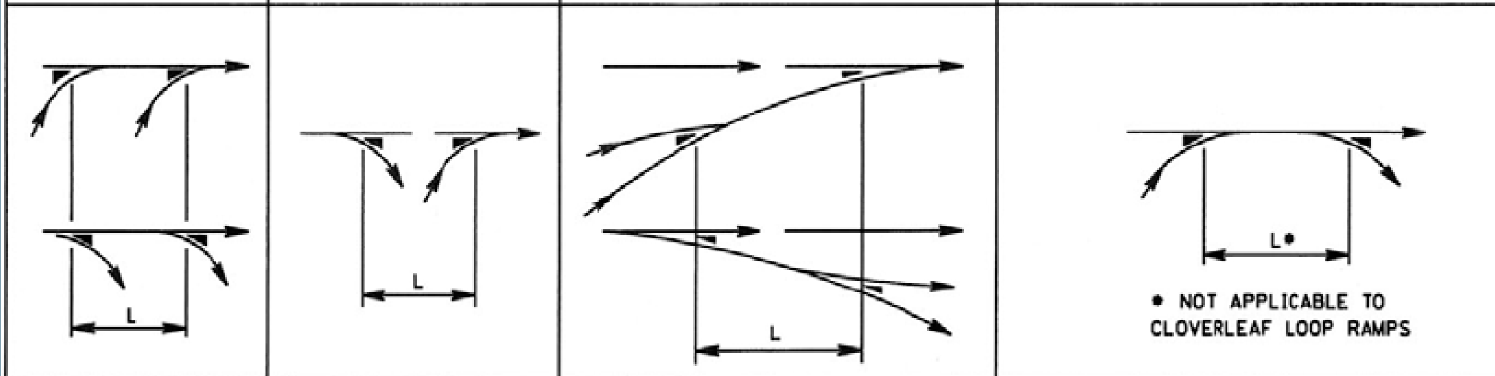


Shoulder width – rural two-lane

Piecing things together

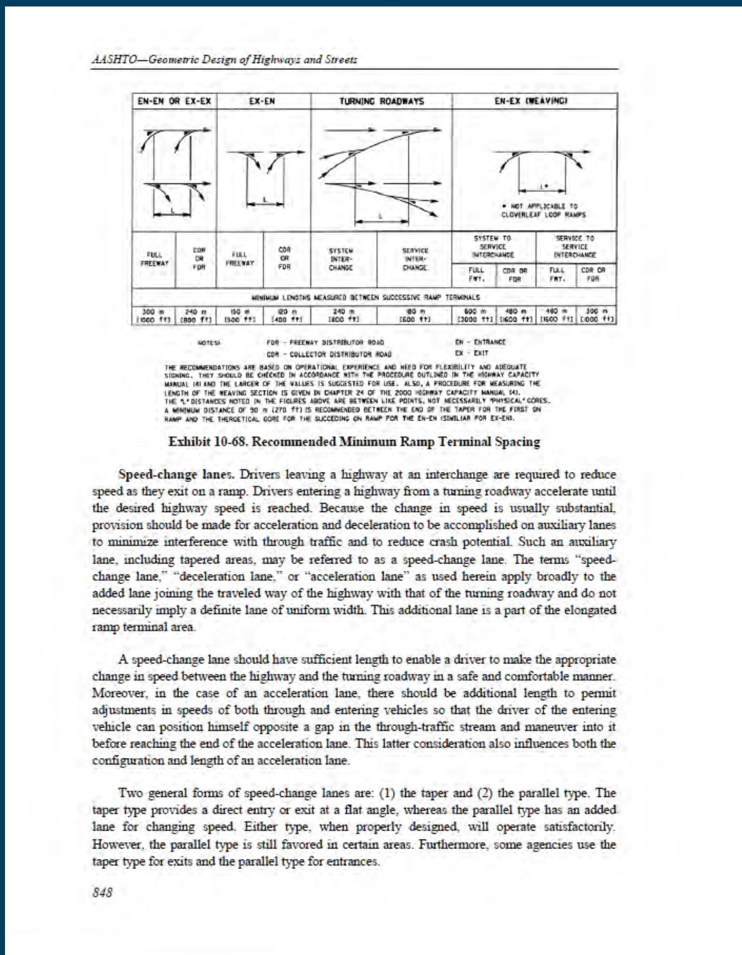
"Code-based" design

EN-EN OR EX-EX		EX-EN		TURNING ROADWAYS		EN-EX (WEAVING)			
FULL FREEWAY	CDR OR FDR	FULL FREEWAY	CDR OR FDR	SYSTEM INTER-CHANGE	SERVICE INTER-CHANGE	SYSTEM TO SERVICE INTERCHANGE		SERVICE TO SERVICE INTERCHANGE	
						FULL FWY.	CDR OR FDR	FULL FWY.	CDR OR FDR
MINIMUM LENGTHS MEASURED BETWEEN SUCCESSIVE RAMP TERMINALS									
300 m [1000 ft]	240 m [800 ft]	150 m [500 ft]	120 m [400 ft]	240 m [800 ft]	180 m [600 ft]	600 m [2000 ft]	480 m [1600 ft]	480 m [1600 ft]	300 m [1000 ft]



Ramp terminal spacing

“Code-based” design



EN-EN OR EX-EX		EX-EN		TURNING ROADWAYS		EN-EX (WEAVING)			
L		L		L		L* * NOT APPLICABLE TO CLOVERLEAF LOOP RAMPS			
FULL FREEWAY	CDR OR FDR	FULL FREEWAY	CDR OR FDR	SYSTEM INTER-CHANGE	SERVICE INTER-CHANGE	SYSTEM TO SERVICE INTERCHANGE		SERVICE TO SERVICE INTERCHANGE	
						FULL FWY.	CDR OR FDR	FULL FWY.	CDR OR FDR
MINIMUM LENGTHS MEASURED BETWEEN SUCCESSIVE RAMP TERMINALS									
300 m (1000 ft)	240 m (800 ft)	150 m (500 ft)	120 m (400 ft)	240 m (800 ft)	180 m (600 ft)	600 m (2000 ft)	480 m (1600 ft)	480 m (1600 ft)	300 m (1000 ft)

NOTES: FDR - FREEWAY DISTRIBUTOR ROAD EN - ENTRANCE
CDR - COLLECTOR DISTRIBUTOR ROAD EX - EXIT

THE RECOMMENDATIONS ARE BASED ON OPERATIONAL EXPERIENCE AND NEED FOR FLEXIBILITY AND ADEQUATE SIGNING. THEY SHOULD BE CHECKED IN ACCORDANCE WITH THE PROCEDURE OUTLINED IN THE HIGHWAY CAPACITY MANUAL (4) AND THE LARGER OF THE VALUES IS SUGGESTED FOR USE. ALSO, A PROCEDURE FOR MEASURING THE LENGTH OF THE WEAVING SECTION IS GIVEN IN CHAPTER 24 OF THE 2000 HIGHWAY CAPACITY MANUAL (4).
THE "L" DISTANCES NOTED IN THE FIGURES ABOVE ARE BETWEEN LIKE POINTS, NOT NECESSARILY "PHYSICAL" GORES.
A MINIMUM DISTANCE OF 90 m (270 ft) IS RECOMMENDED BETWEEN THE END OF THE TAPER FOR THE FIRST ON RAMP AND THE THEROETICAL GORE FOR THE SUCCEDING ON RAMP FOR THE EN-EN (SIMILIAR FOR EX-EX).

Exhibit 10-68. Recommended Minimum Ramp Terminal Spacing

Speed-change lanes. Drivers leaving a highway at an interchange are required to reduce speed as they exit on a ramp. Drivers entering a highway from a turning roadway accelerate until the desired highway speed is reached. Because the change in speed is usually substantial, provision should be made for acceleration and deceleration to be accomplished on auxiliary lanes to minimize interference with through traffic and to reduce crash potential. Such an auxiliary lane, including tapered areas, may be referred to as a speed-change lane. The terms “speed-change lane,” “deceleration lane,” or “acceleration lane” as used herein apply broadly to the added lane joining the traveled way of the highway with that of the turning roadway and do not necessarily imply a definite lane of uniform width. This additional lane is a part of the elongated ramp terminal area.

A speed-change lane should have sufficient length to enable a driver to make the appropriate change in speed between the highway and the turning roadway in a safe and comfortable manner. Moreover, in the case of an acceleration lane, there should be additional length to permit adjustments in speeds of both through and entering vehicles so that the driver of the entering vehicle can position himself opposite a gap in the through-traffic stream and maneuver into it before reaching the end of the acceleration lane. This latter consideration also influences both the configuration and length of an acceleration lane.

Two general forms of speed-change lanes are: (1) the taper and (2) the parallel type. The taper type provides a direct entry or exit at a flat angle, whereas the parallel type has an added lane for changing speed. Either type, when properly designed, will operate satisfactorily. However, the parallel type is still favored in certain areas. Furthermore, some agencies use the taper type for exits and the parallel type for entrances.

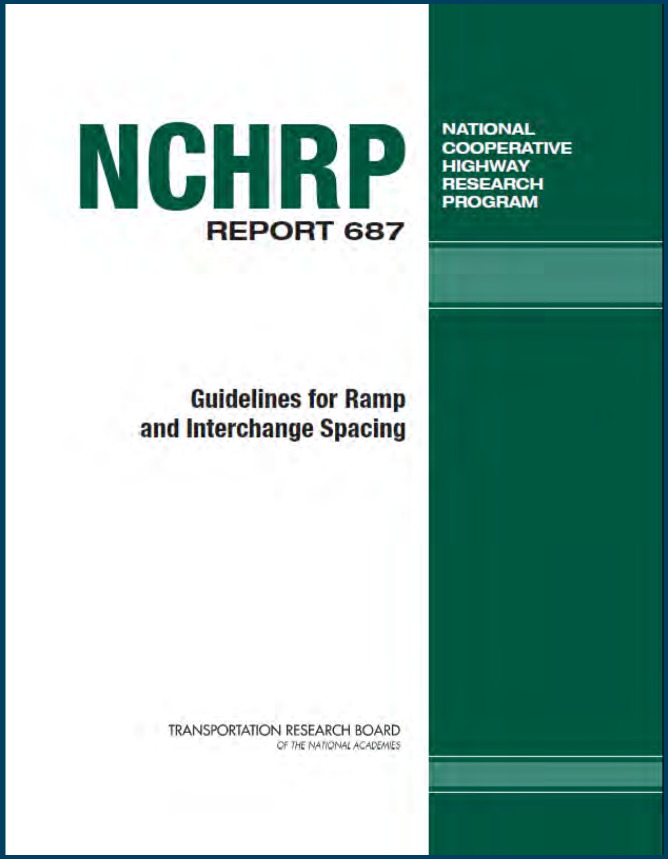
It doesn’t account for…

- Respective ramp volumes
- Mainline traffic density
- Speeds
- Geometry
- Signing considerations
- Cost or feasibility of attaining the standard
- Design context

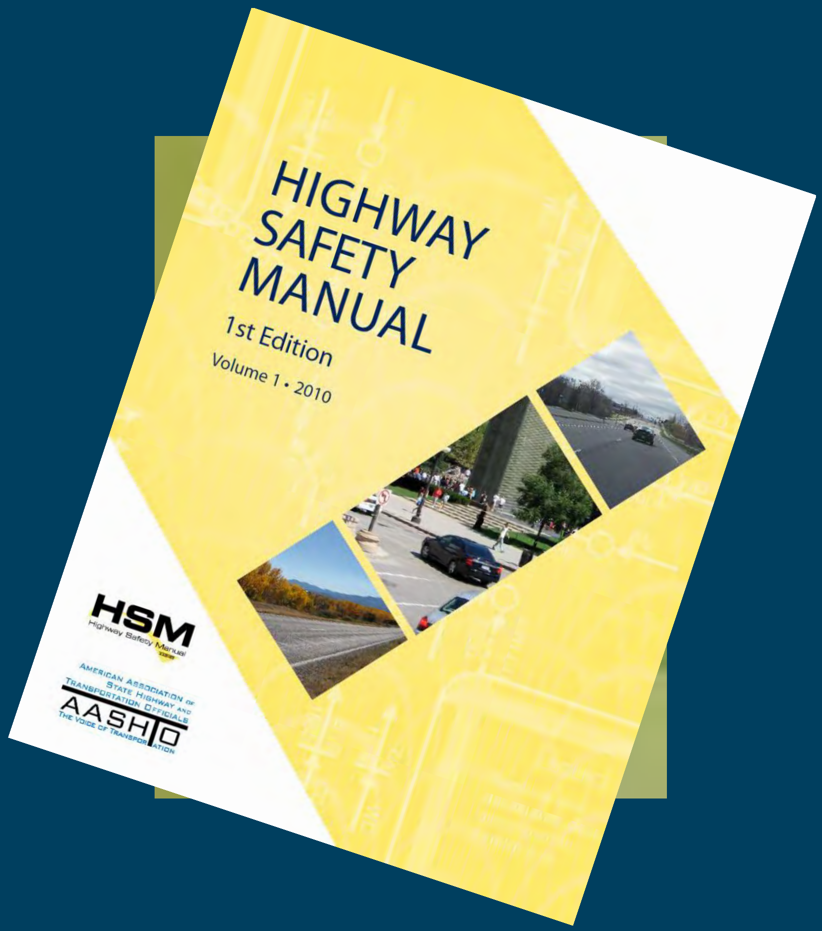
Performance-based methodology

"…balance system efficiency and safety with the need to provide access…

"The selection criteria include geometric design needs, operational performance, signing needs, and safety performance."



Code-based vs. performance-based design

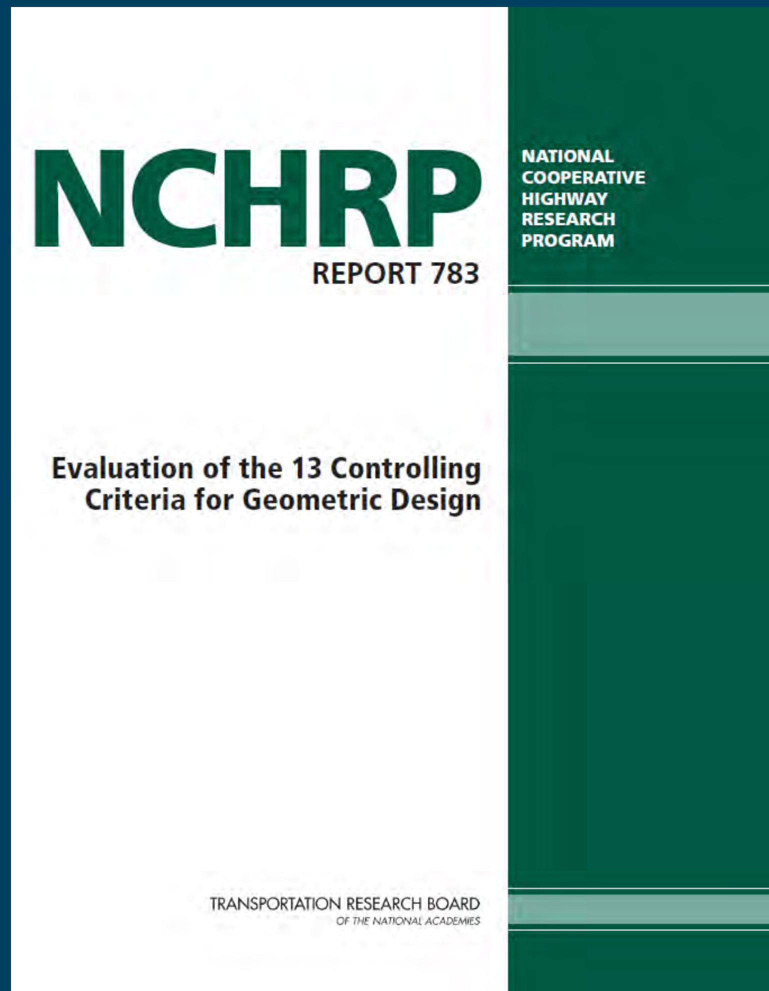


For example…

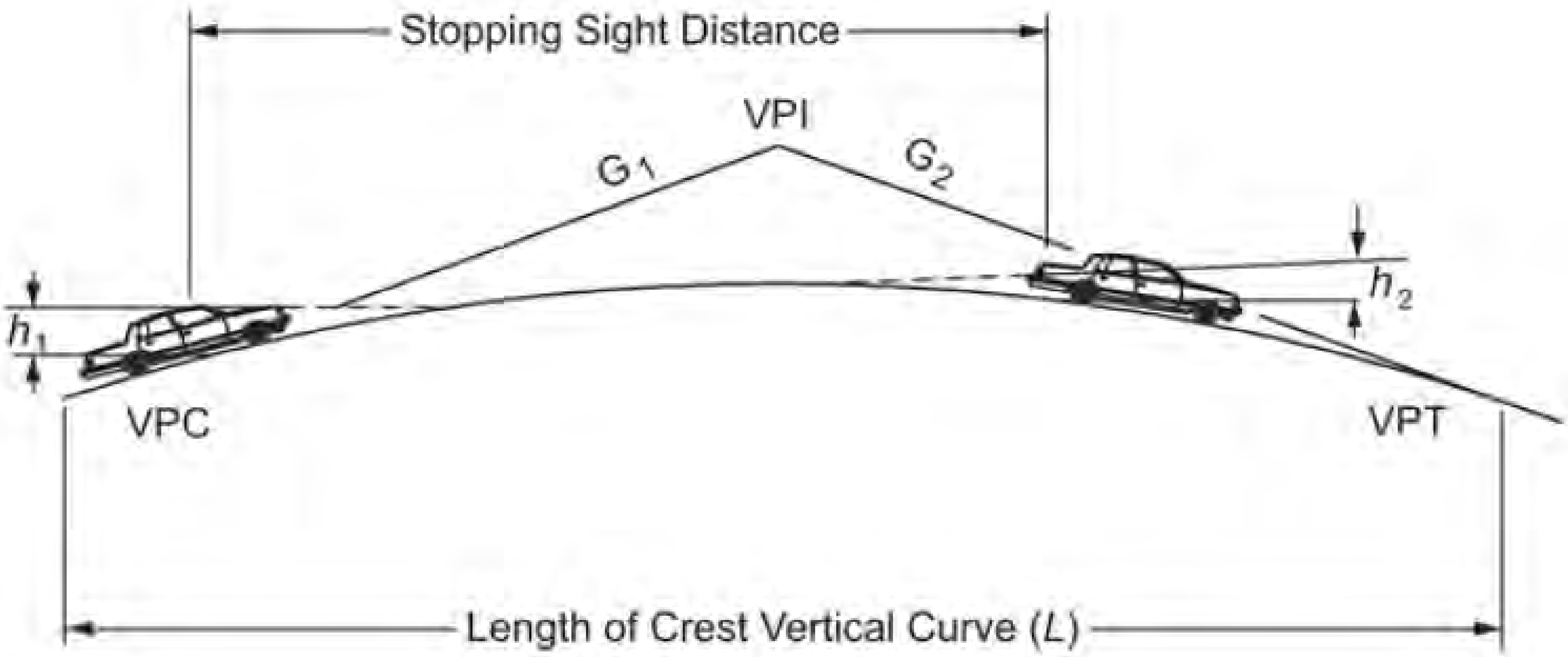
Parking lane width

Code-based vs. performance-based

Performance-based evaluation of the code



Stopping Sight Distance



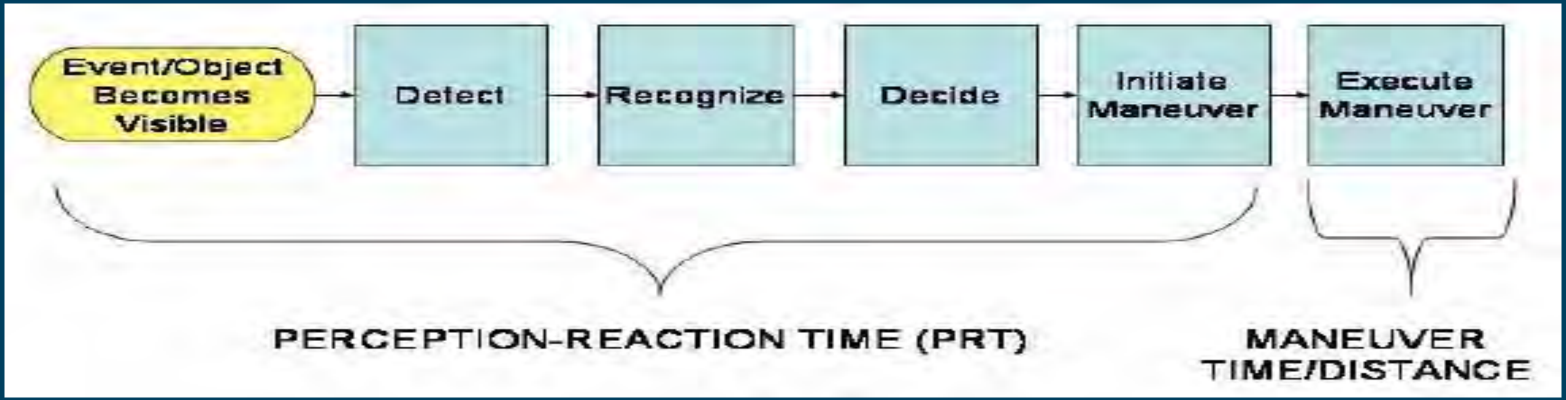
Stopping Sight Distance

Based on two premises:

1. The ability to see the road ahead is critical to safety

2. The critical event is an emergency stop, which is comprised of perception/reaction time and stopping distance

Stopping Sight Distance



SSD = perception/reaction distance + braking distance

$$SSD = 1.47Vt + 1.075V^2/a$$

V = design speed in mph

t = perception/reaction time (2.5 sec)

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

Remember all that research…?

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Horizontal Curve Design Philosophy (Should it be for driver			

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ct outcomes."

A definition

…an **OUTCOME** based
rather than
OUTPUT based
methodology

All that research…

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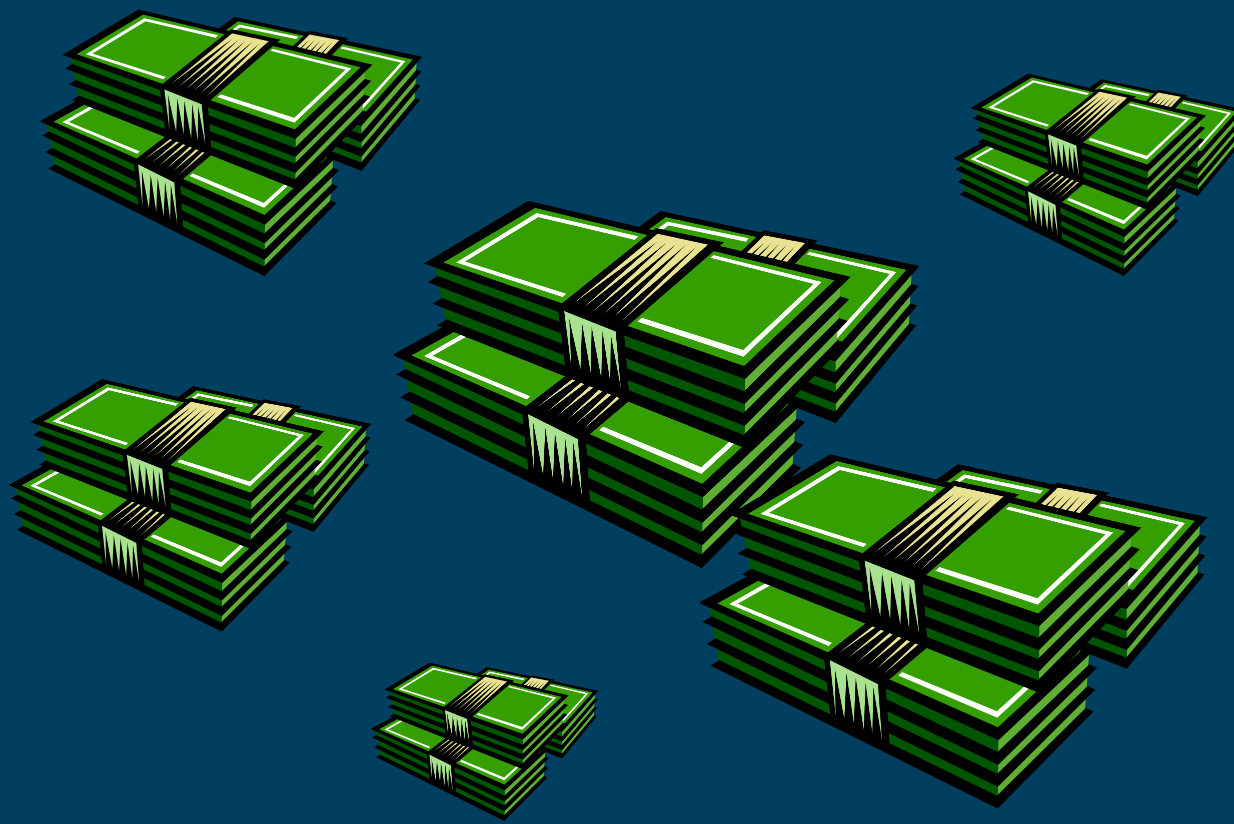
Horizontal Curve Design Philosophy (Should it be for driver [illegible]	[illegible]	[illegible]	[illegible]

Ongoing research

NCHRP Project 15-47 "An Improved Geometric Design Process"

- AASHTO criteria should reflect known interactive effects
- AASHTO policy should replace dimensional guidance with direct performance
- Concept of "conservatism" needs to be reconsidered

Why it's necessary



Why it's necessary

Why it's necessary

Context Sensitive Solutions

"You can always count on Americans to do the right thing – after they've tried everything else."

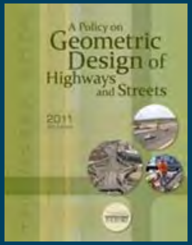
Winston Churchill

Overall goal

Context Sensitive Solutions

Tailoring solutions to the unique needs of each project context

Flexible ranges



Criteria

Tools

So do design standards matter?

- Basically….. it depends
- Design standards provide a basis for consistent design of roads and highways
- A starting point in design, but not an absolute

The more things change…

Engineering and Contracting

Devoted to the Economics of Civil Engineering Design and to Methods and Cost of Construction

Volume XLII. CHICAGO, ILL., AUGUST 12, 1914. Number 7.

The Adverse Freight Rate Decision as an Incentive to Speedy Completion of Railway Appraisals.

Classification of the Steel Production in 1913.

The Use and Abuse of Road Standards.

‘Engineering and Contracting’

- August 12, 1914

The Use and Abuse of Road Standards.

“Strictly interpreted, the meaning would indicate that the standard design was the best design.” “Standards are merely recommended designs which are to be adhered to unless conditions indicate that a variation in the design would meet them better.”

“The temptation is to neglect the detailed study of local conditions…”

Safety Performance vs. Design Speed

Rural 2-Lane 2-Way Highways
Examined 3,633 Miles

Posted Speed	Number of Miles	Average Crash Rate	Average Fatal and Serious Injury Rate
40	8.0	1.29	0.00
45	6.0	0.85	0.00
50	191	0.66	2.53
55	3,226	0.35	1.71
60	203	0.27	1.40
STATEWIDE AVERAGE	**8,369**	**0.32**	**1.60**

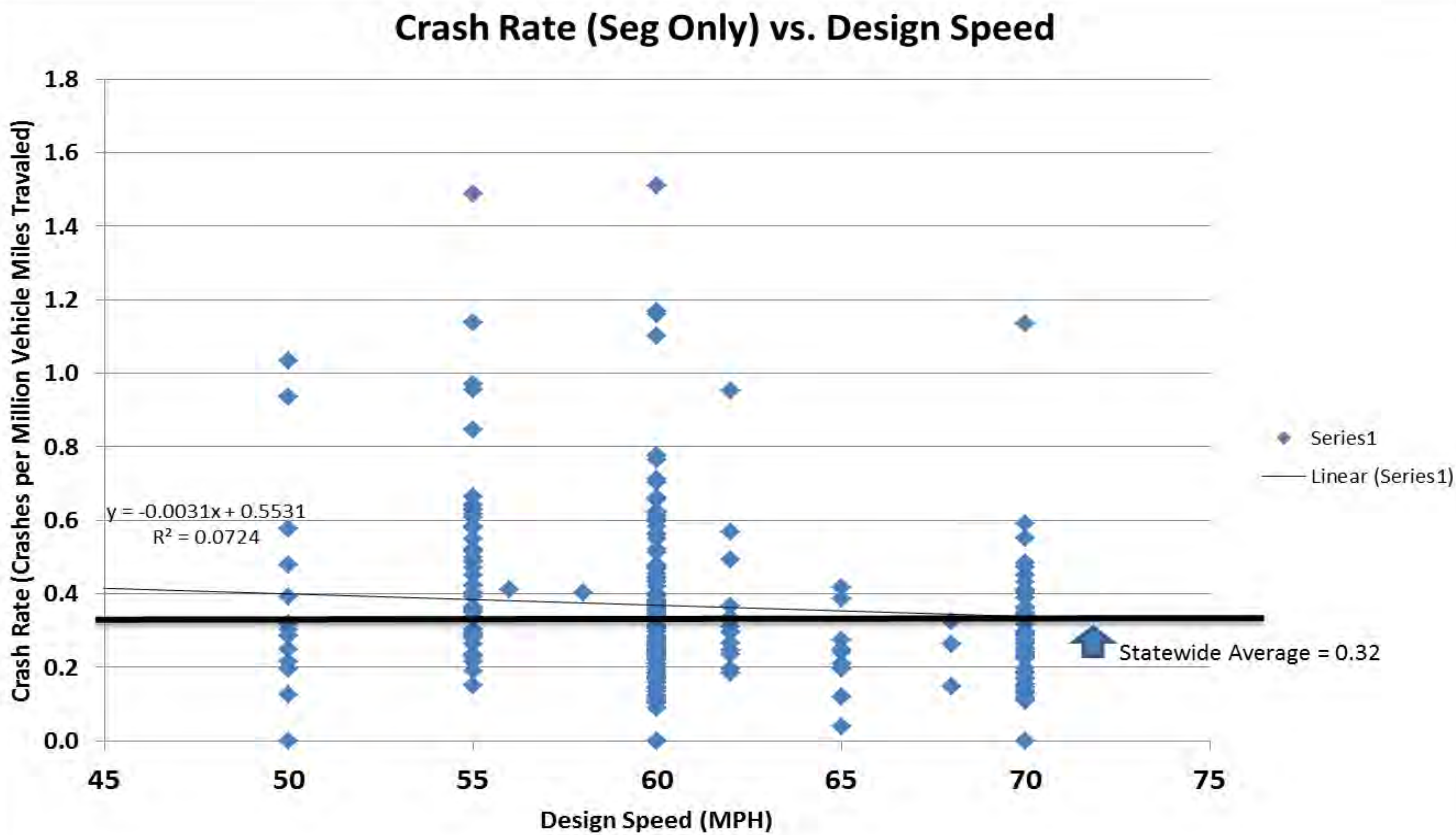
Safety Performance vs. Design Speed

Rural 2-Lane 2-Way Highways
Examined 3,633 Miles

Design Speed	Number of Miles	Average Crash Rate	Average Fatal and Serious Injury Rate
No Design Speed	584	0.43	2.17
30-40	79	0.51	3.68
50	182	0.36	1.46
55-59	494	0.43	1.78
60-64	1,522	0.36	1.53
65-69	160	0.22	1.09
70+	612	0.28	1.85
STATEWIDE AVERAGE	**8,369**	**0.32**	**1.60**

Safety Performance vs. Design Speed

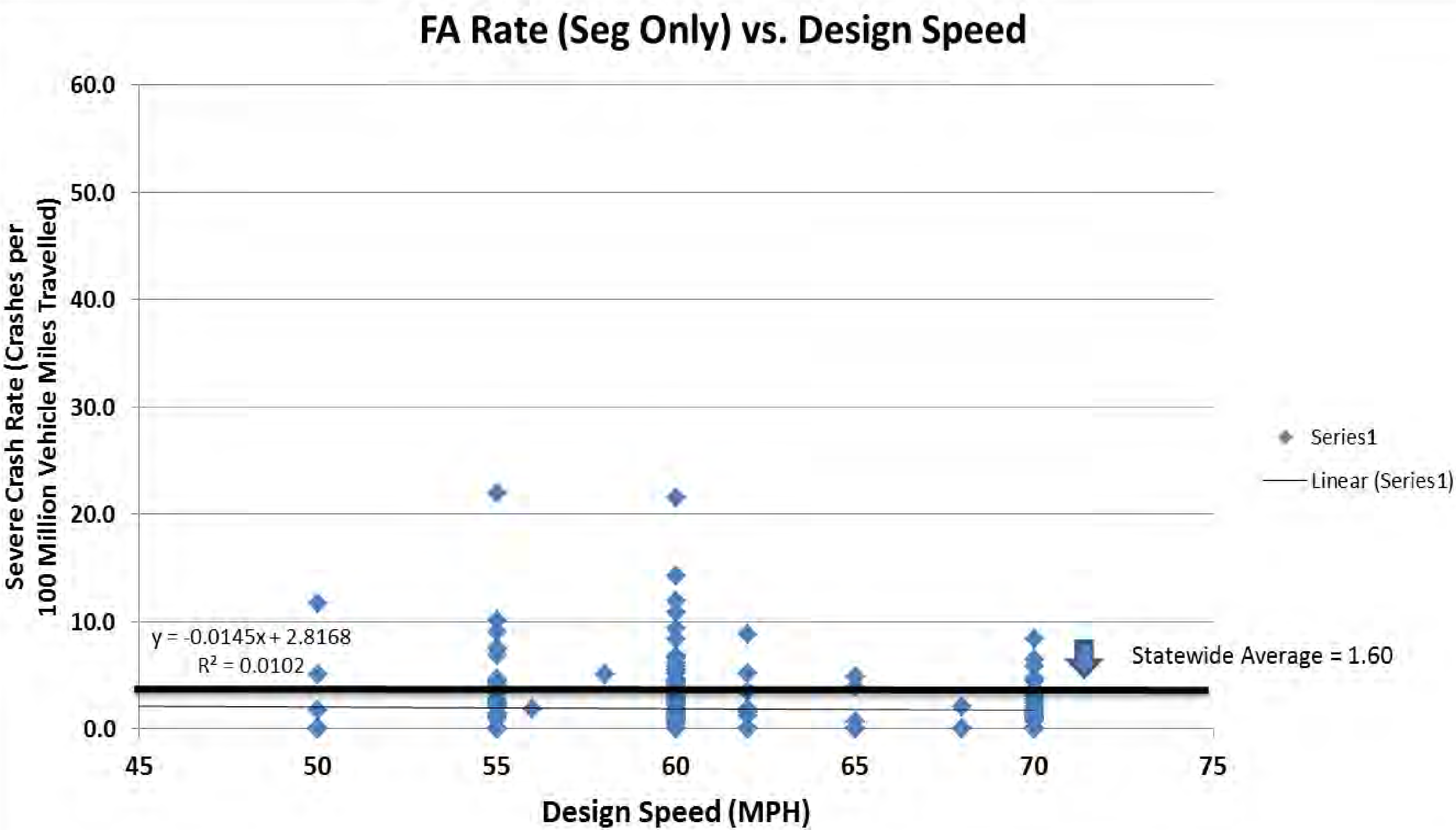
Rural 2-Lane 2-Way Highways
Examined 3,633 Miles



Safety Performance vs. Design Speed

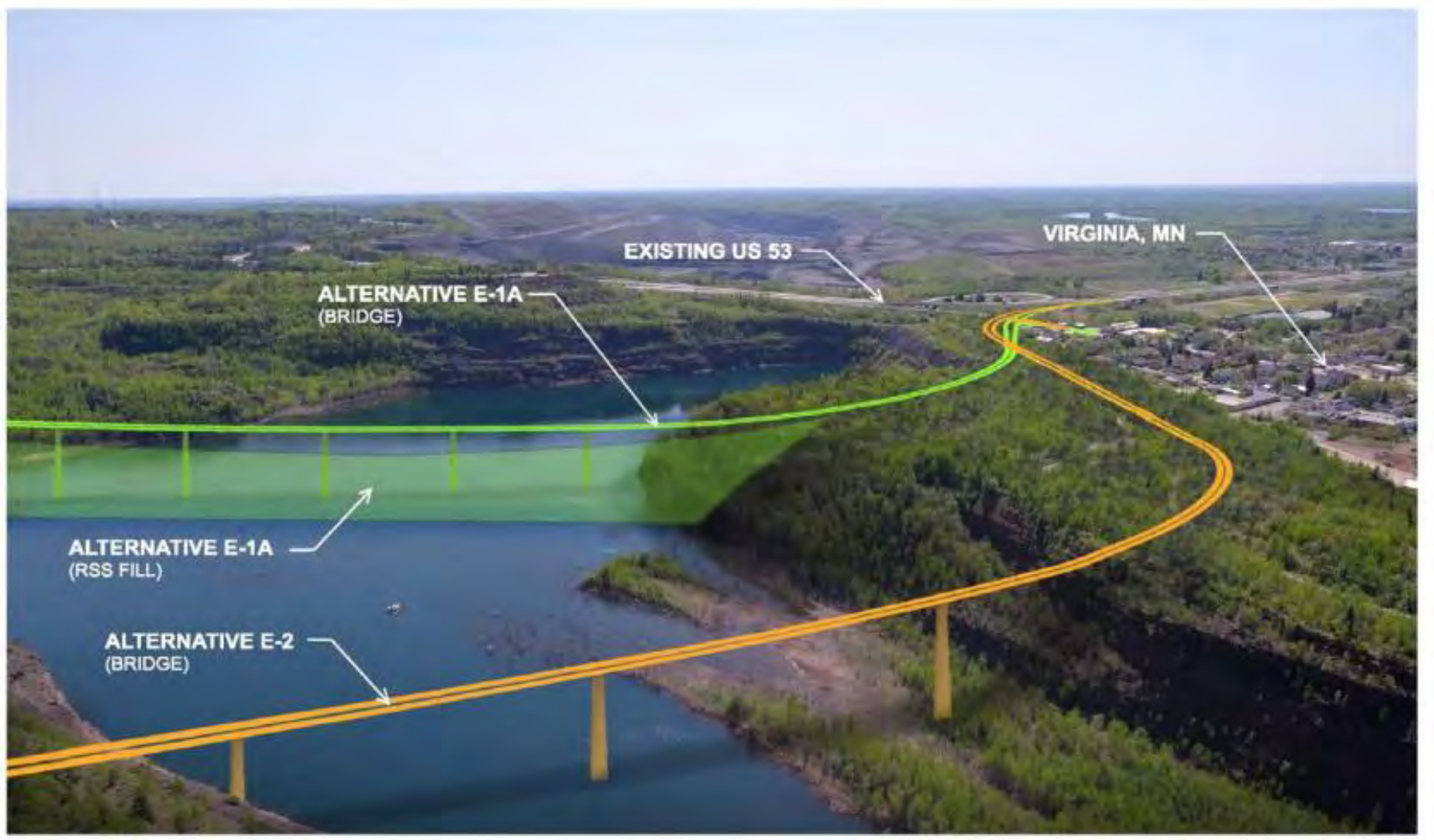
Rural 2-Lane 2-Way Highways

Examined 3,633 Miles



US 53 Alternates

1,135' Bridge Cross Section Anaysis



US 53 Alternates

1,135’ Bridge Cross Section Anaysis

For the 1135' US53/ Virginia Bridge: 2017-2026, 10 years of Total Predicted Crashes , Both Directions

Alt No.	Description	Total Typical Section (ft)	Injury (For 1135', for 10 years)	PDO (For 1135', for 10 years)	Total (For 1135', for 10 years)	Cost of Injury	Cost of PDO	Benefit over 10 years	Benefit over 30 Years	Cost Per Square Foot	Additional Square Footage (SQ FT)	Total Additional Cost	Benefit/Cost
1	4'-12'-12'-8' (BASE)	36	4.5	8.7	13.1	$ 158,200	$ 7,400	NA	NA	NA	NA	NA	NA
2	4'-12'-12'-10'	38	4.0	8.7	12.7	$ 158,200	$ 7,400	$ 68,026	$ 204,078	$ 100.00	4,540	$ 454,000.00	$ 0.45
3	4'-12'-12'-12'	40	3.7	8.7	12.3	$ 158,200	$ 7,400	$ 125,848	$ 377,544	$ 100.00	9,080	$ 908,000.00	$ 0.42
4	6'-12'-12'-10'	40	3.9	8.4	[illegible]	$ 158,200	$ 7,400	$ 90,343	$ 271,029	$ 100.00	9,080	$ 908,000.00	$ 0.30
5	6'-12'-12'-12'	42	3.5	8.4	11.9	158,200	$ 7,400	$ 148,165	$ 444,495	$ 100.00	13,620	$ 1,362,000.00	$ 0.33
10	2'-12'-12'-10'	36	4.2	8.9	[illegible]	$ 158,200	$ 7,400	$ 42,149	$ 126,446	$ 100.00	NA	No Cost/Only Benefit	
13	4'-11'-11'-8'	34	4.6	8.7	13.3	$ 158,200	$ 7,400	$ (27,210)	$ (81,631)	$ 100.00	(4,540)	$ (454,000.00)	$ 5.56
14	4'-11'-11'-10'	36	4.2	8.7	12.9	$ 158,200	$ 7,400	$ 40,816	$ 122,447	$ 100.00	-	No Cost/Only Benefit	
11a	2'-12'-12'-8'	34	4.6	8.9	[illegible]	$ 158,200	$ 7,400	$ (29,279)	$ (87,836)	$ 100.00	(4,540)	$ (454,000.00)	$ 5.17
7a	2'-11'-11'-4'	28	5.9	8.9	14.9	$ 158,200	$ 7,400	$ (233,357)	$ (700,070)	$ 100.00	(18,160)	$ (1,816,000.00)	$ 2.59
8a	4'-11'-11'-4'	30	5.7	8.7	14.4	$ 158,200	$ 7,400	$ (200,677)	$ (602,030)	$ 100.00	(13,620)	$ (1,362,000.00)	$ 2.26
9a	4'-11'-11'-6'	32	5.1	8.7	13.8	$ 158,200	$ 7,400	$ (108,842)	$ (326,525)	$ 100.00	(9,080)	$ (908,000.00)	$ 2.78

Yellow	Best for Category
Orange	2nd Best
Red	Last Place for Category
Green	Only Benefit, No Costs (Total Benefit Amount)

*Assumptions:

Modeled as a rural freeway segment with barriers on both sides

2% Traffic Growth for 10 Years

The intersections/interchanges are not influencing the section.

There is no adjustment to the model for adverse weather or extreme curcumstances, but are included within the crash frequency numbers.

No Congestion was added into the model.

The model is not calibrated for Minnesota Traffic Conditions. Prior calibrations have resulted in reducing the number of predicted crashes.

Rumble Strips added $10,000 to the "Cost" side

Questions?

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MINNESOTA DEPARTMENT OF TRANSPORTATION