NATIONAL ACADEMIES *Sciences Engineering Medicine*

TRB TRANSPORTATION RESEARCH BOARD

TRB Webinar: Speed and Sight Criteria for Geometric Design

February 6, 2025

1:00PM – 2:30 PM

PDH Certification Information

1.5 Professional Development Hours (PDH) – see follow-up email

You must attend the entire webinar.

Questions? Contact Andie Pitchford at TRBwebinar@nas.edu

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Program. Credit earned on completion of this program will be reported to RCEP at RCEP.net. A certificate of completion will be issued to each participant. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the RCEP.

ENGINEERING RCEP REGISTERED CONTINUING EDUCATION PROGRAM

Purpose Statement

This webinar will cover the findings from recent studies that assess design policies related to these criteria and informed recommendations for updates to the AASHTO Green Book.

Learning Objectives

At the end of this webinar, you will be able to:

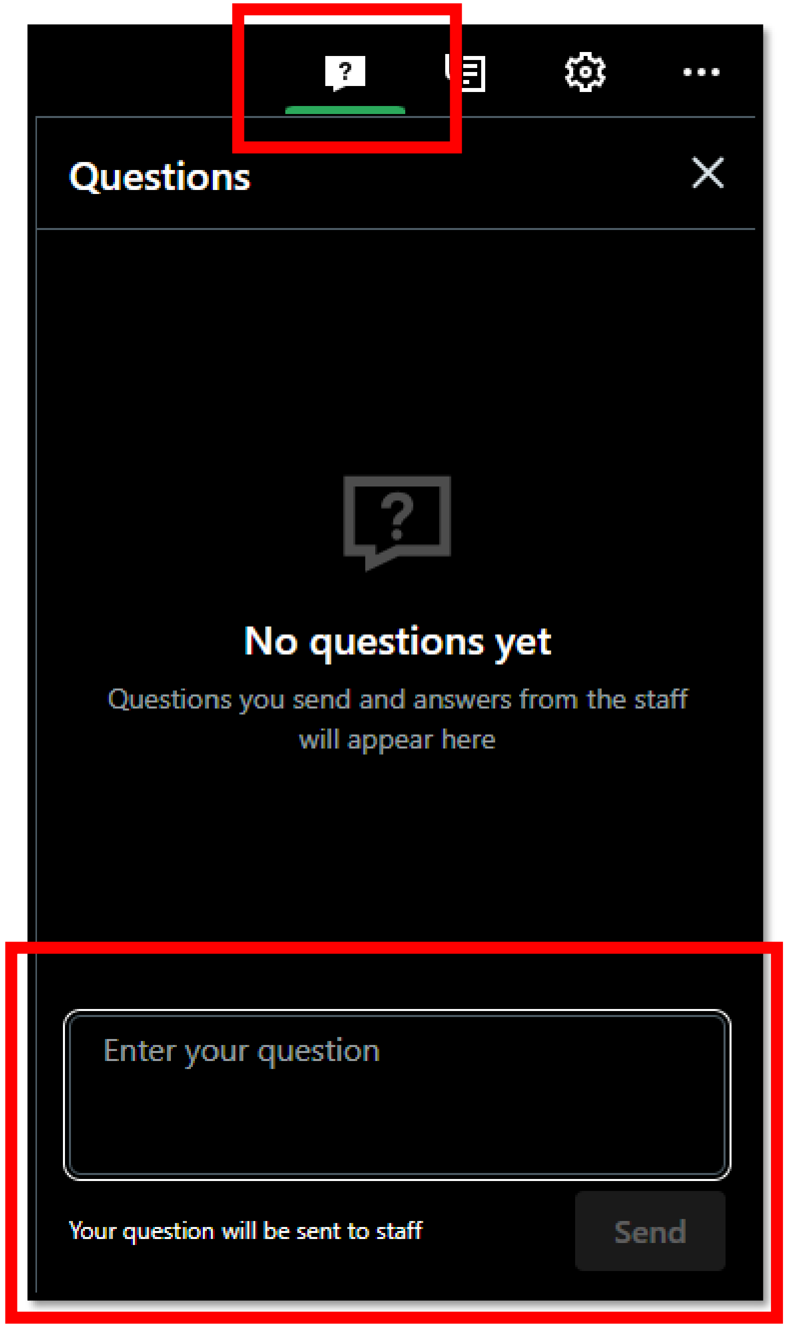
(1) Understand the differences between current design assumptions and associated parameters that describe driver behavior and vehicle performance

(2) Design acceleration and deceleration lanes in consideration of revised guidance based on driver behavior

(3) Determine the recommended SSD for various scenarios and relate anticipated safety performance to available sight distance

Questions and Answers

- Please type your questions into your webinar control panel
- We will read your questions out loud, and answer as many as time allows



Today’s presenters

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mn DEPARTMENT OF TRANSPORTATION

TRB Webinar: Speed and Sight Criteria for Geometric Design

Peter T. Savolainen, Michigan State University
Eric T. Donnell, Pennsylvania State University
James A. Rosenow, Minnesota Department of Transportation

February 6, 2025

Webinar Agenda & Presenters

1. Overview of NCHRP 15-75 and Related Crash and Field Studies

   Dr. Peter T. Savolainen

   Professor & Chairperson

   Michigan State University

2. Development of Revised Design Guidelines

   Dr. Eric T. Donnell

   Professor & Senior Associate Dean

   Pennsylvania State University

3. Translating Results into Practice

   James A. Rosenow

   Design Flexibility Engineer

   Minnesota Department of Transportation

Overview of NCHRP 15-75 and Related Crash and Field Studies

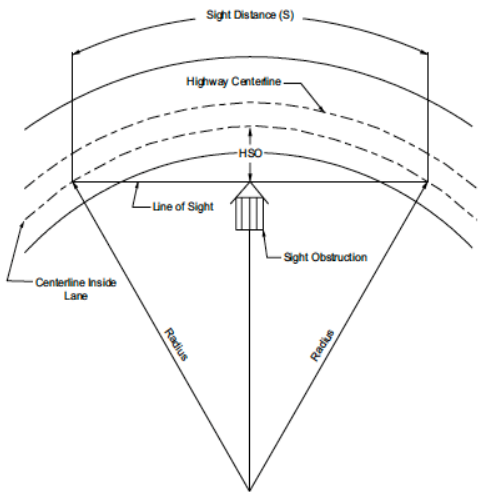
Dr. Peter T. Savolainen
Professor & Chairperson
Michigan State University

Introduction

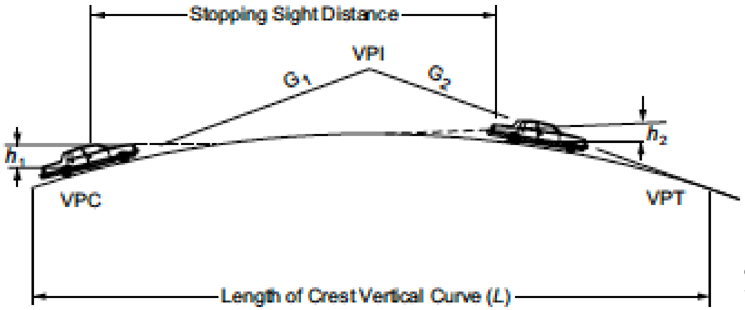
- In September 2018, the American Association of State Highway and Transportation Officials (AASHTO) published the 7th edition of A Policy on Geometric Design of Highways and Streets (also known as the Green Book).
- The 2018 Green Book provides guidance for determining geometric design criteria of roadways, including guidance on acceleration/deceleration and stopping sight distance criteria.
- The objective of this research was to update these guidelines.

AASHTO SSD Model

- $SSD = 1.47Vt + \frac{V^2}{30\left[\left(\frac{a}{32.2}\right) \pm G\right]}$
  - Where:
  - V = design speed (mph)
  - t = brake reaction time (s)
  - a = deceleration rate (ft/s2)
  - G = grade (ft/ft)



Source: AASHTO



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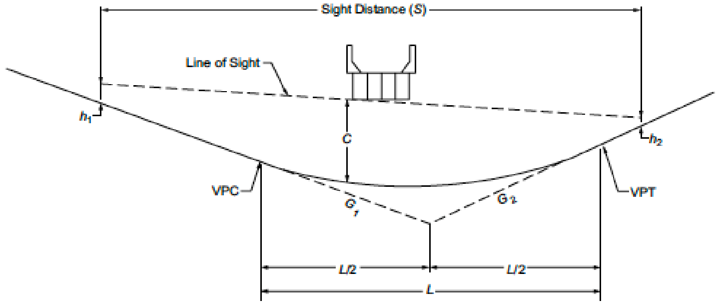

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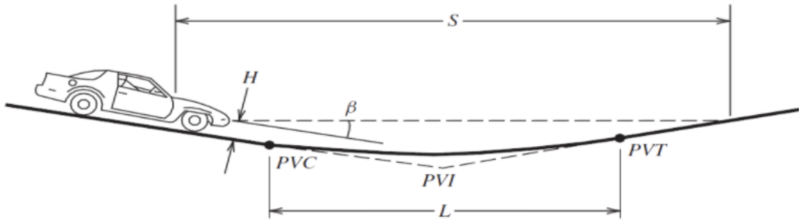


Source: AASHTO

AASHTO Acceleration Lane Design

- $L_{Acc} = \frac{(1.47V_m)^2 - (1.47V_r)^2}{2a}$

  - Where:
  - V_m = merge speed (mi/h)
  - V_r = initial speed on ramp (or speed after exiting the controlling feature) (mi/h)
  - a = average acceleration rate between these points (ft/s²)

U.S. Customary										
		Acceleration Lane Length, L_a (ft) for Design Speed of Controlling Feature on Ramp, V' (mph)								
Highway		Stop Condition	15	20	25	30	35	40	45	50
Design Speed, V (mph)	Merge Speed, V_a (mph)	Average Running Speed (i.e., Initial Speed) at Controlling Feature on Ramp, V'_a (mph)								
		0	14	18	22	26	30	36	40	44
30	23	180	140	—	—	—	—	—	—	—
35	27	280	220	160	—	—	—	—	—	—
40	31	360	300	270	210	120	—	—	—	—
45	35	560	490	440	380	280	160	—	—	—
50	39	720	660	610	550	450	350	130	—	—
55	43	960	900	810	780	670	550	320	150	—
60	47	1200	1140	1100	1020	910	800	550	420	180
65	50	1410	1350	1310	1220	1120	1000	770	600	370
70	53	1620	1560	1520	1420	1350	1230	1000	820	580
75	55	1790	1730	1630	1580	1510	1420	1160	1040	780
80	57	2000	1900	1800	1750	1680	1600	1340	1240	980

Note: Uniform 50:1 to 70:1 tapers are recommended where lengths of acceleration lanes exceed 1,300 ft.

V = design speed of highway (mph)
V_a = merge speed (mph)
V' = design speed of controlling feature on ramp (mph)
V'_a = average running speed (i.e., initial speed) at controlling feature on ramp (mph)
L_a = acceleration lane length (ft)

Source: AASHTO

AASHTO Deceleration Lane Design

- $L_{Decel} = 1.47V_h t_n - 0.5d_n(t_n)^2 + \frac{(1.47V_r)^2 - (1.47V_a)^2}{2d_{wb}}$
  - Where:
  - V_h = highway design speed (mi/h
  - V_a = speed (mi/h) after t_n s of deceleration without brakes
  - d_n = deceleration rate without brakes (ft/s^2)
  - V_r = entering speed for the controlling exit ramp curve (mi/h)
  - d_{wb} = deceleration rate with brakes applied (ft/s^2)

U.S. Customary										
		Deceleration Lane Length, L_a (ft) for Design Speed of Controlling Feature on Ramp, V' (mph)								
Highway Design Speed, V (mph)	Diverge Speed, V_a (mph)	Stop Condition	15	20	25	30	35	40	45	50
		Average Running Speed at Controlling Feature on Ramp, V'_a (mph)								
		0	14	18	22	26	30	36	40	44
30	28	235	200	170	140	—	—	—	—	—
35	32	280	250	210	185	150	—	—	—	—
40	36	320	295	265	235	185	155	—	—	—
45	40	385	350	325	295	250	220	—	—	—
50	44	435	405	385	355	315	285	225	175	—
55	48	480	455	440	410	380	350	285	235	—
60	52	530	500	480	460	430	405	350	300	240
65	55	570	540	520	500	470	440	390	340	280
70	58	615	590	570	550	520	490	440	390	340
75	61	660	635	620	600	575	535	490	440	390
80	64	705	680	665	645	620	580	535	490	440

V = design speed of highway (mph)
V_a = average running speed on highway (i.e., diverge speed) (mph)
V' = design speed of controlling feature on ramp (mph)
V'_a = average running speed at controlling feature on ramp (mph)
L_a = deceleration lane length (ft)

Source: AASHTO

Summary of Findings: Stopping Sight Distance

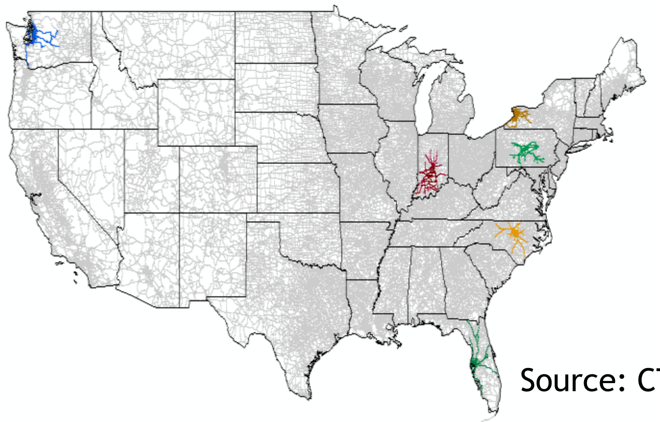
Summary of Brake Reaction Time Research

	N	Ages	Distraction-Involved?	Mean (sec.)	Std. Dev (Sec.)	85th Pct. (Sec.)	95th Pct. (Sec.)	Stimulus
Unsuspecting Driver (Unexpected Event)								
Field Collection (Drivers were unaware of being observed)								
Sivak et al., 1982	1,644	Mix	No	1.21	0.63	1.78	2.40	Unexpected signal
Wortman and Matthias, 1983	839	Mix	No	1.30	0.60	1.80	2.35	Unexpected signal
Chang et al., 1985	579	Mix	No	1.30	0.74	1.90	2.50	Unexpected signal
Test Track Driving (Drivers were aware of being observed)								
Olson and Sivak, 1986	49	Young	No	1.10	0.15	1.35	1.60	Unexpected object
Olson and Sivak, 1986	15	Old	No	1.06	0.10	1.40	1.50	Unexpected object
Lerner et al., 1995	56	Mix	No	1.51	0.40	1.91	2.20	Unexpected object
Fambro et al., 1997	38	Mix	No	0.99	0.22	/	/	Unexpected object
Fitch et al.. 2010	64	Mix	No	0.96	0.19	/	/	Unexpected objected
Naturalistic Driving (Drivers were aware of being observed)								
Dozza, 2013	472	Mix	No	1.30	1.03	/	/	Unexpected hazard
Dozza, 2013	472	Mix	Yes	1.55	1.08	/	/	Unexpected hazard
Dozza, 2013	472	Mix	Yes (some)	1.45	1.07	/	/	Unexpected hazard
Gao and Davis, 2017	103	Mix	No	1.58	1.26	/	/	Unexpected hazard
Gao and Davis, 2017	103	Mix	Yes	2.11	1.36	/	/	Unexpected hazard
Cai and Savolainen, 2020	159	Mix	Mix	1.51	1.24	2.61	8.44	Unexpected hazard
Alerted Driver (Expected Event)								
Test Driving (Drivers were aware of being observed)								
Olson, Sivak, 1985 [20]	49	Young	No	0.72	0.11	0.95	1.11	Anticipated object
Olson, Sivak, 1985 [20]	15	Old	No	0.73	0.10	1.00	1.29	Anticipated object
Fambro et al., 1997 [5]	26	Mix	No	0.59	0.19	/	/	Anticipated object
Fitch et al.. 2010 [44]	64	Mix	No	0.78	0.03	/	/	Anticipated barricade
Fitch et al.. 2010 [44]	64	Mix	No	0.55	0.02	/	/	Anticipated auditory alarm

Summary of Deceleration Rate Research

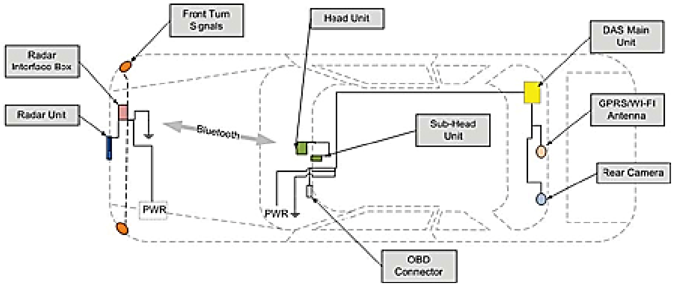
Unsuspecting Driver (Unexpected Event, Unknown Time and Location)					
	Pavement/ Wheel Condition	**Tangent/ Curve**	**Mean (g)**	**Std. Dev (g)**	**Stimulus**
Test Track Driving (Drivers were aware of being observed)					
Fambro et al., 1997	Dry/ABS	Tangent	0.63	0.08	Unexpected object
Fambro et al., 1997	Dry/No ABS	Tangent	0.62	0.08	Unexpected object
Fitch et al., 2010	Dry	Tangent	0.48	0.03	Unexpected barrica
Paquette and Porter, 2014	Dry	Tangent	0.82	0.27-0.67	Unexpected Signal
Naturalistic Driving (Drivers were aware of being observed, but under real environment)					
Wood, Zhang, 2017	Mix	Mix	0.44	0.26	Unexpected hazard
Lindheimer et al., 2018	Mix	Mix	0.26		Unexpected hazard
Savolainen et al., 2021	Mix	Mix	0.40	0.17	Unexpected hazard
Alerted Driver (Expected Event, Unknown Time and Location)					
Test Track Driving (Drivers were aware of being observed)					
Fambro et al., 1997	Dry/No ABS	Curve	0.54	0.20	Anticipated object
Fambro et al., 1997	Dry/No ABS	Tangent	0.53	0.08	Anticipated object
Fambro et al., 1997	Wet/No ABS	Curve	0.45	0.04	Anticipated object
Fambro et al., 1997	Wet/No ABS	Tangent	0.49	0.04	Anticipated object
Fitch et al., 2010	Dry	Tangent	0.44	0.02	Anticipated barrica
Fitch et al., 2010	Dry	Tangent	0.63	0.01	Anticipated alarm
EI-Shawarby et al., 2007	Dry	Tangent	0.22-0.60		Anticipated signal
Mean Estimates			0.51	0.07	

SHRP2 Naturalistic Driving Study (NDS):



Source: CTRE

- Largest NDS to date:
  - 6 geographic areas
  - 3,400+ drivers/vehicles
  - 5,400,000+ trips
  - 1800+ crashes
  - ~7000 near-crashes



Source: Campbell

Source: Wang et al.

- Roadway Information Database
  - 12,500+ miles of roadway information
  - Horizontal and vertical alignment
  - Cross-sectional characteristics

Source: Campbell

NDS Contextual Information

Rural

Rural Town

Suburban

Urban

Urban Core

Source: AASHTO

Sample Screenshots of Forward-View Video

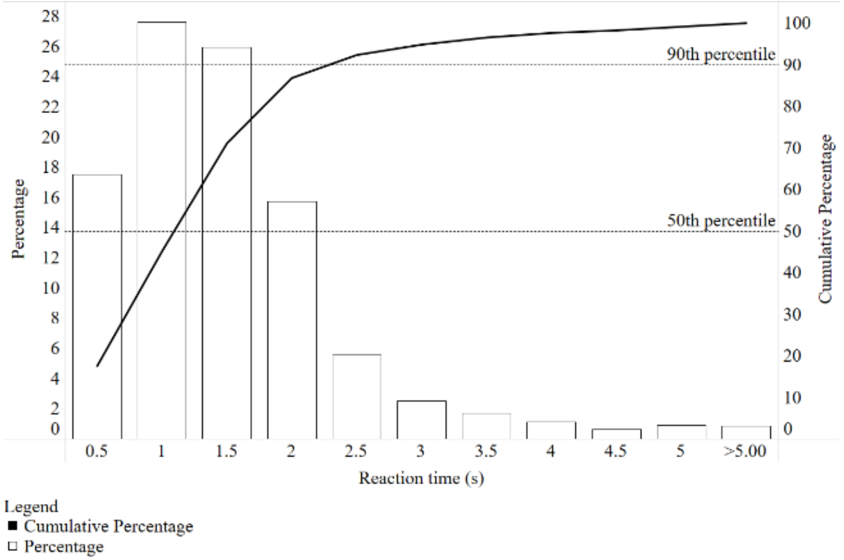
Source: MSU

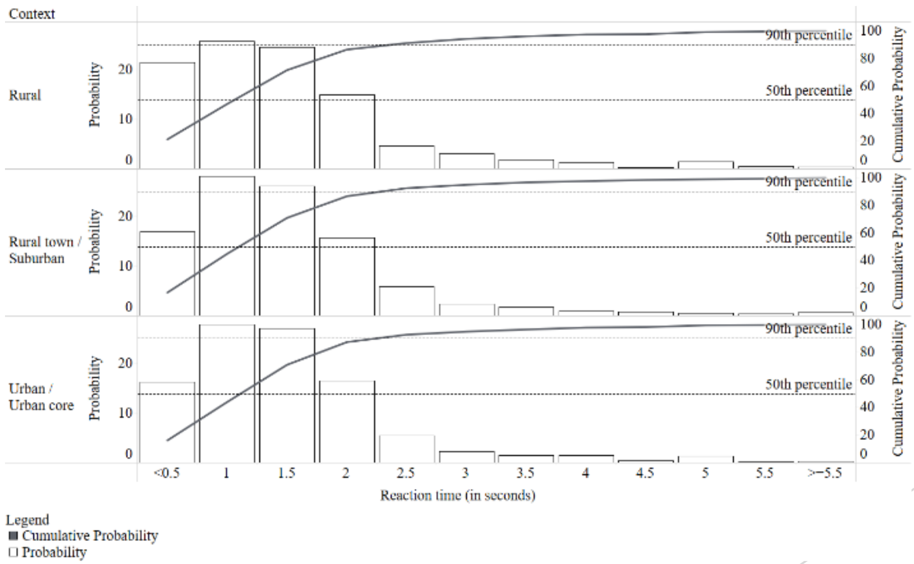
Number of Crash/Near-Crash Events by Contextual Environment

Contextual Environment	Number of Crash/Near-Crash Events
Suburban	1,961
Rural	453
Rural Town	29
Urban	1,263
Urban Core	215
Total	**3,921**

NDS Reaction Time Results

Scenario	Reaction Time (s)	
	Mean	Std. Dev.
NCHRP Report 400 (Fambro et al., 1997)	1.140	0.204
SHRP 2 NDS – No secondary task events	1.120	0.884
SHRP 2 NDS – All safety-critical events	1.255	0.932
SHRP 2 NDS – Only secondary task events	1.332	0.950



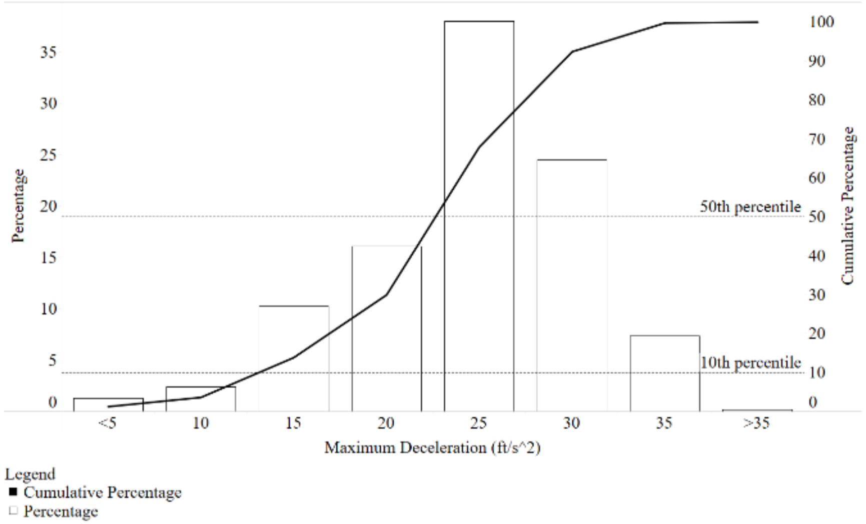


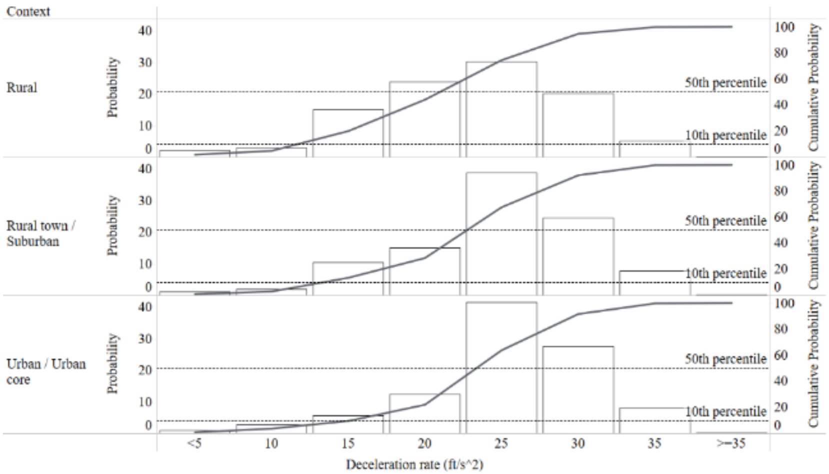
Source: NCHRP 15-75, TRB

- Mean and 90th-percentile reaction times were 1.3 s and 2.2 s.

NDS Deceleration Rate Results

Scenario	Deceleration Rate (ft/s^2)	
	Mean	Std. Dev.
NCHRP Report 400 (Fambro et al., 1997)	29.302	4.508
SHRP 2 NDS – No secondary task events	20.707	6.269
SHRP 2 NDS – All safety-critical events	21.996	6.078
SHRP 2 NDS – Only secondary task events	22.727	5.843

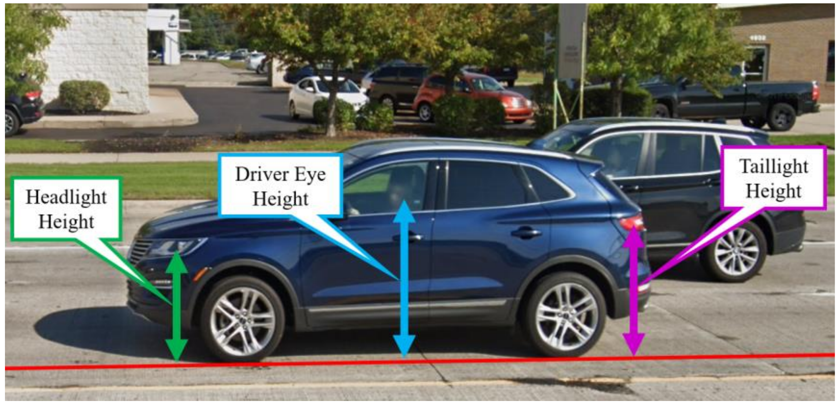




Source: NCHRP 15-75, TRB

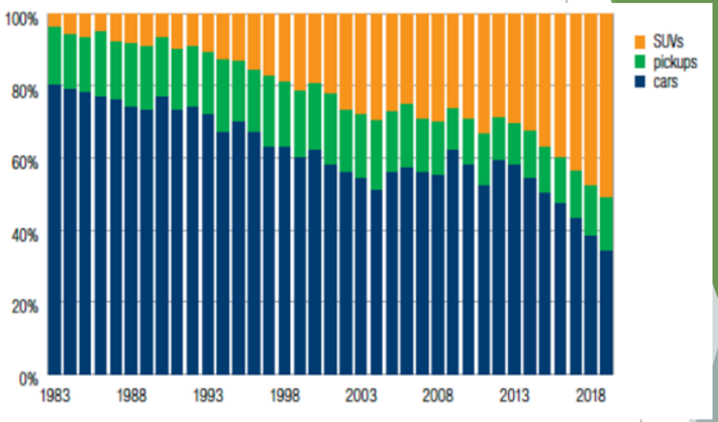
- In higher-speed contexts and rural areas, 10th-percentile and average deceleration rates were 11.8 ft/s^2 and 20.4 ft/s^2, respectively.
- In lower speed contexts and urban areas, 10th-percentile and average deceleration rates were 15.0 ft/s^2 and 22.8 ft/s^2, respectively.

Headlight, Taillight, and Driver Eye Height



Example of Proposed Collection of Vehicle Dimensions from Roadside Video

Source: MSU



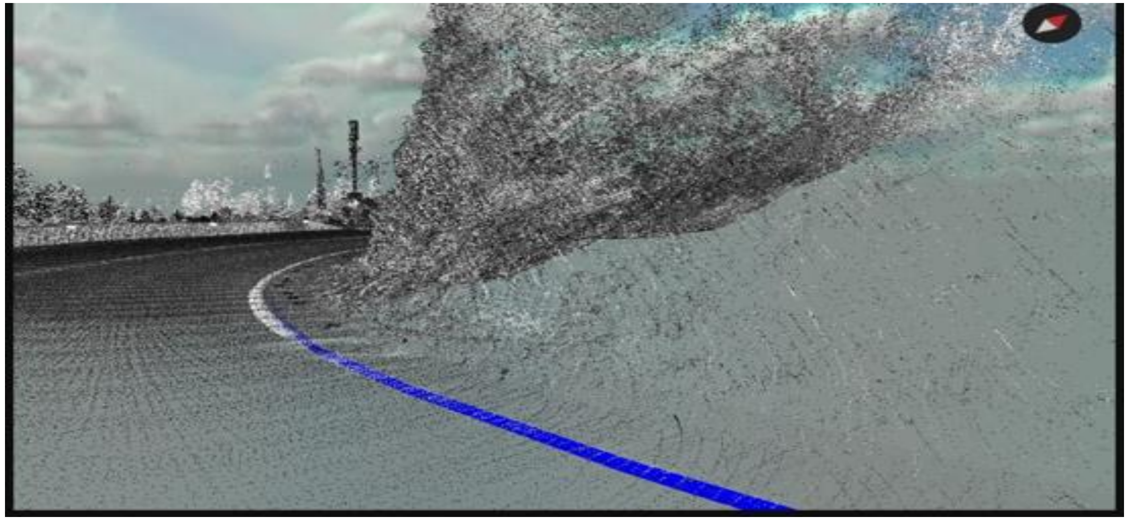
Vehicle Type Distribution

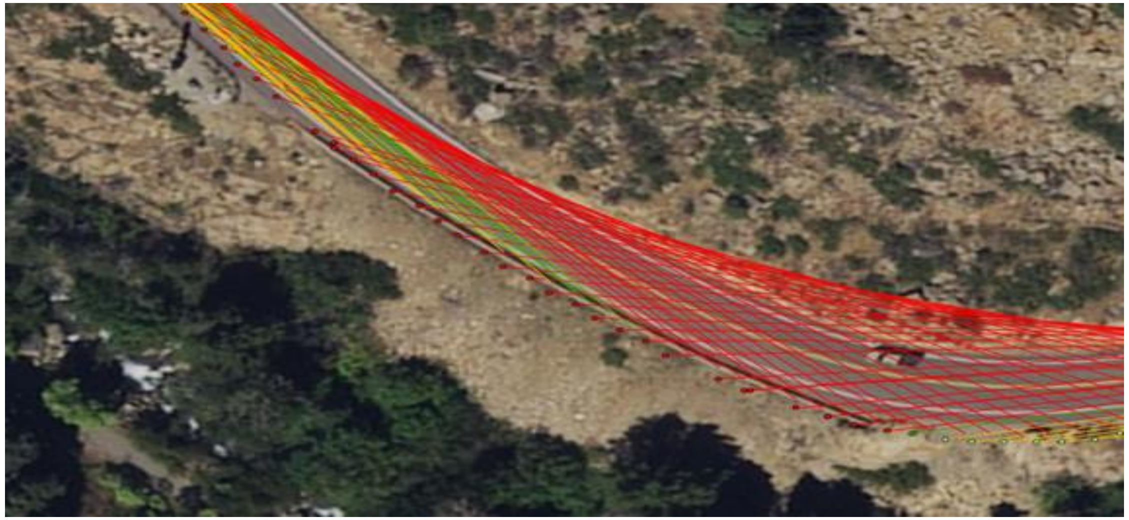
Source: HLDI

Descriptive Statistics	Headlight Height				Taillight Height			
	Passenger Cars		Multipurpose Vehicles		Passenger Cars		Multipurpose Vehicles	
	Present Study	NCHRP -400	Present Study	NCHRP -400	Present Study	NCHRP -400	Present Study	NCHRP-400
Sample Size	1,172	1318	1,442	992	1,172	858	1,442	534
Mean (ft)	2.31	2.13	3.00	2.76	2.97	2.38	3.57	3.16
10th Percentile (ft)	2.12	1.98	2.66	2.34	2.74	2.11	3.19	2.68

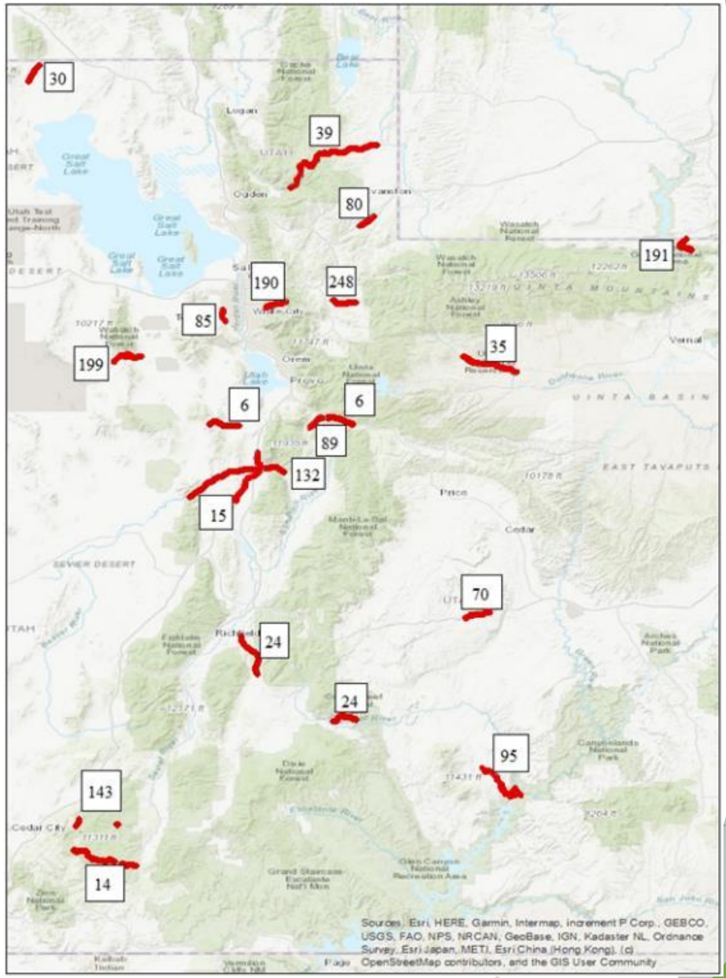
Descriptive Statistics	Center of Headrest and Driver Eye Height			
	Passenger Cars		Multipurpose Vehicles	
	Present Study	NCHRP-400	Present Study	NCHRP-400
Sample Size	1,172	875	1,442	629
Mean (ft)	3.86	3.77	4.59	4.86
10th Percentile (ft)	3.62	3.55	4.23	4.28

Stopping Sight Distance – Safety Analysis



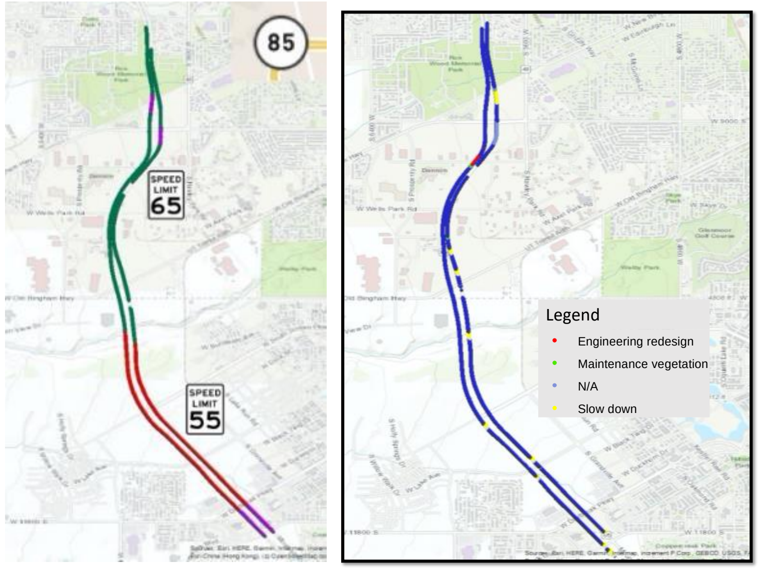


Source: RDV Systems

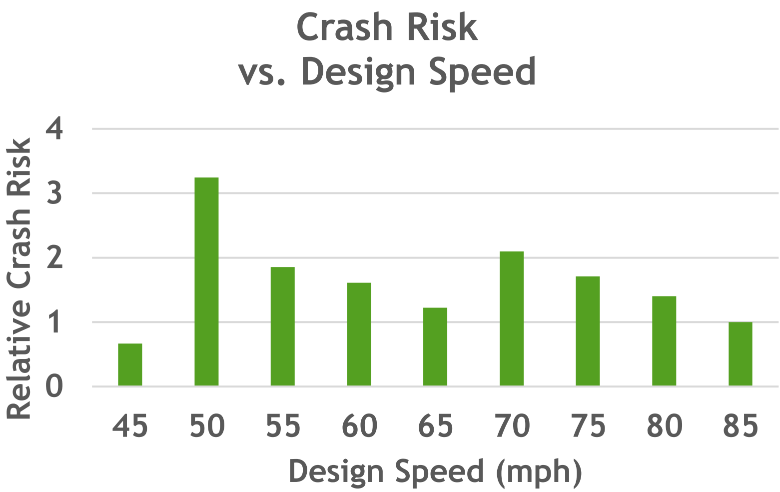


Source: MSU

Sample Corridor Data: Utah State Route 85



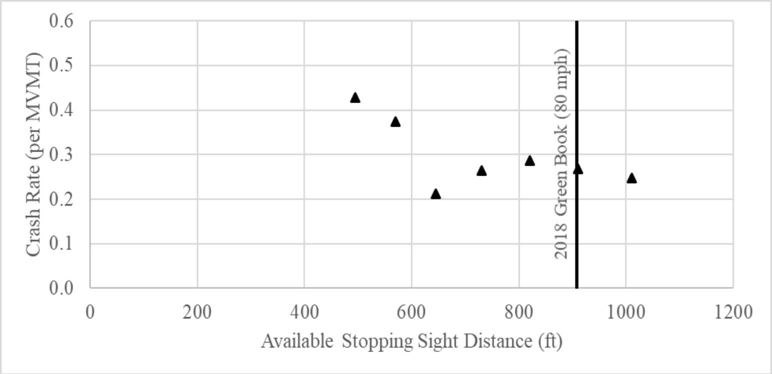
Source: MSU



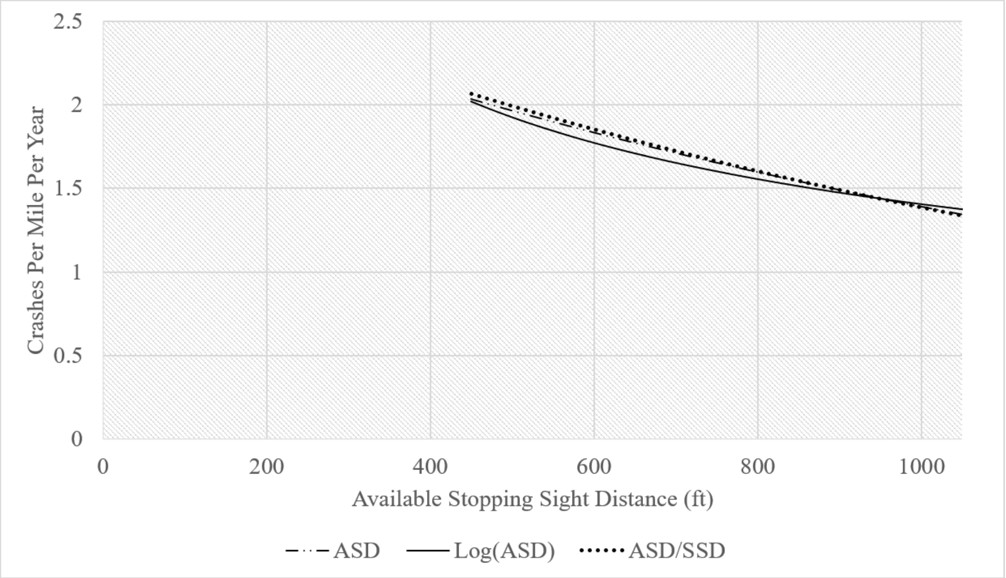
Source: MSU

Crash Risk vs. Available SSD – Freeways

Minimum Available SSD (ft)	No. of Segments	No. of Miles	Avg. AADT	Total MVMT	Total Crashes	Crash Rate per MVMT
≤495	72	7.14	18702	242.76	104	0.43
570	13	1.26	17468	40.02	15	0.37
645	34	3.41	15550	94.65	20	0.21
730	37	3.57	18146	117.17	31	0.26
820	54	5.17	15952	149.54	43	0.29
910	26	2.52	14749	67.36	18	0.27
1010	132	12.46	14392	322.37	80	0.25



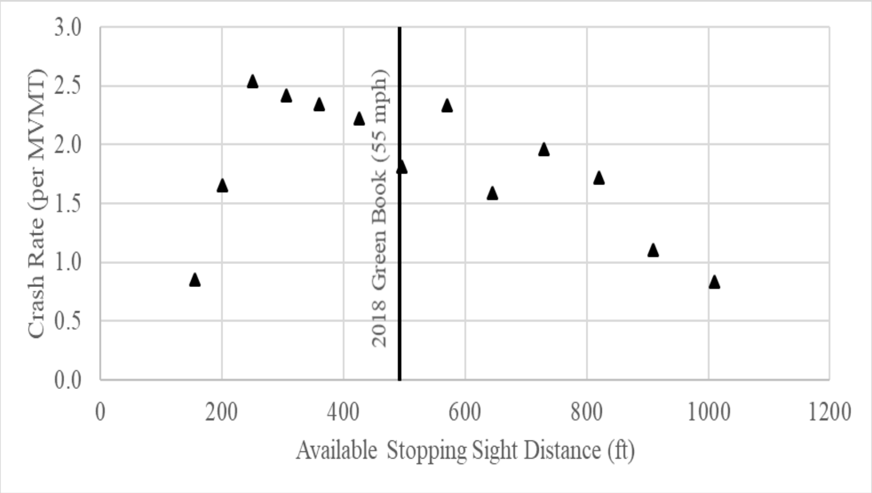
Source: NCHRP 15-75, TRB



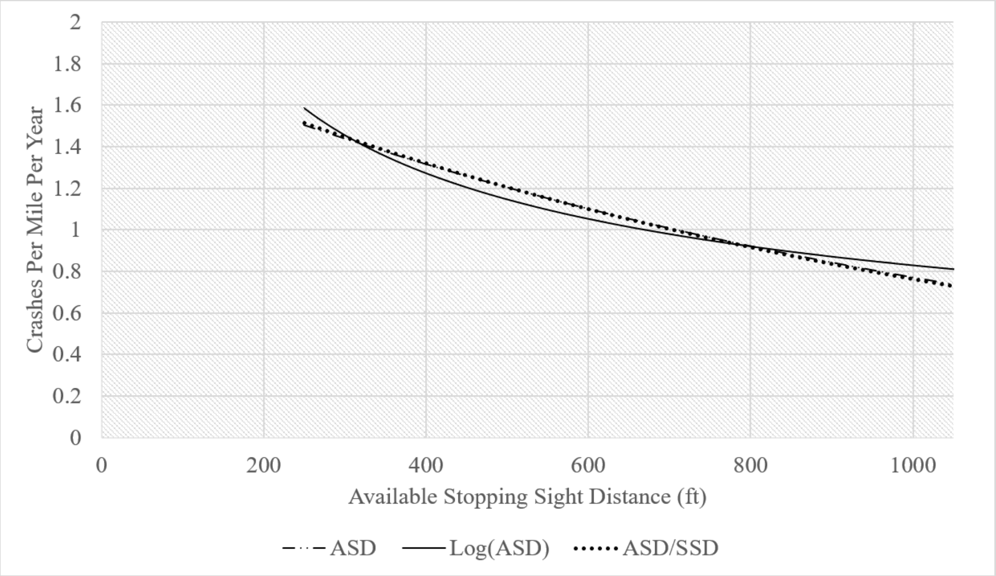
Source: NCHRP 15-75, TRB

Crash Risk vs. Available SSD – Non-Freeways

Minimum Available SSD (ft)	No. of Segments	No. of Miles	Avg. AADT	Total MVMT	Total Crashes	Crash Rate per MVMT
≤155	53	5.01	1,054	9.41	8	0.85
200	56	5.28	881	8.45	14	1.66
250	95	8.84	1,237	19.31	49	2.54
305	172	16.40	1,102	31.82	77	2.42
360	164	15.70	831	23.03	54	2.34
425	265	25.66	683	32.00	71	2.22
495	82	7.85	884	12.14	22	1.81
570	84	8.27	842	12.85	30	2.33
645	59	5.34	911	8.82	14	1.59
730	51	4.69	821	6.61	13	1.97
820	46	4.61	862	6.99	12	1.72
910	55	5.32	1,083	10.87	12	1.10
1010	95	8.97	1,690	27.66	23	0.83



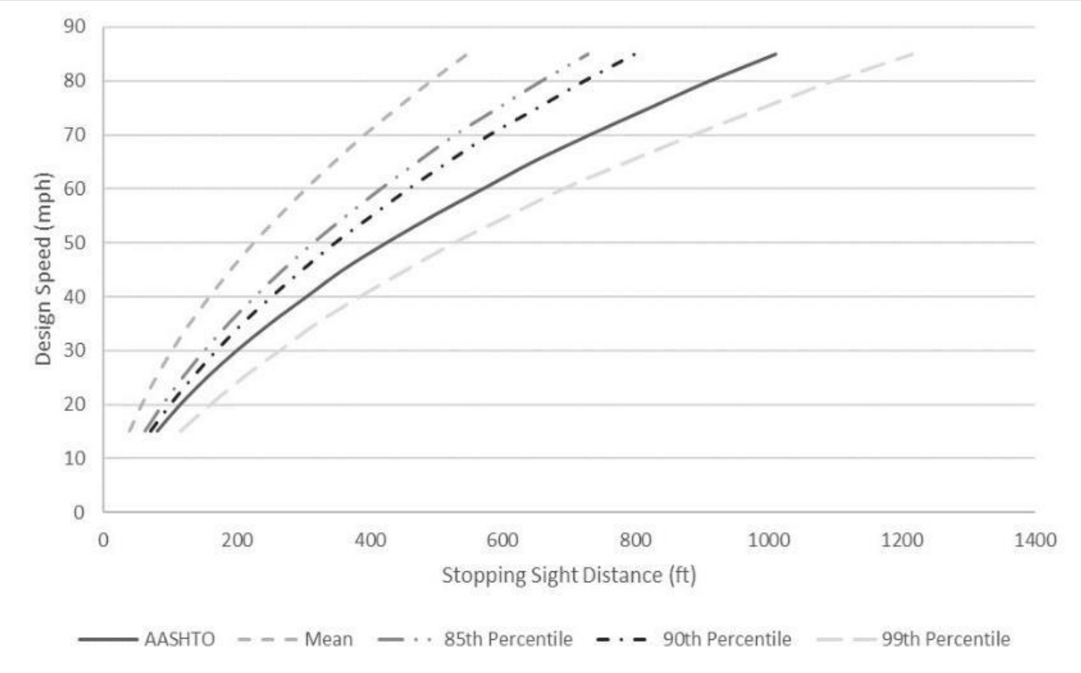
Source: NCHRP 15-75, TRB



Source: NCHRP 15-75, TRB

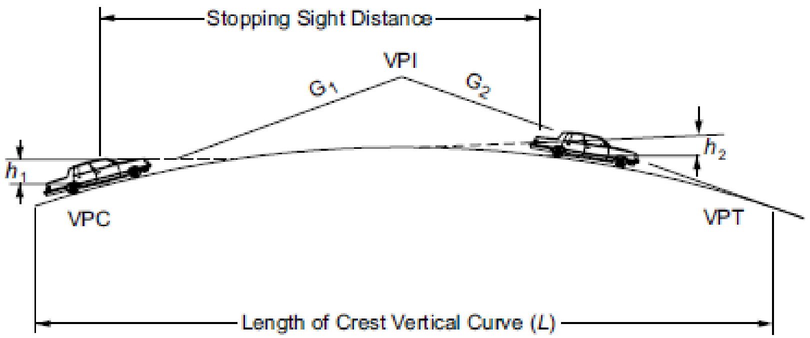
PNC by Design Speed – SHRP 2 NDS (All Events)

Design Speed (mph)	AASHTO SSD (ft)	Calculated Stopping Sight Distance (ft)				
		PNC	Mean	85th Percentile	90th Percentile	99th Percentile
15	80	0.065	40	63	71	116
20	115	0.060	58	89	101	161
25	155	0.055	80	119	134	210
30	200	0.050	104	152	170	265
35	250	0.045	130	188	209	320
40	305	0.041	160	228	253	385
45	360	0.042	192	270	299	456
50	425	0.037	227	316	348	527
55	495	0.036	265	365	403	609
60	570	0.032	305	417	458	691
65	645	0.033	348	472	518	787
70	730	0.031	392	528	579	886
75	820	0.030	442	593	652	989
80	910	0.030	493	658	721	1,095
85	1,010	0.029	547	728	798	1,215



Source: NCHRP 15-75, TRB

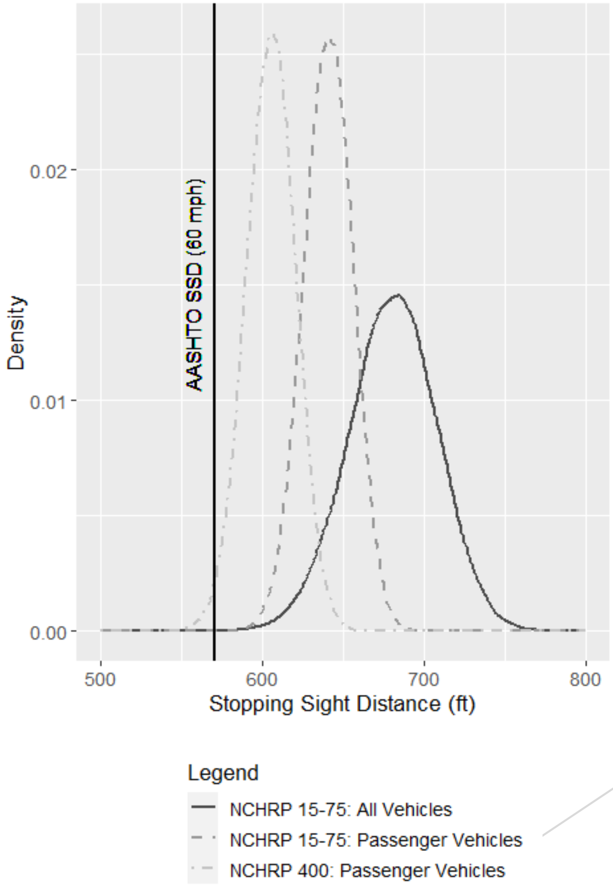
Crest Vertical Curves – PNC by Design Speed



Source: AASHTO, 2018

Design Speed (mph)	SSD (ft)	K = L/A	Calculated Sight Distance (ft)			
			PNC	1st Percentile	5th Percentile	10th Percentile
15	80	3	<0.001	87	89	91
20	115	7	<0.001	132	137	139
25	155	12	<0.001	173	179	182
30	200	19	<0.001	218	225	229
35	250	29	<0.001	269	278	283
40	305	44	<0.001	331	342	348
45	360	61	<0.001	390	403	410
50	425	84	<0.001	458	473	481
55	495	114	<0.001	534	552	561
60	570	151	<0.001	614	634	645
65	645	193	<0.001	695	717	729
70	730	247	<0.001	786	812	825
75	820	308	<0.001	877	906	921
80	910	384	<0.001	979	1,012	1,029

60 mph design speed



Source: NCHRP 15-75, TRB

Summary of Findings: Speed-Change Lanes

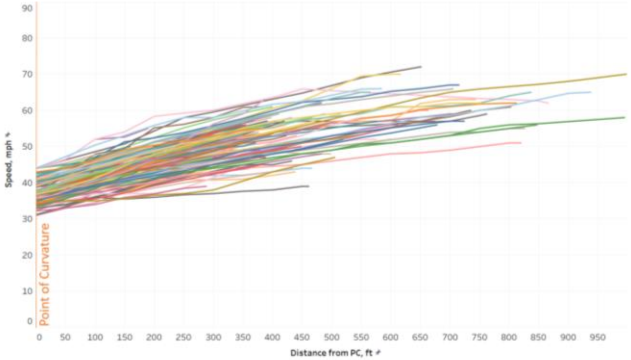
Data Collection Setup

Loop, parallel entrance ramp

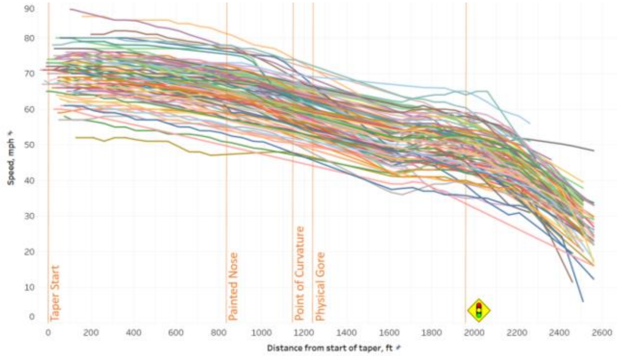
Diamond, parallel exit ramp

Sample Ramp Data Collection Locations in Michigan

Source: MSU



Loop, parallel entrance ramp



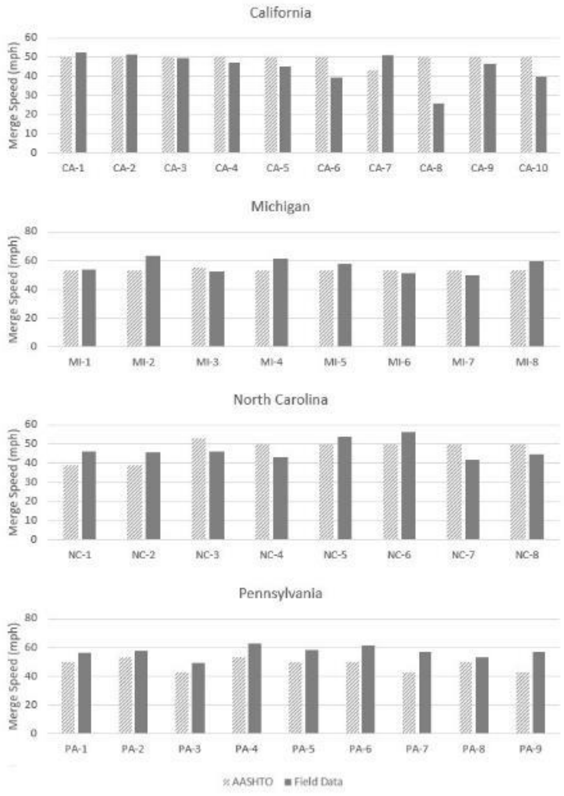
Diamond, parallel exit ramp

Sample LIDAR vehicle speed profiles from two sites in Michigan

Source: MSU

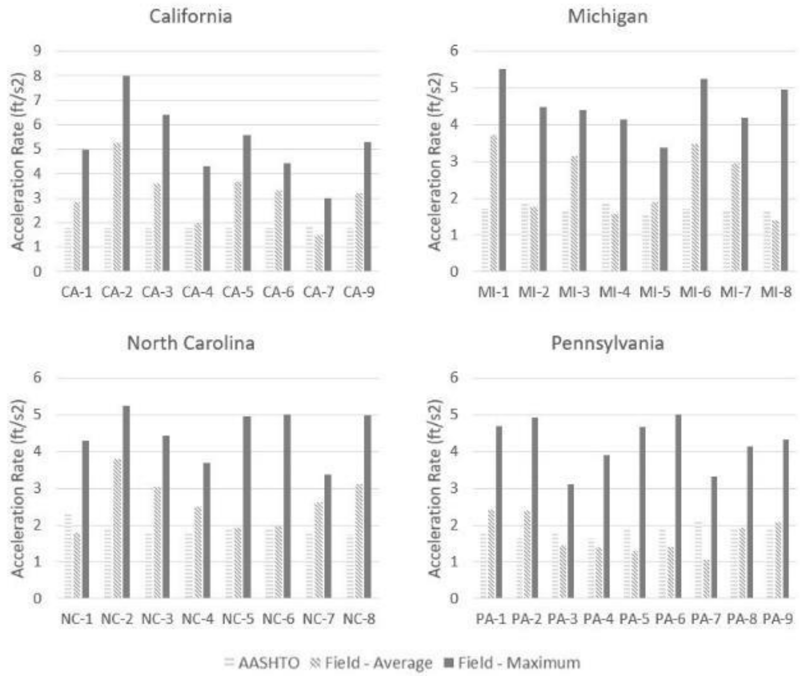
Comparison of Field Data and Assumed Design Values for Acceleration Lanes

Entrance Ramp – Merge Speed



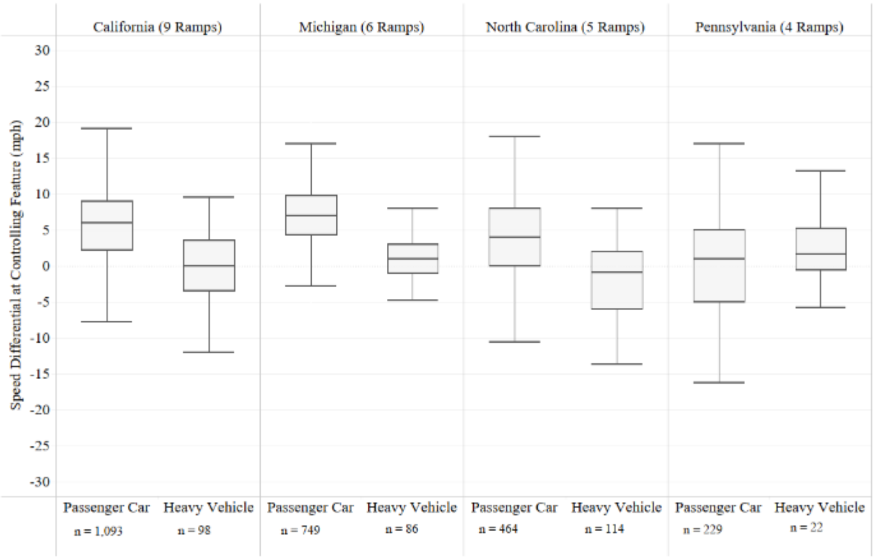
Source: NCHRP 15-75, TRB

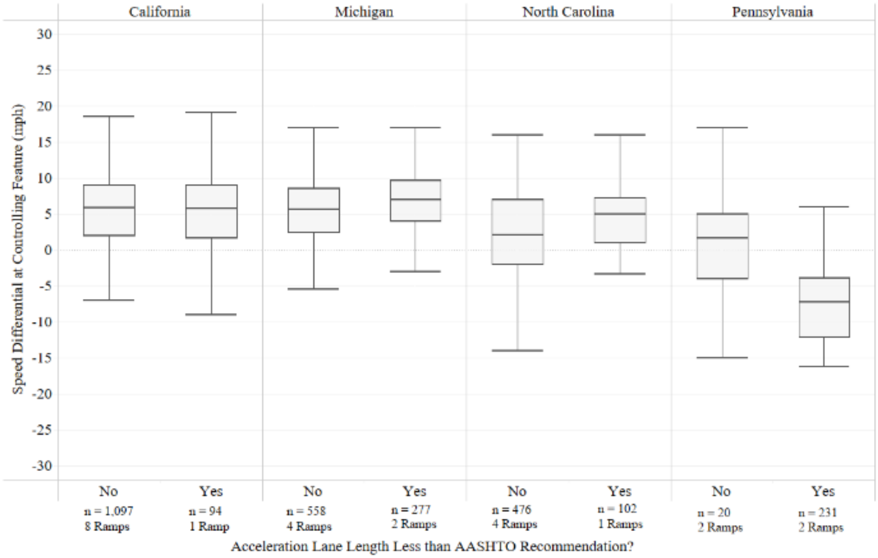
Entrance Ramp – Acceleration Rate



Source: NCHRP 15-75, TRB

Entrance Ramp – Initial Speed (at Controlling Feature)

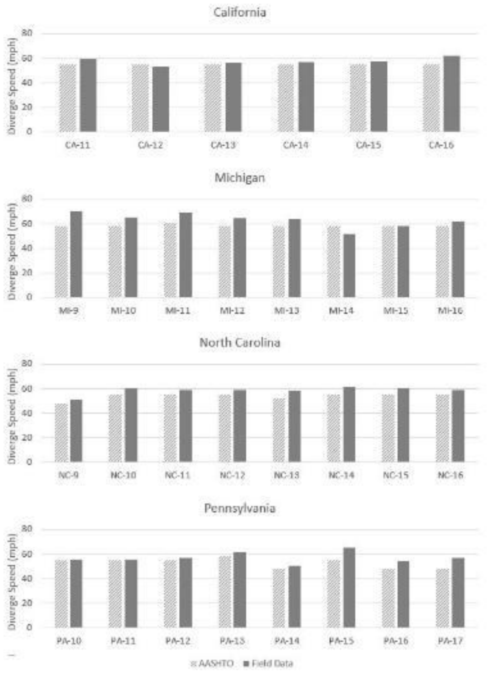




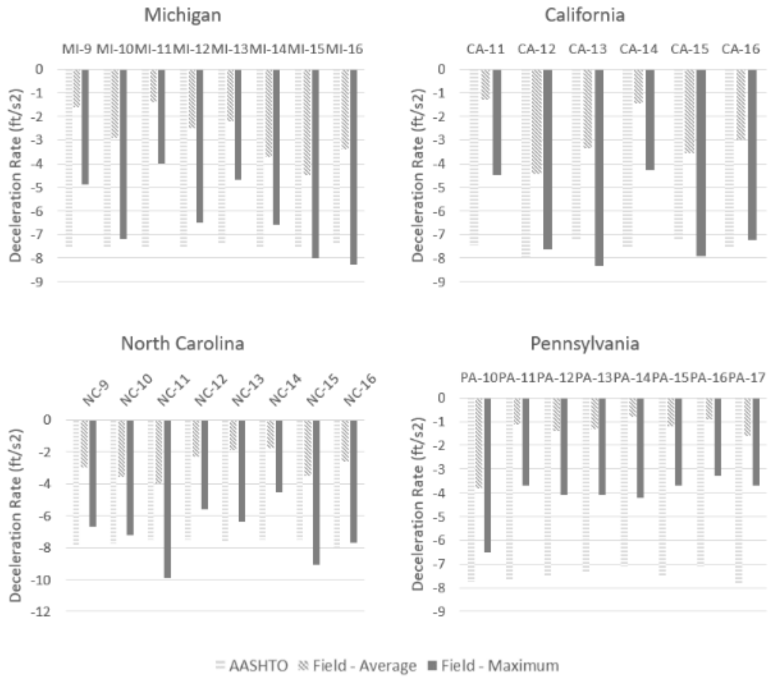
Source: NCHRP 15-75, TRB

Comparison of Field Data and Assumed Design Values for Deceleration Lanes

Exit Ramp – Diverge Speed

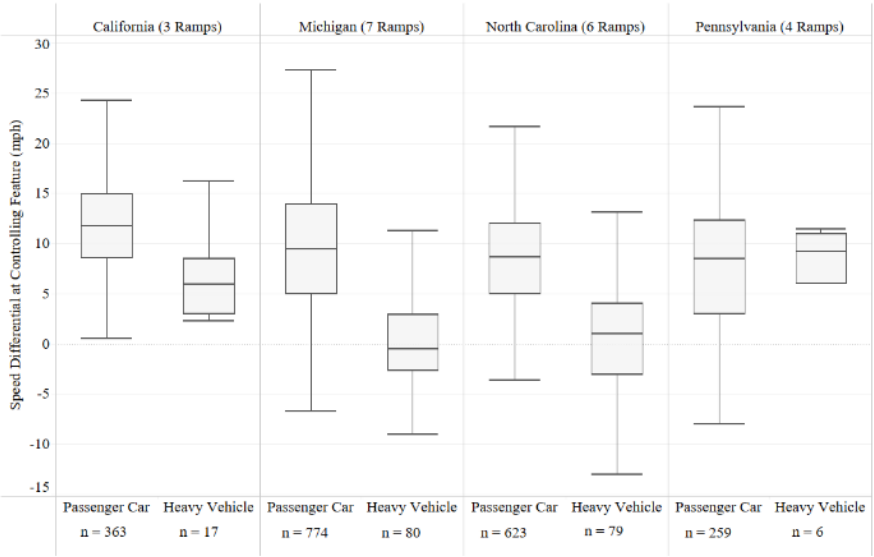


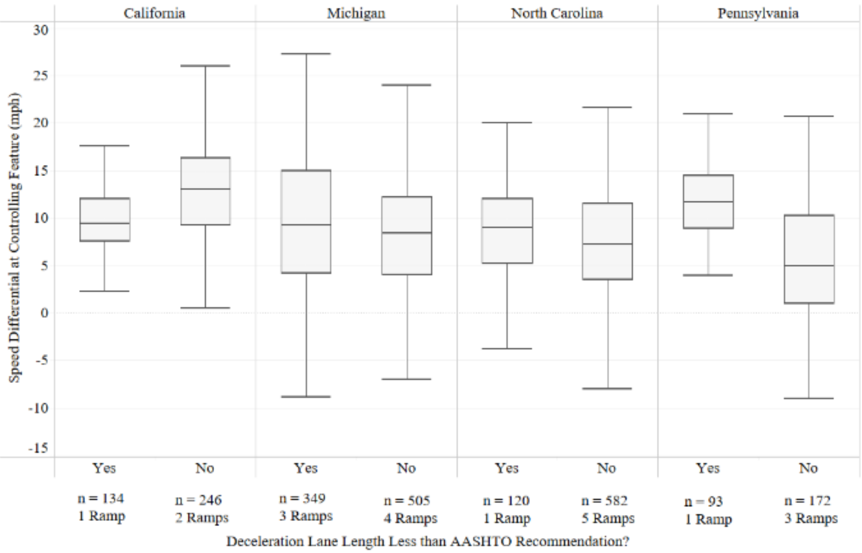
Exit Ramp – Deceleration Rate



Source: NCHRP 15-75, TRB

Exit Ramp – Final Speed (at Controlling Feature)





Source: NCHRP 15-75, TRB

PNC for Acceleration Lane Length

$$L_{Acc} = \frac{(1.47V_m)^2 - (1.47V_r)^2}{2a}$$

where:

L_{Acc} = acceleration lane length (feet).

V_m = merge speed (mph).

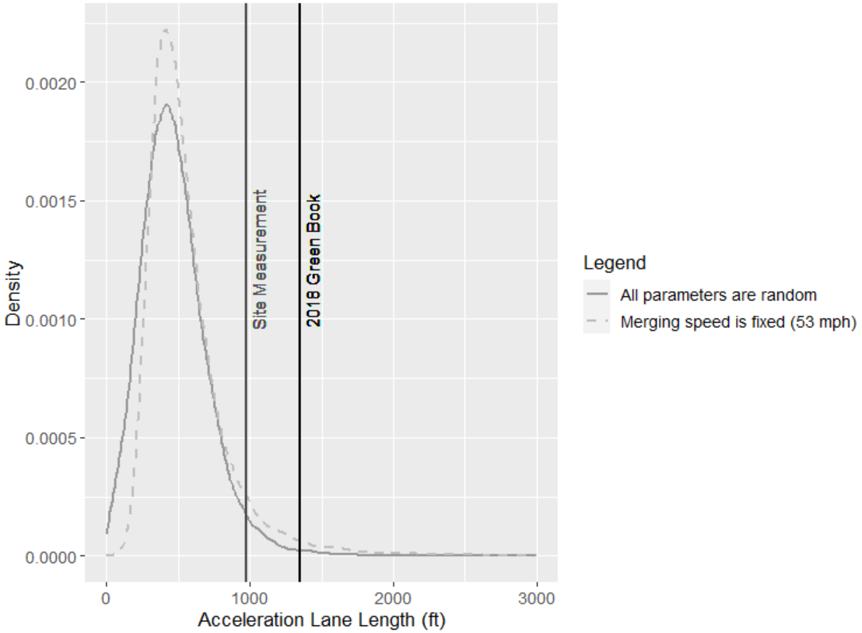
V_r = initial speed on ramp after exiting controlling geometric feature (mph).

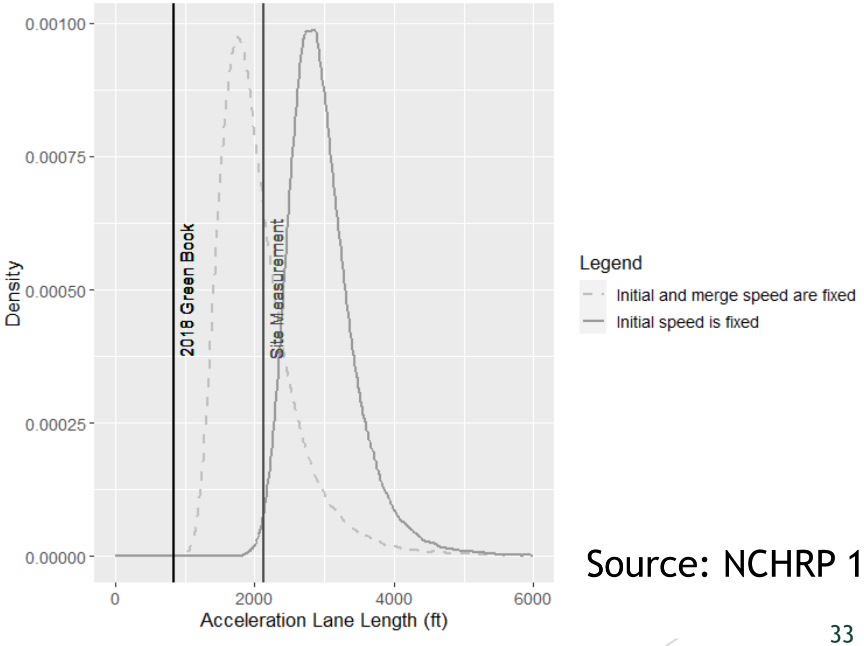
a = acceleration rate (ft/s²).

Source: AASHTO

U.S. Customary										
Acceleration Lane Length, L_a (ft) for Design Speed of Controlling Feature on Ramp, V' (mph)										
Highway		Stop Condition	15	20	25	30	35	40	45	50
Design Speed, V (mph)	Merge Speed, V_a (mph)	Average Running Speed (i.e., Initial Speed) at Controlling Feature on Ramp, V'_a (mph)								
		0	14	18	22	26	30	36	40	44
30	23	180	140	—	—	—	—	—	—	—
35	27	280	220	160	—	—	—	—	—	—
40	31	360	300	270	210	120	—	—	—	—
45	35	560	490	440	380	280	160	—	—	—
50	39	720	660	610	550	450	350	130	—	—
55	43	960	900	810	780	670	550	320	150	—
60	47	1200	1140	1100	1020	910	800	550	420	180
65	50	1410	1350	1310	1220	1120	1000	770	600	370
70	53	1620	1560	1520	1420	1350	1230	1000	820	580
75	55	1790	1730	1630	1580	1510	1420	1160	1040	780
80	57	2000	1900	1800	1750	1680	1600	1340	1240	980

Source: AASHTO





Source: NCHRP 15-75, TRB

Example with Low PNC

Source: NCHRP 15-75, TRB

Example with High PNC

PNC Comparison between Field Observation and Simulation – Acceleration Lanes

State	Site	Site Length (ft)	AASHTO Length (ft)	N	PNC from Field Data	PNC from Simulation
California	CA-1	619	1,220	157	0.54	0.70
	CA-2	480	2,013	127	0.09	0.17
	CA-3	505	610	118	0.31	0.32
	CA-4	692	2,745	151	0.50	0.47
	CA-5	550	1,220	153	0.14	0.15
	CA-6	866	1,310	134	0.00	0.00
	CA-7	540	320	94	0.18	0.18
	CA-9	479	1,310	160	0.50	0.49

State	Site	Site Length (ft)	AASHTO Length (ft)	N	PNC from Field Data	PNC from Simulation
Michigan	MI-1	1,233	1,350	121	0.00	0.01
	MI-2	1,951	1,620	125	0.38	0.99
	MI-3	542	1,510	146	0.13	0.17
	MI-4	2,159	1,620	147	0.37	0.94
	MI-5	1,196	820	153	0.00	0.01
	MI-6	977	1,350	145	0.01	0.03
	MI-7	475	1,230	146	0.10	0.15
	MI-8	1,607	1,230	124	0.19	0.22

State	Site	Site Length (ft)	AASHTO Length (ft)	N	PNC from Field Data	PNC from Simulation
North Carolina	NC-1	815	720	142	0.42	0.99
	NC-2	585	175	120	0.01	0.02
	NC-3	880	852	119	0.04	0.05
	NC-4	835	672	115	0.04	0.03
	NC-5	1,341	1,410	129	0.10	0.91
	NC-6	1,403	1,410	128	0.35	0.92
	NC-7	1,420	1,904	102	0.00	0.00
	NC-8	1,059	1,000	122	0.02	0.02

State	Site	Site Length (ft)	AASHTO Length (ft)	N	PNC from Field Data	PNC from Simulation
Pennsylvania	PA-1	920	1,904	104	0.20	0.83
	PA-2	1,269	2,000	116	0.03	0.25
	PA-3	462	150	124	0.94	0.92
	PA-4	1,283	1,000	130	0.94	0.93
	PA-5	2,948	1,410	106	0.00	0.48
	PA-6	2,132	846	107	0.85	0.99
	PA-7	2,289	960	120	0.98	0.94
	PA-8	1,724	1,410	104	0.02	0.35
	PA-9	1,311	670	110	0.00	0.53

PNC for Deceleration Lane Length

$$L_{Decel} = 1.47V_h t_n - 0.5d_n(t_n)^2 + \frac{(1.47V_r)^2 - (1.47V_a)^2}{2d_{wb}}$$

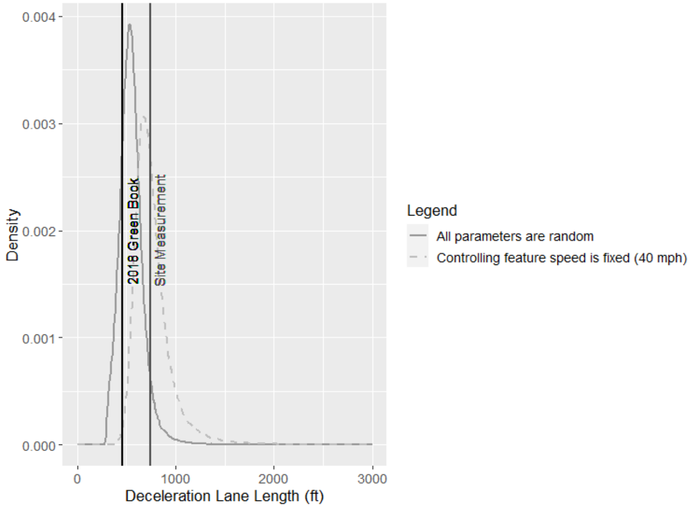
Where:

L_{Decel} = deceleration lane length (feet).
V_h = highway speed (mph).
V_a = speed after tn second of deceleration without brakes (mph).
V_r = speed at the controlling feature of exit ramp (mph).
t_n = deceleration time without brakes (s).
d_n = deceleration rate without brakes (ft/s²).
d_{wb} = deceleration rate with brakes (ft/s²).

Source: AASHTO

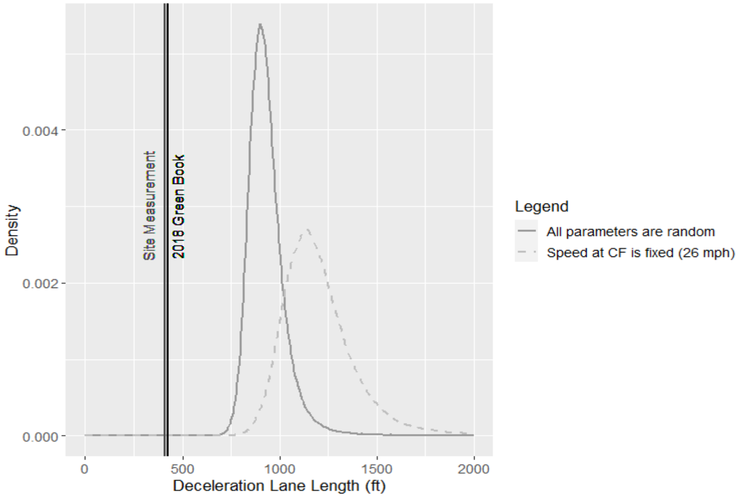
U.S. Customary										
		Deceleration Lane Length, L (ft) for Design Speed of Controlling Feature on Ramp, V' (mph)								
Highway Design Speed, V (mph)	Diverge Speed, V_a (mph)	Stop Condition	15	20	25	30	35	40	45	50
		Average Running Speed at Controlling Feature on Ramp, V'_a (mph)								
		0	14	18	22	26	30	36	40	44
30	28	235	200	170	140	—	—	—	—	—
35	32	280	250	210	185	150	—	—	—	—
40	36	320	295	265	235	185	155	—	—	—
45	40	385	350	325	295	250	220	—	—	—
50	44	435	405	385	355	315	285	225	175	—
55	48	480	455	440	410	380	350	285	235	—
60	52	530	500	480	460	430	405	350	300	240
65	55	570	540	520	500	470	440	390	340	280
70	58	615	590	570	550	520	490	440	390	340
75	61	660	635	620	600	575	535	490	440	390
80	64	705	680	665	645	620	580	535	490	440

Source: AASHTO



Example with Low PNC

Source: NCHRP 15-75, TRB



Example with High PNC

Source: NCHRP 15-75, TRB

PNC Comparison between Field Observation and Simulation – Deceleration Lanes

State	Site	Site Length (ft)	AASHTO Length (ft)	N	PNC from Field Data	PNC from Simulation
California	CA-11	791	440	155	0.61	0.12
	CA-12	335	500	147	0.02	1.00
	CA-13	599	520	99	0.28	0.71
	CA-14	1,387	570	130	0.18	–
	CA-15	889	520	104	0.02	–
	CA-16	915	570	115	0.13	–

State	Site	Site Length (ft)	AASHTO Length (ft)	N	PNC from Field Data	PNC from Simulation
Michigan	MI-9	1,958	490	124	0.09	0.05
	MI-10	733	520	148	0.06	0.36
	MI-11	1,812	440	115	0.01	0.05
	MI-12	1,000	624	150	0.28	0.13
	MI-13	302	440	130	0.02	1.00
	MI-14	200	520	108	0.52	1.00
	MI-15	300	520	111	0.36	1.00
	MI-16	910	615	108	0.09	–

State	Site	Site Length (ft)	AASHT Length (ft)	N	PNC from Field Data	PNC from Simulation
North Carolina	NC-9	404	342	118	0.19	0.94
	NC-10	410	423	120	0.04	1.00
	NC-11	750	570	119	0.31	–
	NC-12	431	390	120	0.08	0.99
	NC-13	730	387	130	0.01	0.14
	NC-14	567	390	111	0.03	0.50
	NC-15	980	570	132	0.03	–
	NC-16	741	450	103	0.21	0.21

State	Site	Site Length (ft)	AASHTO Length (ft)	N	PNC from Field Data	PNC from Simulation
Pennsylvania	PA-10	335	470	103	0.10	1.00
	PA-11	740	459	108	0.00	0.06
	PA-12	855	396	105	0.00	0.04
	PA-13	1,826	615	107	0.00	–
	PA-14	1,385	480	122	0.00	–
	PA-15	1,220	396	99	0.00	–
	PA-16	1,870	576	120	0.00	–
	PA-17	964	380	104	0.00	–

Development of Revised Design Guidelines

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Professor & Senior Associate Dean
Pennsylvania State University

Guidelines Related to SSD

- It is recommended to update the brake reaction time and deceleration rate values as follows:
  - Update brake reaction time from 2.5 s to 2.2 s
    - This represents 90th-percentile driver from NDS crash or near-crash events
  - Deceleration rate to be updated to 11.8 ft/s^2 in rural or high-speed contexts (greater than 45 mph)
    - This represents 10th-percentile driver from NDS crash or near-crash events
  - Deceleration rate to be updated to 15 ft/s^2 in urban and urban core context or low speed contexts (less than or equal to 45 mph)
    - This represents 10th-percentile driver from NDS crash or near-crash events

Guidelines Related to SSD

Proposed Table 3-1: Stopping Sight Distance on Level Roadways

Rural or High Speed

U.S. Customary				
Design Speed (mph)	Brake Reaction Distance (ft)	Braking Distance on Level (ft)	Stopping Sight Distance Calculated (ft)	Stopping Sight Distance Design (ft)
15	48.5	20.5	69.0	70
20	64.7	36.4	101.1	105
25	80.9	56.9	137.8	140
30	97.0	82.0	179.0	180
35	113.2	111.6	224.8	225
40	129.4	145.8	275.1	280
45	145.5	184.5	330.0	335
50	161.7	227.8	389.5	390
55	177.9	275.6	453.5	455
60	194.0	328.0	522.0	525
65	210.2	384.9	595.1	600
70	226.4	446.4	672.8	675
75	242.6	512.4	755.0	760
80	258.7	583.1	841.8	845
85	274.9	658.2	933.1	935

Low Speed Urban

U.S. Customary				
Design Speed (mph)	Brake Reaction Distance (ft)	Braking Distance on Level (ft)	Stopping Sight Distance Calculated (ft)	Stopping Sight Distance Design (ft)
15	48.5	16.1	64.6	65
20	64.7	28.7	93.3	95
25	80.9	44.8	125.6	130
30	97.0	64.5	161.5	165
35	113.2	87.8	201.0	205
40	129.4	114.7	244.0	245
45	145.5	145.1	290.7	295

Source: AASHTO

Guidelines Related to SSD

Proposed Table 3-2: Stopping Sight Distance on Grades

Rural or High Speed

U.S. Customary						
Design Speed (mph)	Stopping Sight Distance (ft)					
	Downgrades			Upgrades		
	3%	6%	9%	3%	6%	9%
15	71	73	76	68	67	65
20	105	109	113	99	96	94
25	143	149	157	134	130	127
30	187	195	206	173	168	163
35	235	247	261	217	209	203
40	288	304	323	264	255	247
45	347	366	390	316	304	294
50	410	434	464	372	358	345
55	478	507	543	433	415	399
60	551	586	629	497	476	457
65	629	670	720	566	541	519
70	712	760	818	639	610	585
75	800	855	921	716	683	654
80	893	955	1031	797	759	727
85	991	1061	1147	883	840	803

Low Speed Urban

U.S. Customary						
Design Speed (mph)	Stopping Sight Distance (ft)					
	Downgrades			Upgrades		
	3%	6%	9%	3%	6%	9%
15	66	67	69	64	63	63
20	96	98	101	92	91	89
25	129	133	137	123	121	119
30	166	171	177	158	155	151
35	207	214	222	196	191	187
40	252	261	272	237	231	226
45	301	312	326	282	274	267

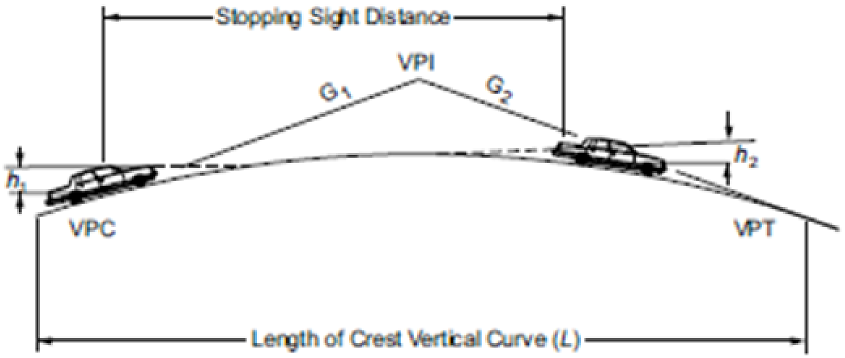
Source: NCHRP 15-75, TRB

Guidelines Related to SSD

- It is recommended to update the criteria for measuring SSD as follows:
  - Driver’s eye height be increased from 3.50 ft to 3.75 ft
    - This represents 90th-percentile driver eye height from passenger vehicle field measurements
  - No change in truck driver’s eye height
    - 7.6 ft is recommended in the 2018 Green Book
  - Object height for SSD scenarios should remain the same
    - Vehicle taillight height increased from 2.0 to 3.0 ft
    - But taillights are not the only relevant objects of concern for SSD scenarios
- These updates will also result in updating object height criteria for passing sight distance (PSD) and intersection sight distance to 3.75 ft
  - Eye height is reciprocal for these cases (object height equals eye height)

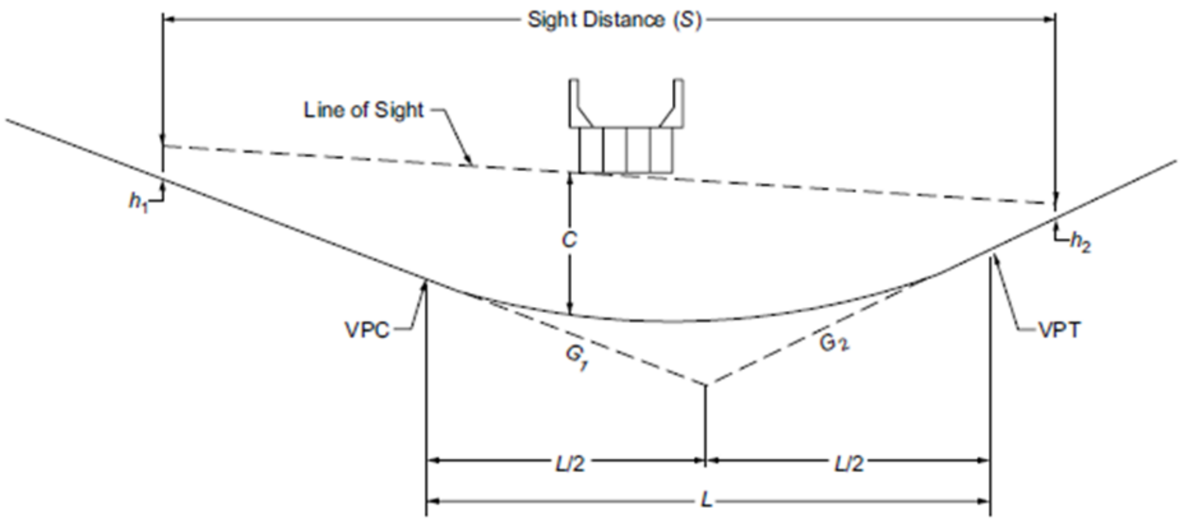
Guidelines Related to Crest Vertical Curves

- Following updates to design parameters are recommended:
  - Eye height should be increased to 3.75 ft
  - Object height should not be changed and remain 2.00 ft.
- These updates will result in revised design controls for crest vertical curves based on SSD and PSD, i.e., revised values for rate of vertical curvature (K_a).



Guidelines Related to Sight Distance at Undercrossings

- Following updates to design parameters are recommended:
  - Eye height should be changed from 8.0 ft to 7.6 ft for truck eye height
  - Object height should be increased to 3.0 ft for taillights of a vehicle
    - Taller object height reduces sight distance at undercrossings



Acceleration Lane Length

- Merging behavior
  - Late merges (after start of taper) were more frequent on shorter SCLs.
  - Late merges were less frequent among heavy vehicles.
  - Vehicles merged earlier on loop ramps versus diagonal ramps.
  - Under designed ramps (RE: AASHTO) had fewer late merges.

- Merging speeds were closer to mainline speeds
  - On freeways with lower speed limits and ramps with higher design speeds.
  - Where the crossroad terminal was the controlling feature (compared to horizontal curves).
  - On ramps with higher design speeds.

Acceleration Lane Length

- Speed at controlling feature
  - Passenger cars had higher speeds at the controlling feature than heavy vehicles.
  - Heavy vehicles had speeds close to the ramp design speed.
  - Under designed acceleration lanes (RE: AASHTO) had higher speeds at the controlling feature.

- Acceleration rates along entrance ramps
  - Were only marginally different between parallel- and tapered-type lanes.
  - Straight ramps had lower acceleration rates than loop ramps.
  - Under-designed acceleration lanes (RE: AASHTO) showed higher acceleration rates.

Deceleration Lane Length

- Diverging behavior
  - Similar behavior on ramps with parallel- versus tapered-type lanes, as well as when the controlling feature was a crossroad versus horizontal curve.
  - Under-designed deceleration lanes (RE: AASHTO) showed vehicles exiting before the start of the SCL.
- Diverging speeds were higher
  - On exit ramps with parallel-type versus tapered-type lanes.
  - On ramps that met recommended deceleration lane lengths (RE: AASHTO).
- Diverging speeds were generally not related to ramp design speeds.
- Field diverge speeds were close to the assumed values from AASHTO.

Deceleration Lane Length

- Speed at controlling feature
  - Passenger cars entered the controlling feature at higher speeds than heavy vehicles.
  - Heavy vehicles entered curves near ramp design speeds.
- Deceleration rates along exit ramps
  - Passenger cars and heavy vehicles showed similar average deceleration rates, but passenger cars showed higher maximum deceleration rates.
  - Tapered-type ramps showed slightly higher deceleration rates than parallel-type ramps.
  - Under designed deceleration lanes (RE: AASHTO) showed higher deceleration rates.

Guidelines Related to Acceleration Lane Lengths for Entrance Ramps

U.S. Customary										
Highway		Acceleration Lane Length, L_a (ft) for Design Speed of Controlling Feature on Ramp, V' (mph)								
Design Speed, V (mph)	Merge Speed, V_a (mph)	Stop Condition	15	20	25	30	35	40	45	50
30	23	180	130	-	-	-	-	-	-	-
35	27	280	210	130	-	-	-	-	-	-
40	31	360	290	240	150	-	-	-	-	-
45	35	560	480	400	310	170	-	-	-	-
50	39	720	650	570	470	330	170	-	-	-
55	43	960	890	770	700	540	360	140	-	-
60	47	1200	1120	1060	940	780	600	370	130	-
65	50	1410	1340	1270	1130	980	800	580	320	-
70	53	1620	1540	1470	1330	1210	1020	800	530	200
75	55	1790	1710	1580	1490	1370	1200	960	730	380
80	57	2000	1880	1750	1660	1530	1380	1130	920	560

Source: NCHRP 15-75, TRB

Guidelines Related to Deceleration Lane Lengths for Exit Ramps

U.S. Customary										
Highway Design Speed, V (mph)	Diverge Speed, V_a (mph)	Deceleration Lane Length, L_a (ft) for Design Speed of Controlling Feature on Ramp, V' (mph)								
		Stop Condition	15	20	25	30	35	40	45	50
30	28	235	195	155	125	-	-	-	-	-
35	32	280	245	195	160	125	-	-	-	-
40	36	320	290	250	210	145	75	-	-	-
45	40	385	345	310	275	215	165	-	-	-
50	44	435	400	370	335	285	230	170	-	-
55	48	480	450	430	390	350	305	240	175	-
60	52	530	495	470	440	400	355	305	240	205
65	55	570	535	510	480	440	395	345	280	215
70	58	615	585	560	530	490	445	395	330	265
75	61	660	630	610	580	545	490	445	380	320
80	64	705	675	655	625	590	535	495	430	370

Source: NCHRP 15-75, TRB

Future Research

- Further investigation is warranted for:
  - Crash risk versus available SSD, including in other states and contextual environments.
  - Object heights as they relate to SSD and crash risk.
  - Speed-change lane performance at mainline speed limits of 75 mph or more.
  - Deceleration lane performance leading into controlling features with design speeds of 45 mph or above.
  - Impacts of advanced driver assistance systems on driver behavior and design.

Integration of Advanced Driver Assistance Systems (ADAS) into New Vehicles

Figure 6: Proportion of vehicle series with forward collision warning, 2000–20 model years

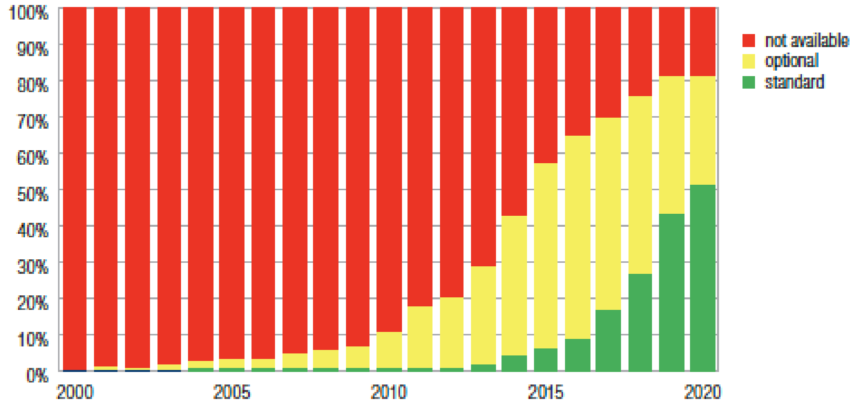
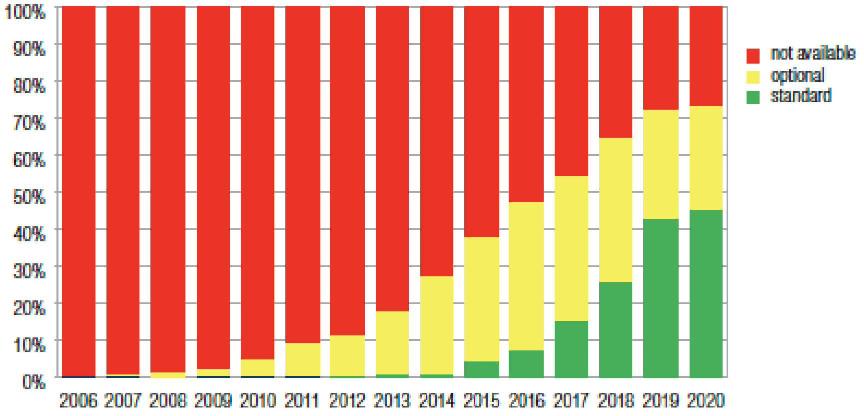


Figure 7: Proportion of vehicle series with forward collision warning with autobrake, 2006–20 model years



Source: HLDI

Fleet Penetration for Forward Collision Warning and Automatic Emergency Braking

Figure 8: Percentage of registered vehicles with front crash prevention by calendar year

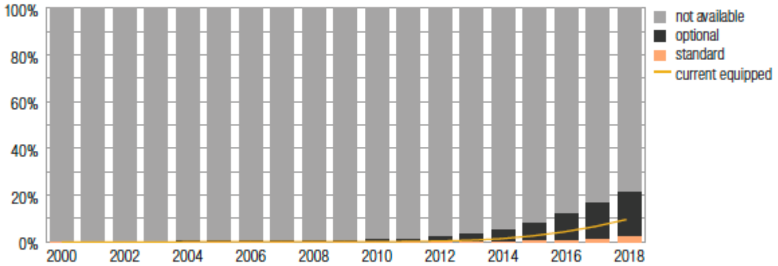


Figure 8 shows the percentage of registered vehicles by calendar year with either standard or optional front crash prevention. In 2006, front crash prevention had become standard on less than 1 percent and optional on less than 1 percent of registered vehicles. By 2018, front crash prevention was standard or optional on 21 percent of registered vehicles, with about 10 percent of registered vehicles estimated to be equipped with the feature.

Figure 11: Percentage of registered vehicles with front automatic emergency braking by calendar year

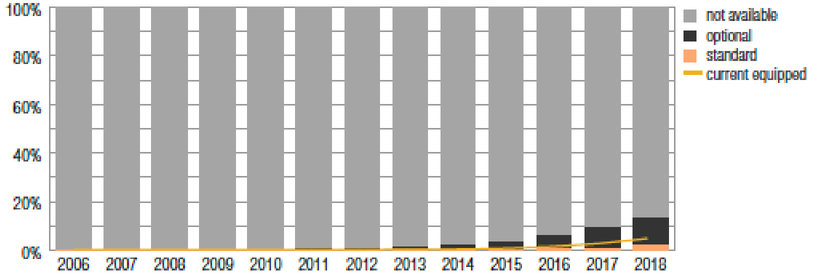


Figure 11 shows the percentage of registered vehicles by calendar year with either standard or optional front AEB. In 2012, AEB had become standard on less than 1 percent and optional on 1 percent of registered vehicles. By 2018, AEB was standard or optional on 13 percent of registered vehicles but estimated to be equipped only on 5 percent.

Figure 9: Predicted percentage of registered vehicles with front crash prevention by calendar year

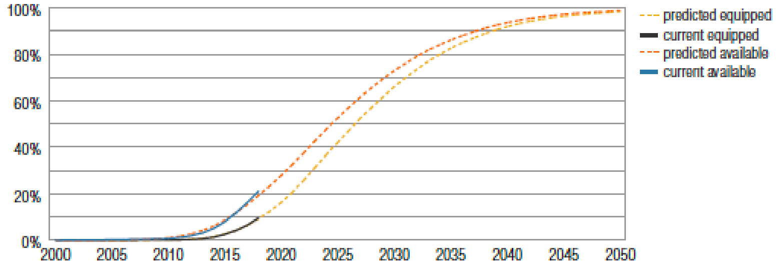


Figure 9 takes into account a voluntary commitment by many manufacturers to make front AEB standard on most of their vehicles by 2022. It shows the predicted registered vehicles by calendar year with front crash prevention. One prediction is for vehicles with front crash prevention available (standard or optional) and the other prediction is for vehicles equipped (standard or optionally equipped) with front crash prevention. It is predicted that 95 percent of registered vehicles will be equipped with the feature in 2043.

Figure 12: Predicted percentage of registered vehicles with front automatic emergency braking by calendar year

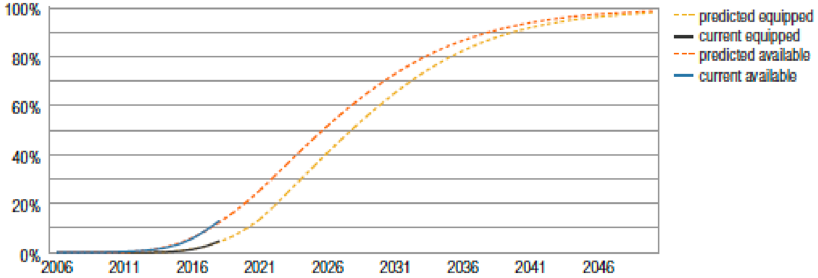


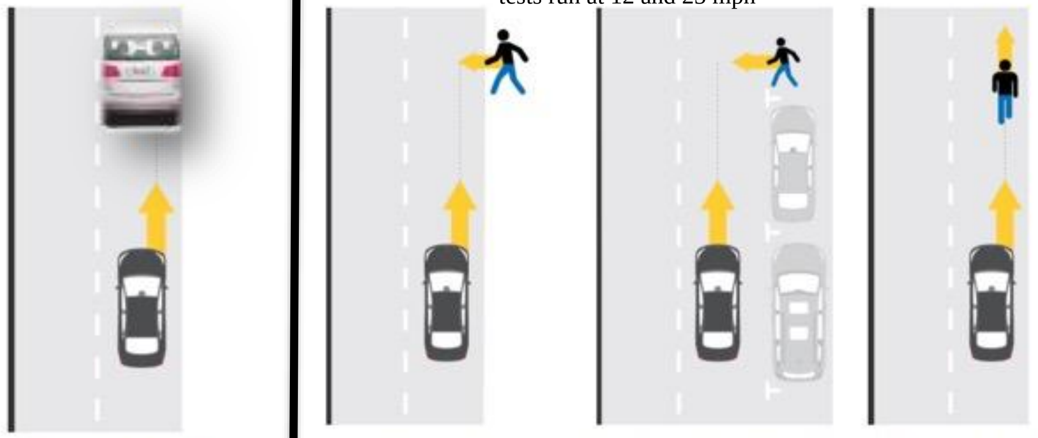
Figure 12 takes into account the 2022 voluntary commitment and shows the predicted registered vehicles by calendar year with front AEB. One prediction is for vehicles with AEB available (standard or optional) and the other prediction is for vehicles equipped (standard or optionally equipped) with AEB. It is predicted that 95 percent of registered vehicles will be equipped with AEB in 2044.

Source: HLDI

Automatic Emergency Braking (AEB) Test Scenarios

Vehicle-to-Vehicle Test (AEB)

Vehicle-to-Pedestrian Test Scenarios (P-AEB)
-tests run at 12 and 25 mph



Stationary balloon car: Stationary dummy vehicle
-tests run at 12 and 25 mph

Perpendicular adult: Adult walks across road
-tests run at 12 and 25 mph

Perpendicular child: Child runs into road; parked vehicles obstruct view
-tests run at 12 and 25 mph

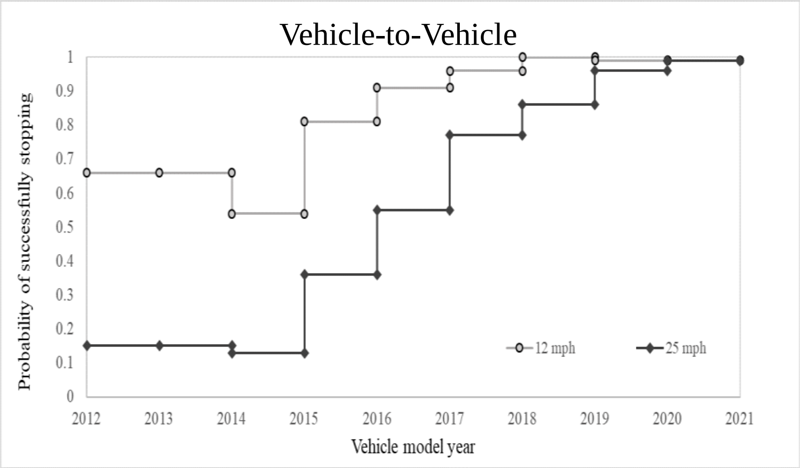
Parallel adult: Adult in right lane near edge of road, facing away from traffic
-tests run at 25 and 37 mph

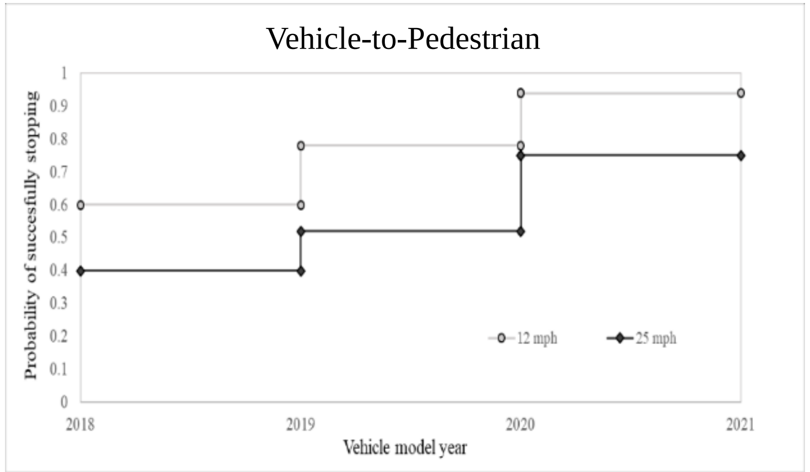
CPNA-25 **CPNC-50** **CPLA-25**

Source: NCHRP 15-75, TRB

AEB Test Results

Test Type	Test Speed (mph)	Sample Size	Success Rate (%)	Avg. Speed Reduction (mph)	Avg. FCW TTC(s)	Avg. AEB TTC (s)	Max. Decel. Rate (ft/s^2)
AEB	12	1323	87.0	11.6	1.4	0.8	27.1
AEB	25	1273	62.4	19.0	2.1	1.1	27.1
P-AEB	12	400	88.0	18.1	1.1	0.7	29.6
P-AEB	25	400	75.8	34.4	1.3	0.9	30.1
P-AEB	12	402	80.3	16.9	1.0	0.7	27.8
P-AEB	25	401	48.6	27.9	0.9	0.7	29.6
P-AEB	25	400	82.3	21.8	1.7	1.2	29.0
P-AEB	37	400	34.0	25.2	1.7	1.2	28.9

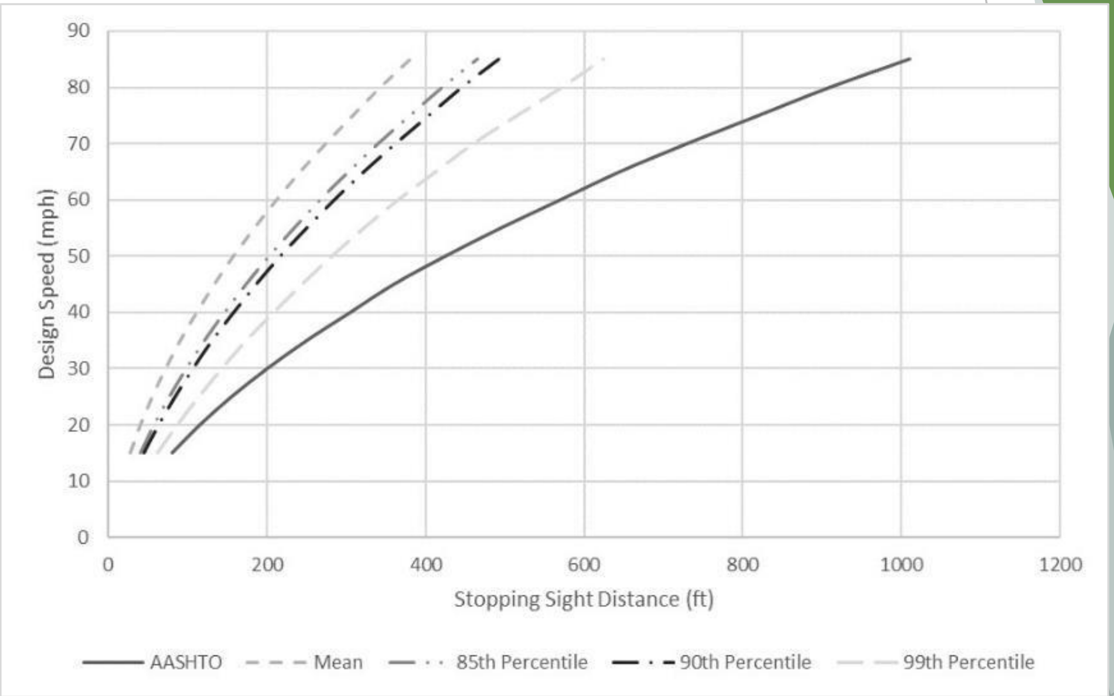




Source: NCHRP 15-75, TRB

PNC by Design Speed – IIHS (AEB Tests)

Design Speed (mph)	AASHTO SSD (ft)	Calculated Stopping Sight Distance (ft)				
		PNC	Mean	85th Percentile	90th Percentile	99th Percentile
15	80	<0.001	28	40	44	63
20	115	<0.001	41	57	63	88
25	155	<0.001	55	77	84	115
30	200	<0.001	72	98	106	144
35	250	<0.001	91	121	130	175
40	305	<0.001	111	146	158	209
45	360	<0.001	134	174	186	245
50	425	<0.001	158	203	216	283
55	495	<0.001	184	234	250	323
60	570	<0.001	212	267	285	366
65	645	<0.001	242	303	322	413
70	730	<0.001	274	341	362	461
75	820	<0.001	308	381	404	516
80	910	<0.001	343	421	446	572
85	1010	<0.001	381	466	492	624



Source: NCHRP 15-75, TRB

Translating Results into Practice

James A. Rosenow
Design Flexibility Engineer
Minnesota Department of Transportation

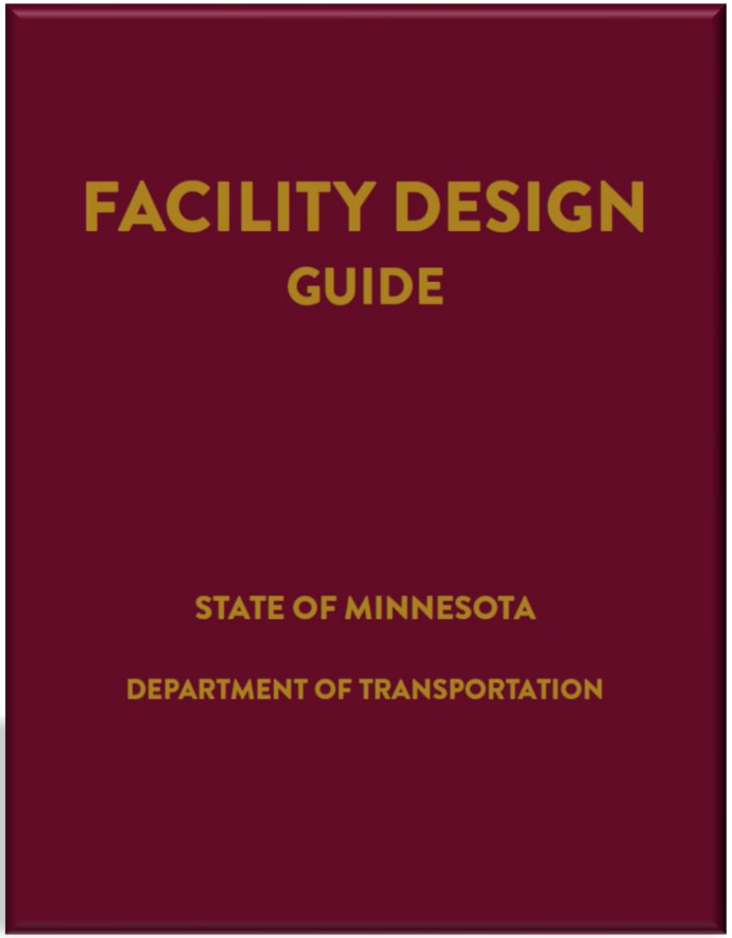
Translating Results Into Practice

Jim Rosenow

TRB Webinar: Speed and Sight Distance Criteria for Geometric Design

February 6, 2025

DEPARTMENT OF TRANSPORTATION



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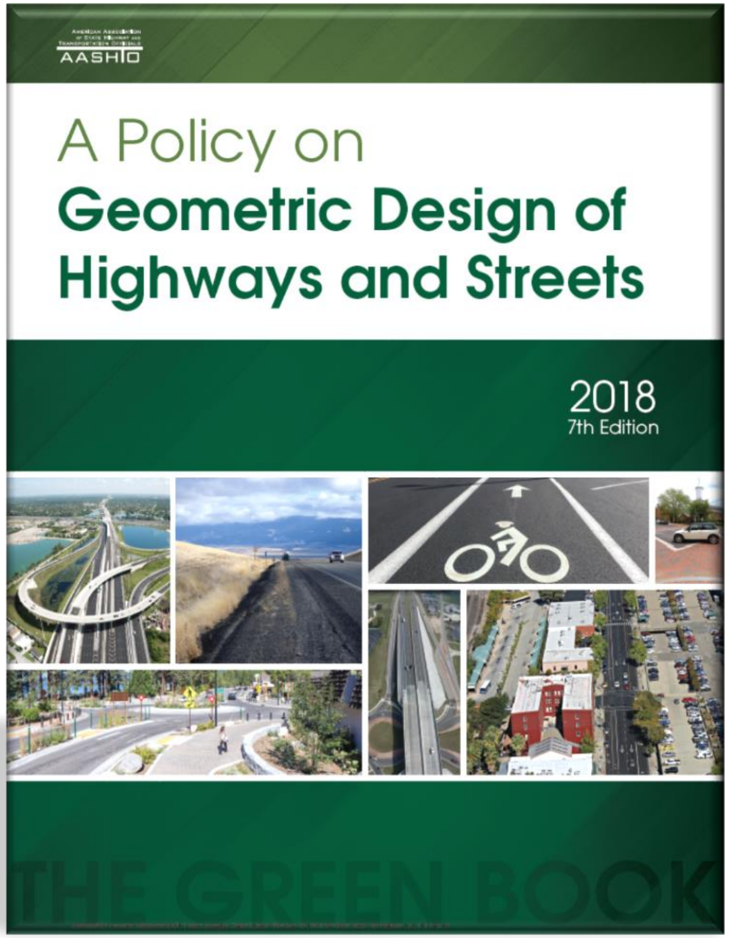
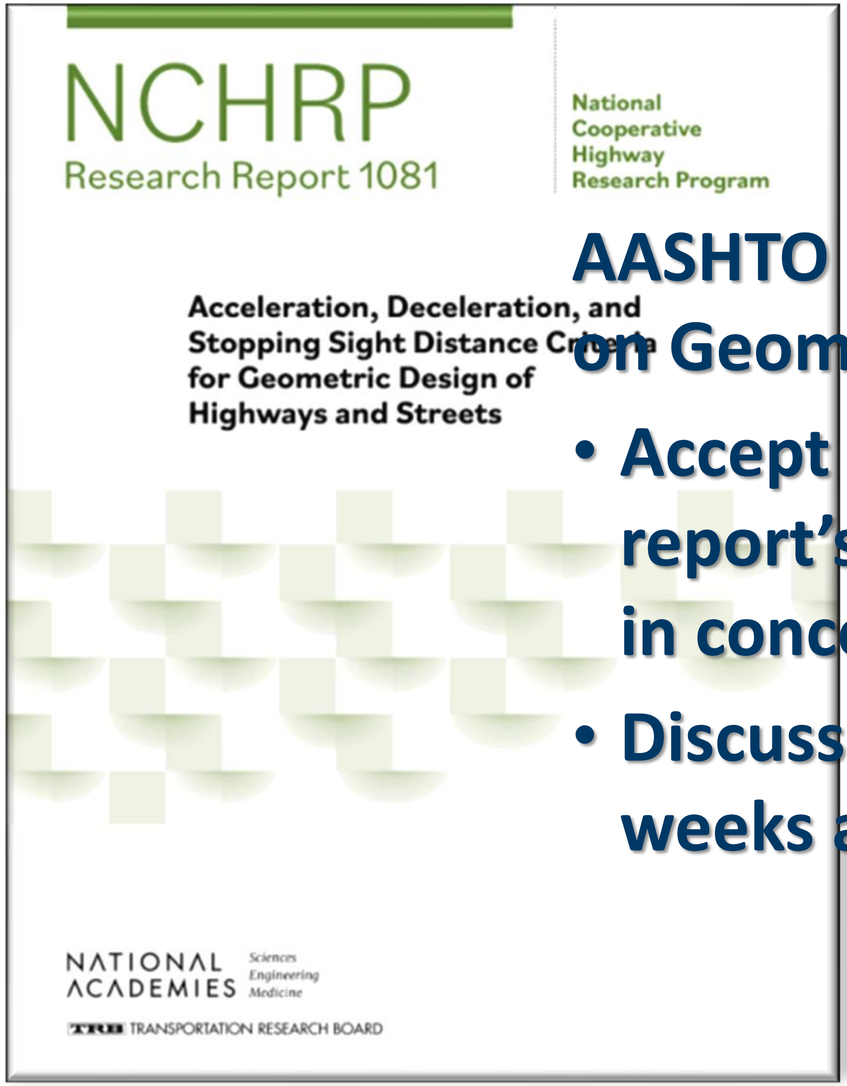


AASHTO Green Book

Outline

- For implementation in each of those guidance documents…
  - Stopping sight distance model/criteria
  - Acceleration and deceleration lengths
- Policy and practice needs: gaps and future research

What's new



AASHTO Technical Committee on Geometric Design (TCGD):

- **Accept and implement the report's recommendations in concept**
- **Discuss details in the coming weeks and months**

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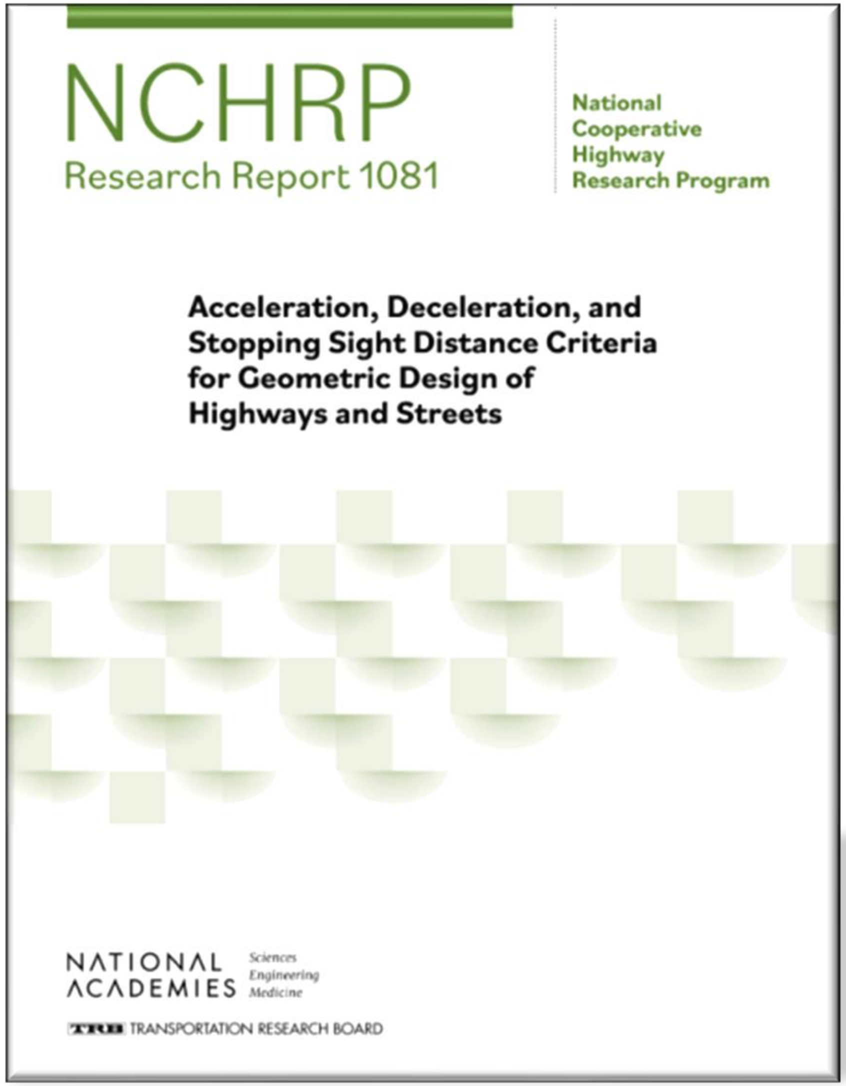
Stopping Sight Distance

What’s new



PRT 2.5 s → 2.2 s

Deceleration rate

11.2 → 11.8 rural

11.2 → 15.0 urban

Eye height

3.5 ft → 3.75 ft

Risk and conservatism

Component	Percentile
Perception-reaction time	90^{th}
Deceleration rate	90^{th}
Eye height	90^{th}
Taillight height	90^{th}

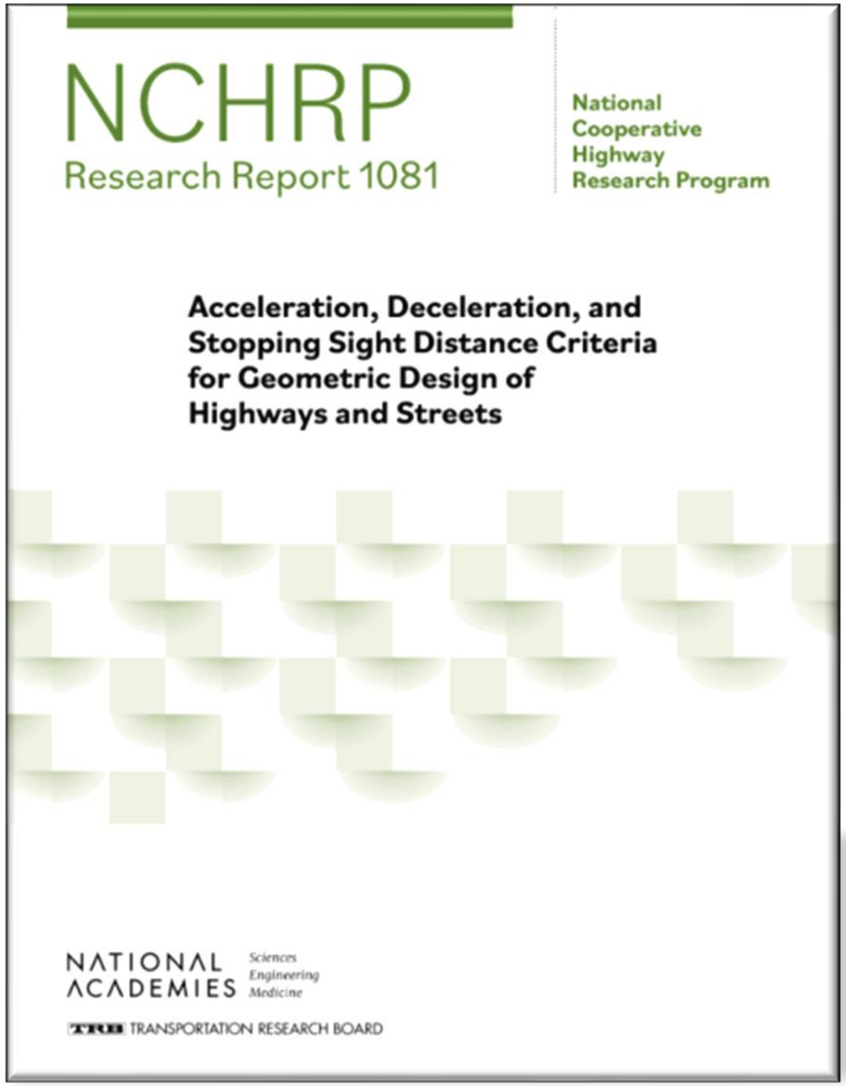
Multiplicative total = 99.999%

Jibes with Report 1081’s percentage of non-compliance (PNC) of 0.001

Variance

Component	90th %-ile	Average
Perception-reaction time	2.5 sec	1.3 sec
Deceleration rate	11.8 fps^2	20.4 fps^2

Precision



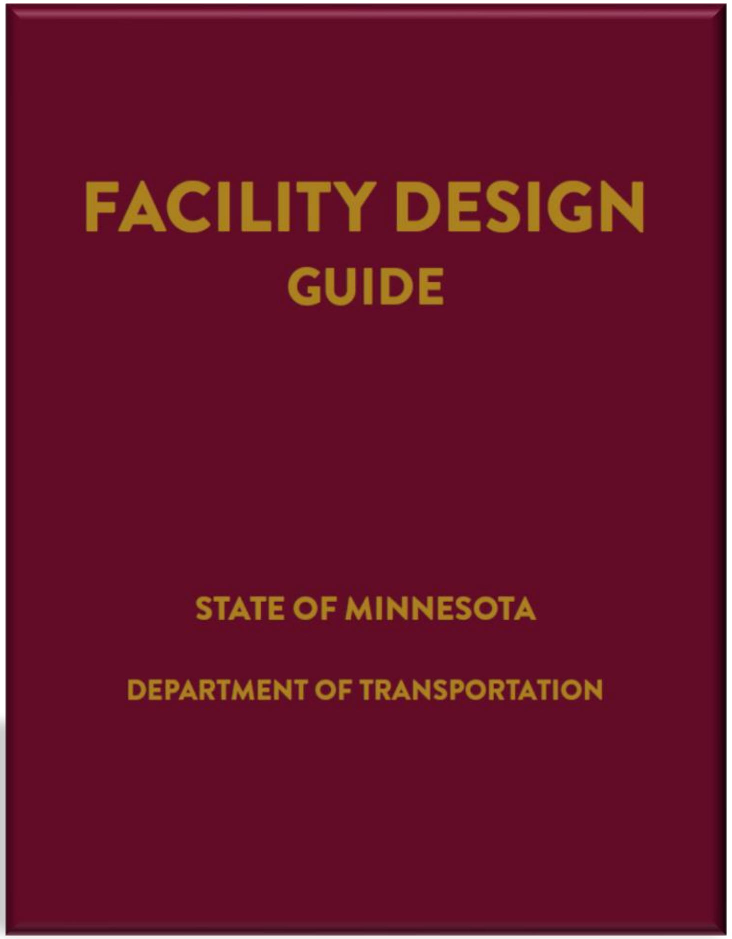
PRT	**2.2 s**
Deceleration	**11.8 rural** **15.0 urban**
Eye height	**3.75 ft**

Bob Uecker:

"The easiest way to catch [a knuckleball] was to wait until it stopped rolling and just pick it up."

Exercising reasonable flexibility

- Understand the SSD model and how it works
- Be aware of how conservative and ripe for flexibility the current SSD components are
- Perception/reaction time: much of the rest of the world uses 2.0 seconds, which is still a high-percentile value
- Deceleration rate:
  - The standard value is fairly leisurely and comfortable as emergency maneuvers go
  - Example: an earlier version of the ITE Traffic Engineering Handbook suggested 15 ft/sec^2 as the comfort threshold value



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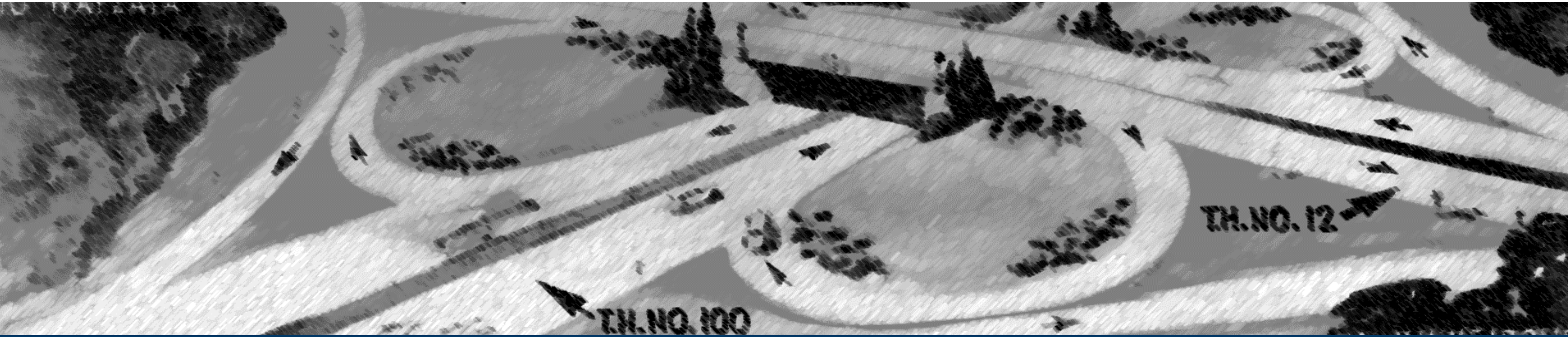
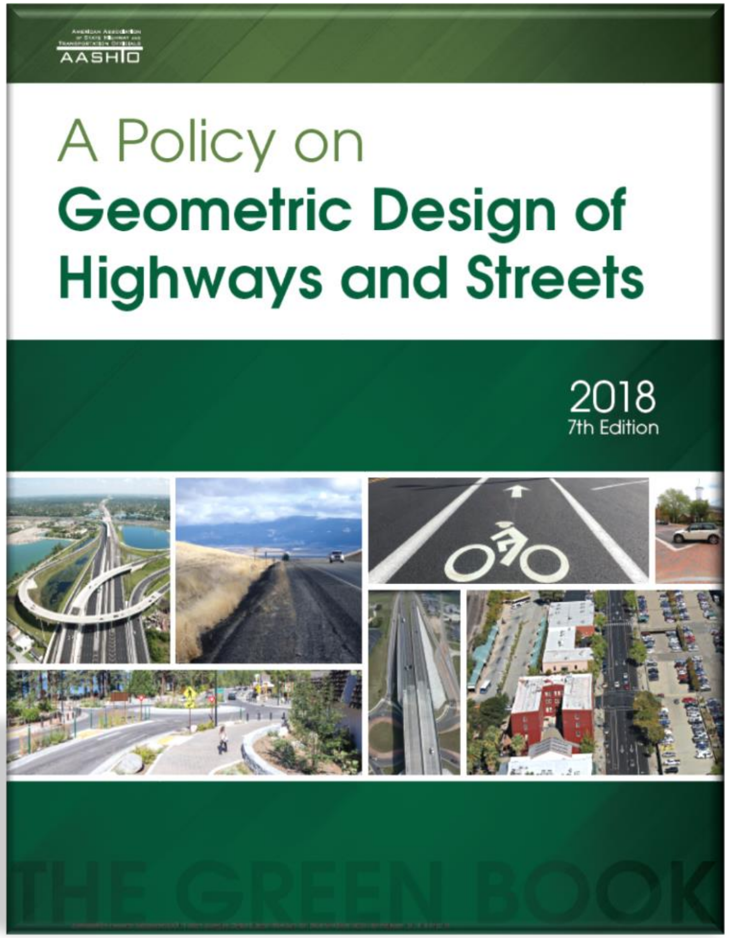


Ramp Acceleration and Deceleration Length



Likely to be incorporated verbatim

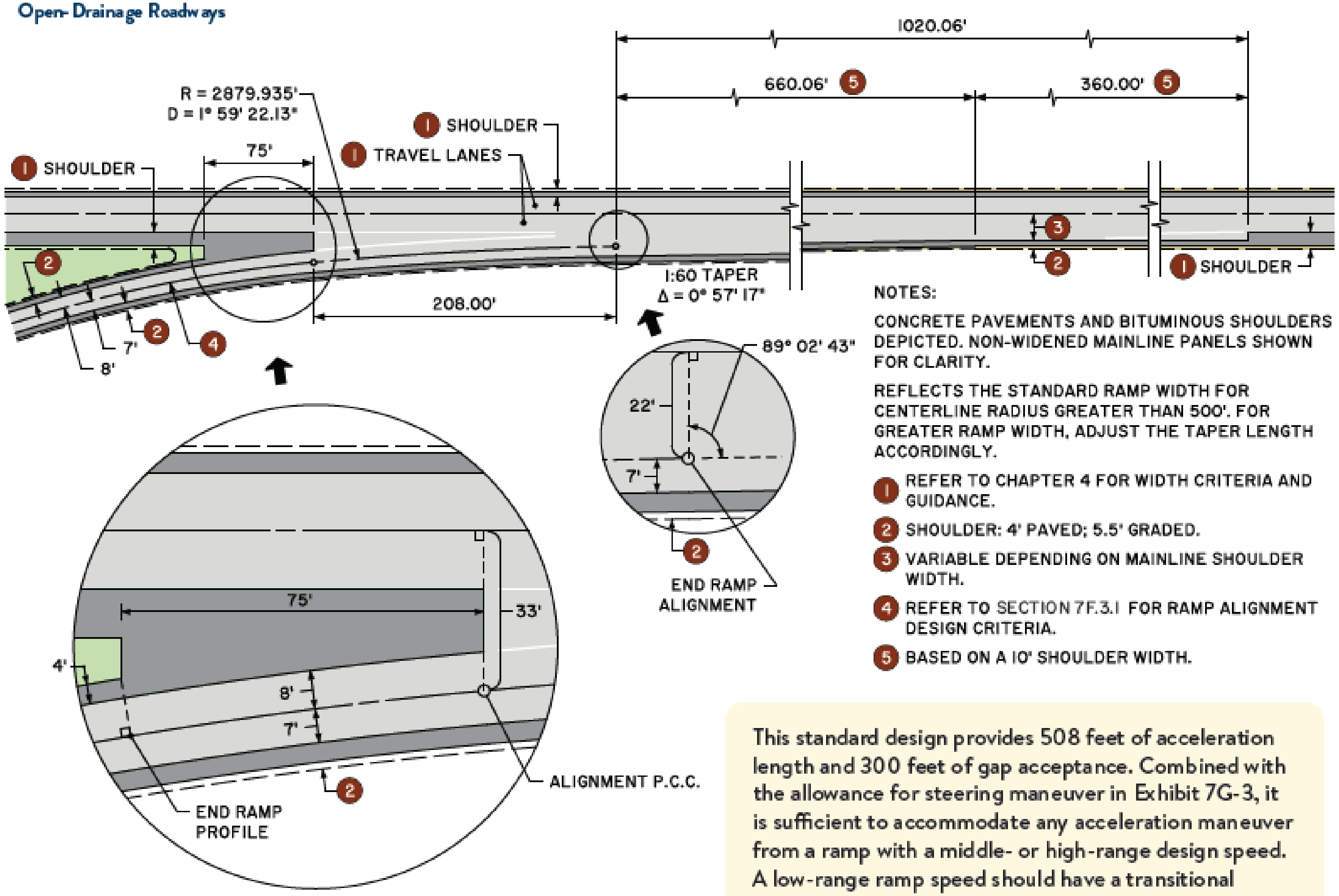
Practical effects of the change

Common application: **50 mph ramp design speed**
70 mph mainline design speed

	Current Criterion	Report 1081
Ramp speed	44 mph	50 mph
Merging speed	53 mph	53 mph
Acceleration length	**580 ft**	**200 ft**

Exhibit 7G-7a

Acceleration Lane—Tapered Design
Open-Drainage Roadways



NOTES:

CONCRETE PAVEMENTS AND BITUMINOUS SHOULDERS DEPICTED. NON-WIDENED MAINLINE PANELS SHOWN FOR CLARITY.

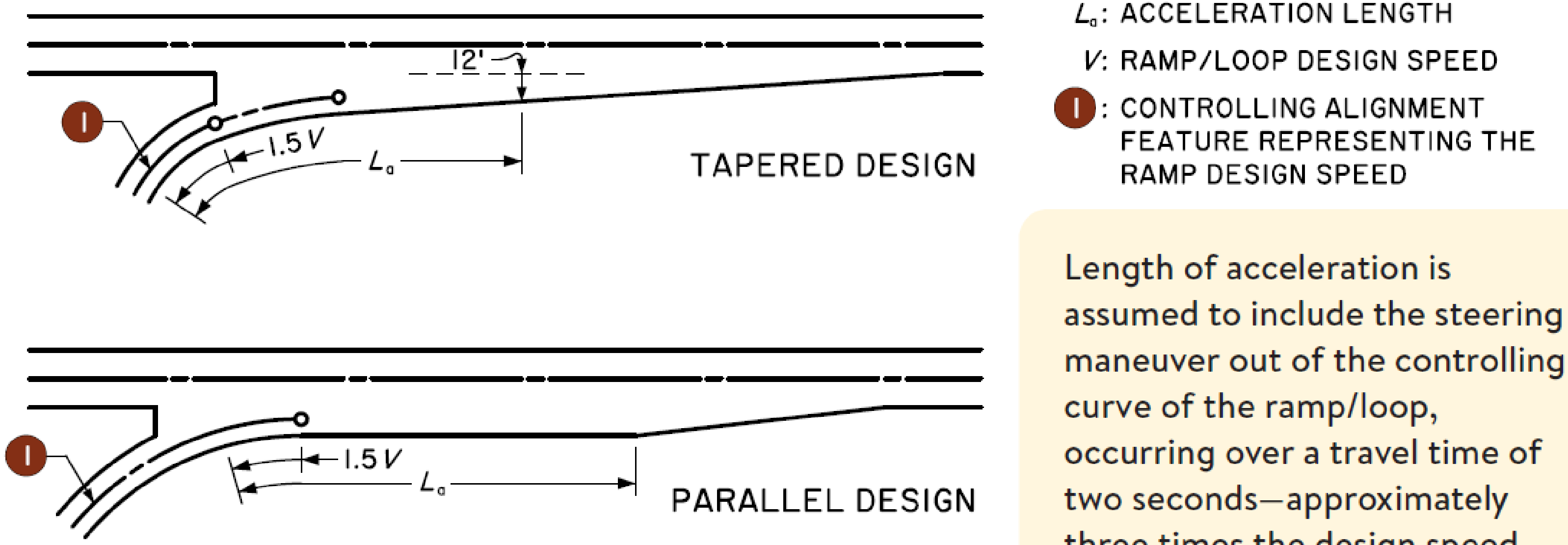
REFLECTS THE STANDARD RAMP WIDTH FOR CENTERLINE RADIUS GREATER THAN 500'. FOR GREATER RAMP WIDTH, ADJUST THE TAPER LENGTH ACCORDINGLY.

1. REFER TO CHAPTER 4 FOR WIDTH CRITERIA AND GUIDANCE.
2. SHOULDER: 4' PAVED; 5.5' GRADED.
3. VARIABLE DEPENDING ON MAINLINE SHOULDER WIDTH.
4. REFER TO SECTION 7F.3.1 FOR RAMP ALIGNMENT DESIGN CRITERIA.
5. BASED ON A 10' SHOULDER WIDTH.

This standard design provides 508 feet of acceleration length and 300 feet of gap acceptance. Combined with the allowance for steering maneuver in Exhibit 7G-3, it is sufficient to accommodate any acceleration maneuver from a ramp with a middle- or high-range design speed. A low-range ramp speed should have a transitional treatment in accordance with Section 7G.3.2.

Exhibit 7G-4

Turning Roadway Acceleration Lengths



Length of acceleration is assumed to include the steering maneuver out of the controlling curve of the ramp/loop, occurring over a travel time of two seconds—approximately three times the design speed—on either side of the curve P.C.

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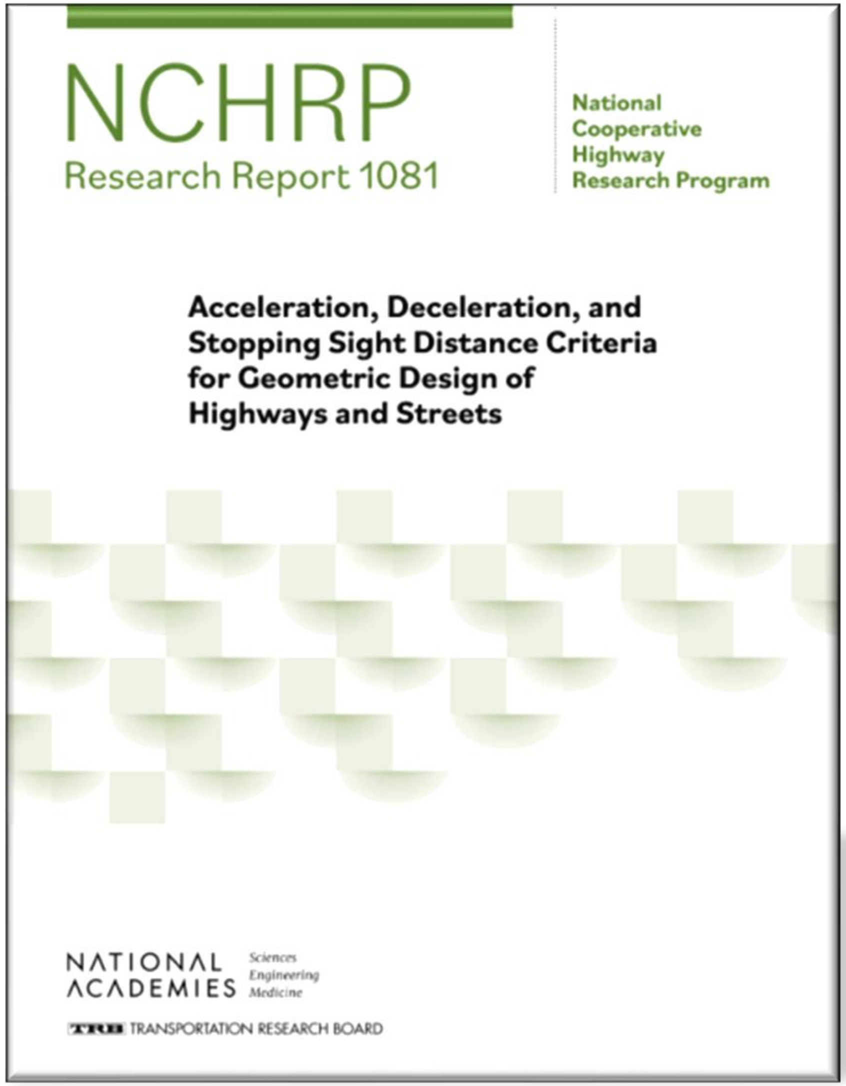
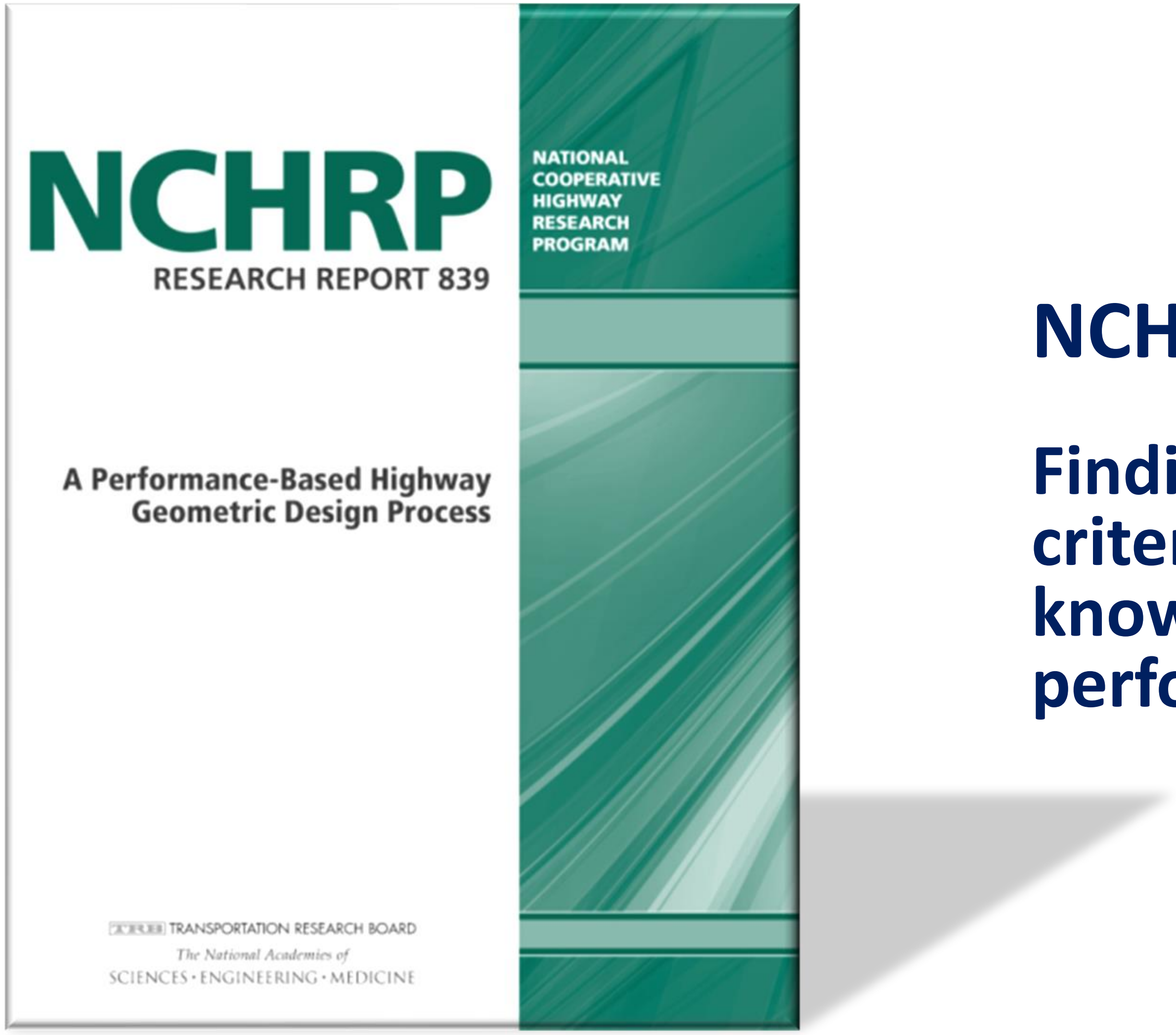
Gaps and Research Needs

Stopping sight distance



Remains the rational stopping sight distance model without known direct relationships to empirical safety and operational performance

Stopping sight distance



NCHRP Report 839 (2017)

Finding 4: AASHTO dimensional criteria should ideally be based on known and proven measurable performance effects.

Stopping sight distance

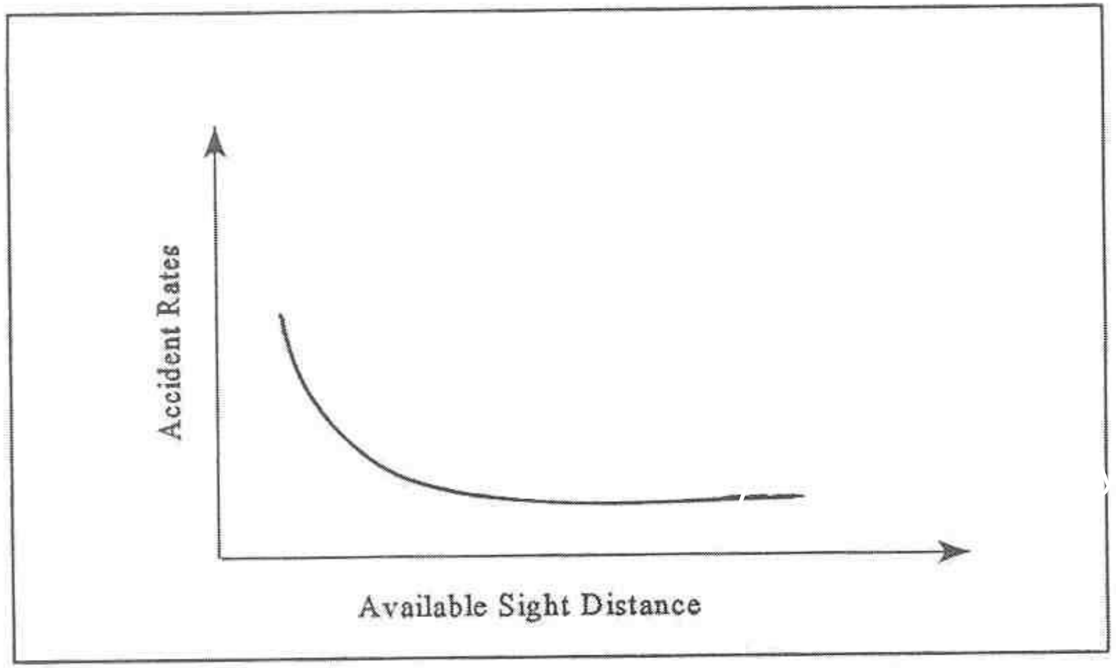


Figure 4. Conceptual Relationship Between Available Sight Distance and Safety at Crest Vertical Curves

NCHRP Report 400 (1997):

“Accident rates are high for short sight distances and relatively insensitive to sight distance beyond some threshold values.”

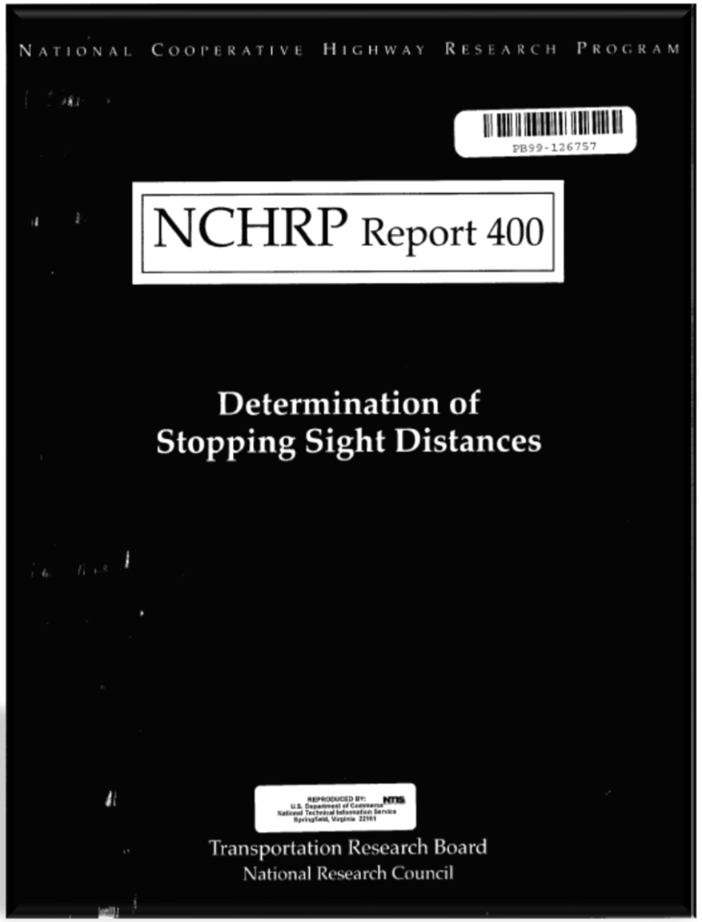
Stopping sight distance

Texas study:

- Data from 222 segments of highway were collected and analyzed
- Hypothesis: crash rates were a function of sight distance
- In the sight distance ranges studied (>300 ft), limited stopping sight distance had no discernable effect on crash frequency or rate.

Michigan study:

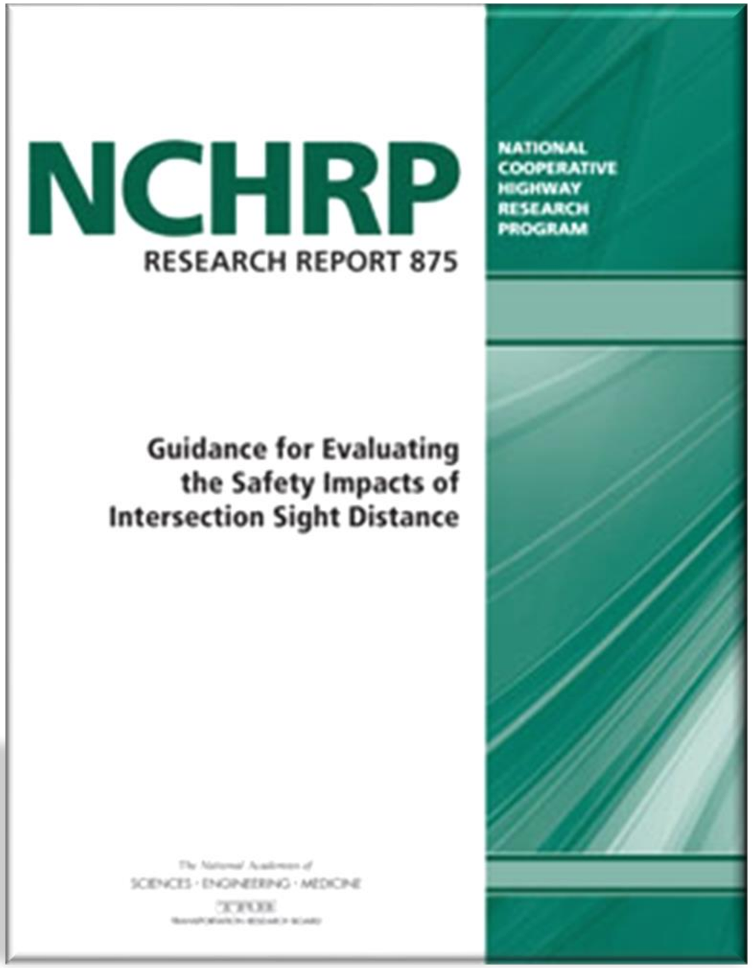
- Ten crest vertical curves with limited SSD were studied in comparison to ten crest VCs with “adequate” SSD
- VCs with SSD less than 90 m [300 ft] had a higher number of crashes than VC’s with very long SSD’s



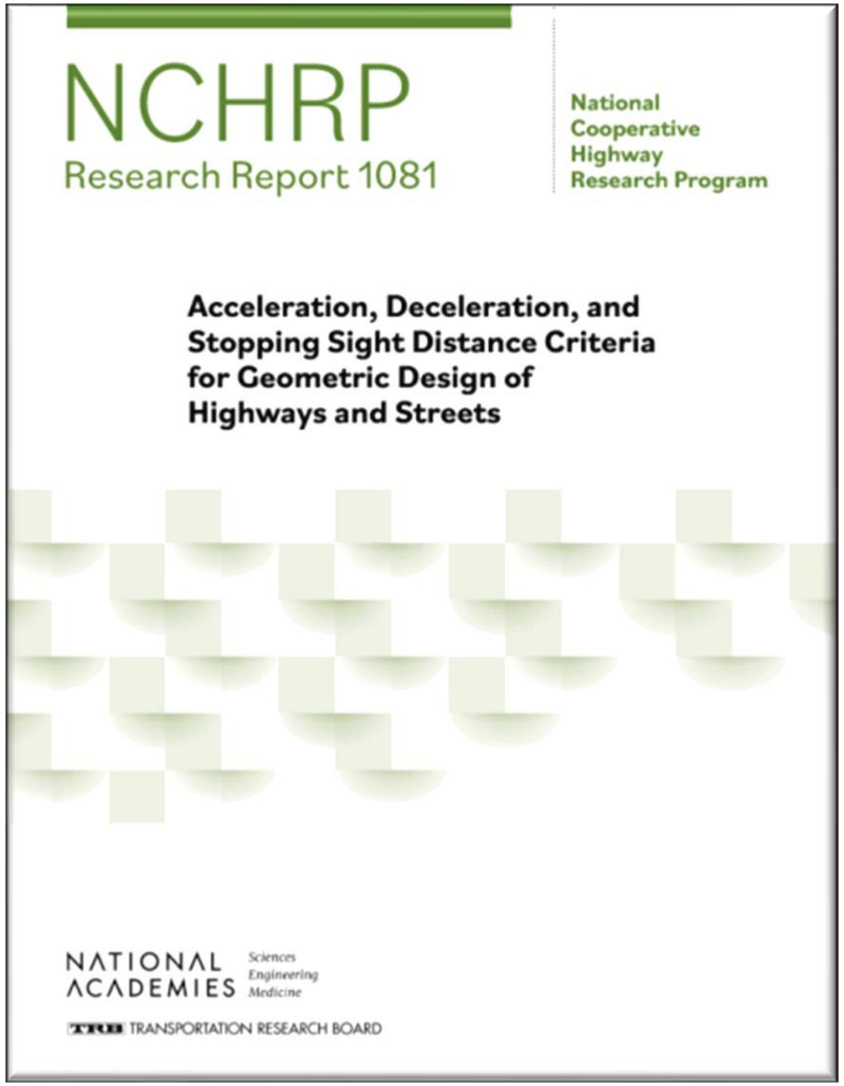
Stopping Sight Distance

NCHRP Report 875: Guidance for Evaluating the Safety Impacts of Intersection Sight distance

- “…provides information on how to estimate the effect of intersection sight distance (ISD) on crash frequency at intersections and describes data collection methods and analysis steps for making safety-informed decisions about ISD.”
- Crash modification factors for incorporation into the next edition of the Highway Safety Manual.



Acceleration and deceleration lane design



Report 1081:

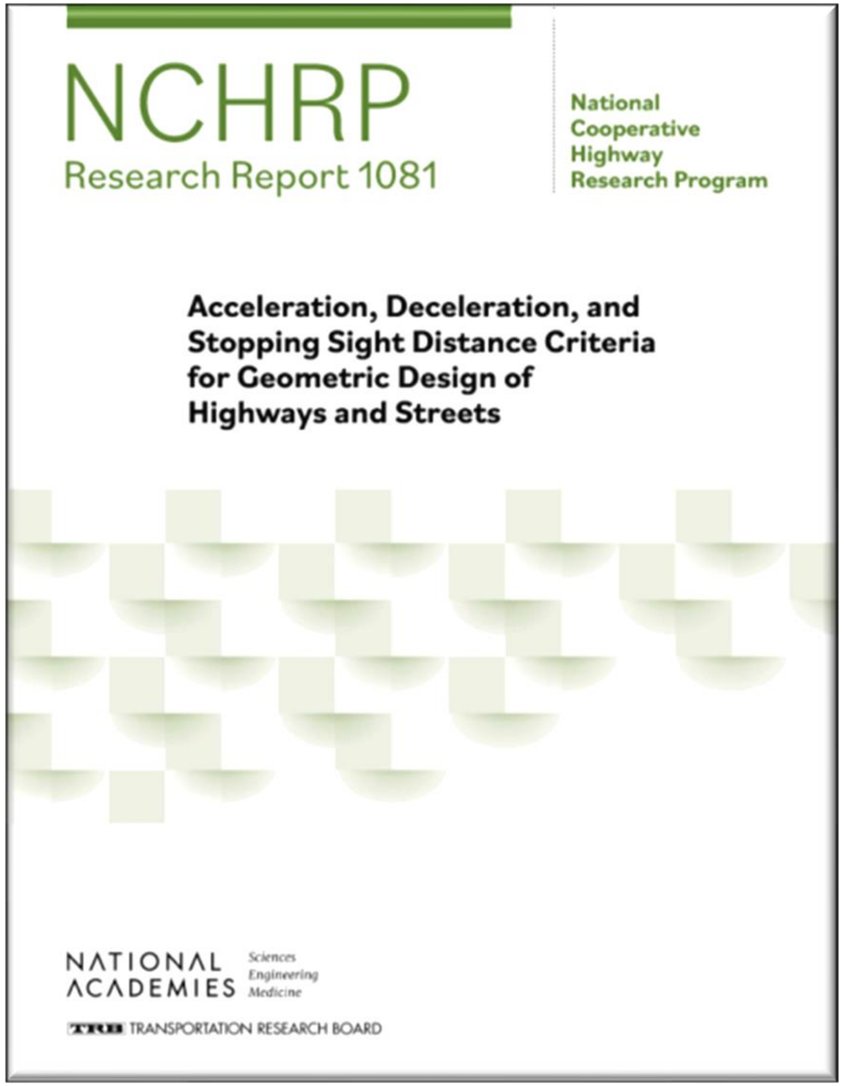
Observations and recommendations for tapered vs parallel geometry

Acceleration and deceleration lane design

Report 730 (2012):

Observations and recommendations for tapered vs parallel geometry

Acceleration and deceleration lane design



Questions/discussion…

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mn DEPARTMENT OF TRANSPORTATION

Upcoming events for you

February 11, 2025

TRB Webinar: Quality Assurance of Transportation Materials and Construction—Part I

February 19, 2025

TRB Webinar: Collaborative Metrics for Strategic Freight Demand Performance Management

https://www.nationalacademies.org/trb/events

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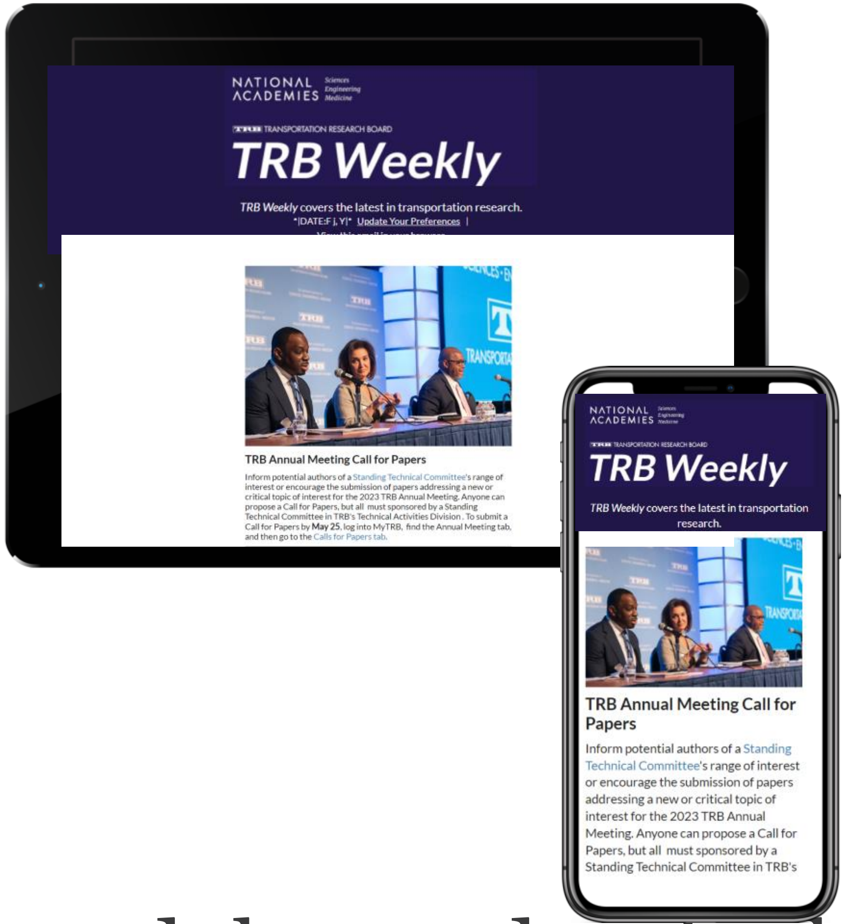

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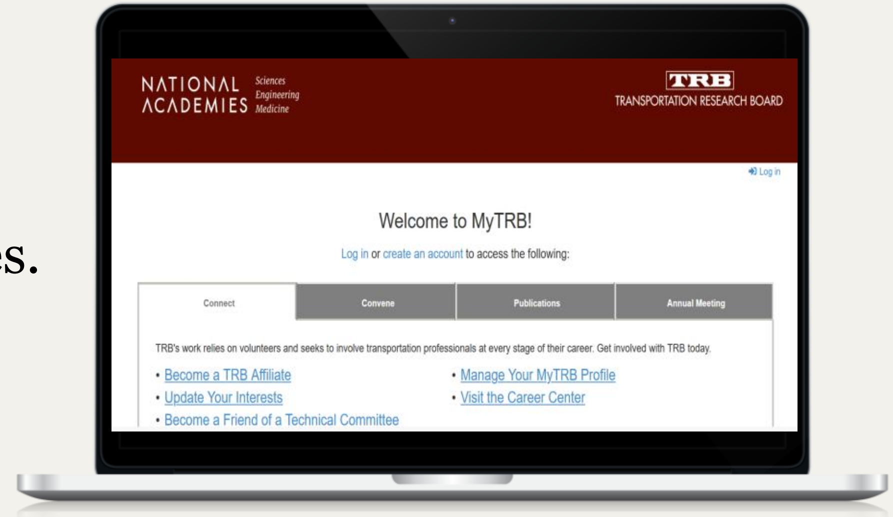

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