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# Relating Available Stopping Sight Distance to Crash Risks and Other Insights from NCHRP 15-75

Peter T. Savolainen, Ph.D., P.E.
MSU Research Foundation Professor & Chairperson
Department of Civil & Environmental Engineering
Michigan State University

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# Overview

- Introduction, Scope, and Review of Existing Guidance
- Summary of Findings
- Recommended Changes to 2018 AASHTO Green Book
- SSD vs. Crash Risk
- The Future
- Question-and-Answer

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# Review of Existing Guidance for Stopping Sight Distance (SSD)

# Stopping Sight Distance (SSD)

- **"The minimum sight distance required for a driver to stop a vehicle after seeing an object in the roadway without hitting the object"**

- In general, enough distance should be provided so that a below average driver can stop.

- Greater lengths may be desirable.

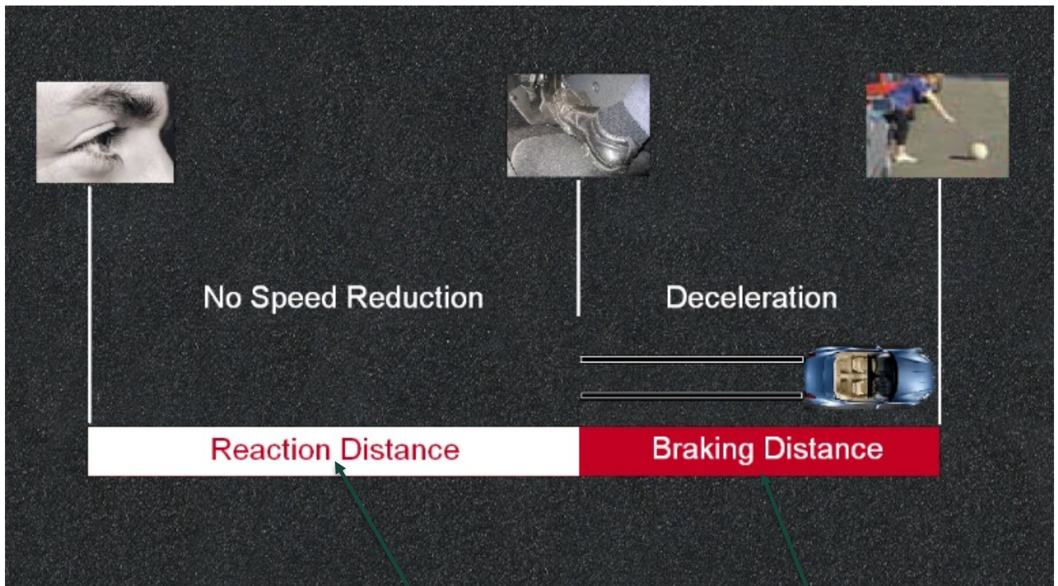
# Why is SSD Important?

- Highways must be designed so that there is adequate stopping sight distance
- SSD influences:
  - Lengths of crest vertical curves
  - Lengths of sag vertical curves
  - Overpass heights
  - Horizontal offset to objects along horizontal curves

# Study Overview

- The American Association of State Highway and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets* (i.e., the "Green Book") provides guidance for determining geometric design criteria of roadways, including stopping sight distance (SSD).
- SSD is influenced by many factors (e.g., perception reaction time, object height, driver's eye height). Changes in the driving population, vehicle fleet, and other areas motivate the need to critically assess this guidance, which was last updated in the 2001 edition of the Green Book.

# Stopping Sight Distance (SSD)




$$\text{Distance}_{\text{Stopping}} = \text{Distance}_{\text{Perception/Reaction}} + \text{Distance}_{\text{Braking}}$$

$$SSD = D_r + D_b$$

# AASHTO SSD Model

- $SSD = d_R + d_B$
  - Where:
  - $SSD$ = stopping sight distance
  - $d_R$ = reaction distance
  - $d_B$ = braking distance

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

# Evolution of SSD Model

| Year | Driver's Eye Height (ft.) | Object Height (ft.) | Brake Reaction Time (sec.) | Vehicle Speed | Pavement Condition | Friction Factors | Decelera-tion Rate (ft/s²) |
|---|---|---|---|---|---|---|---|
| 1928 | horizontal and vertical curves be used which provide a sight distance at least 500 feet | | | | | | |
| 1940 | 4.5 | 0.33 | 3.0 for 30 mph; 2.0 for 70 mph | Design Speed | Dry | 0.50 at 30 mph to 0.40 at 70 mph | |
| 1954 | 4.5 | 0.33 | 2.5 | Lower than design speed | Wet | 0.36 at 30 mph to 0.29 at 70 mph | |
| 1965 | 3.75 | 0.5 | 2.5 | Lower than design speed | Wet | 0.36 at 30 mph to 0.27 at 70 mph | |
| 1970 | 3.75 | 0.5 | 2.5 | Min: lower than design speed; Max: design speed | Wet | 0.35 at 30 mph to 0.27 at 70 mph | |
| 1984 | 3.5 | 0.5 | 2.5 | Min: lower than design speed; Max: design speed | Wet | 0.35 at 30 mph to 0.28 at 70 mph | |
| 1990 | 3.5 | 0.5 | 2.5 | Min: lower than design speed; Max: design speed | Wet | 0.35 at 30 mph to 0.28 at 70 mph | |
| 1994 | 3.5 | 0.5 | 2.5 | Min: lower than design speed; Max: design speed | Wet | 0.35 at 30 mph to 0.28 at 70 mph | |
| 2001 | 3.5 | 2 | 2.5 | Design Speed | Wet | | 11.2 |
| 2004 | 3.5 | 2 | 2.5 | Design Speed | Wet | | 11.2 |
| 2011 | 3.5 | 2 | 2.5 | Design Speed | Wet | | 11.2 |
| 2018 | 3.5 | 2 | 2.5 | Design Speed | Wet | | 11.2 |

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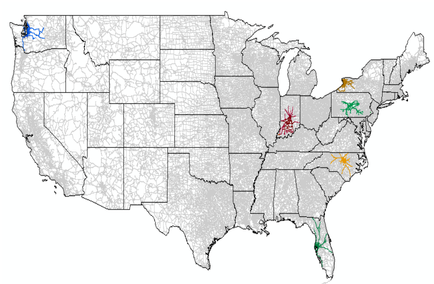
# Summary of Brake Reaction Time Research

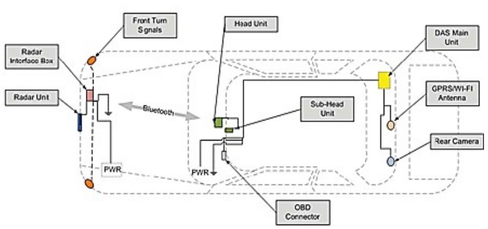
| Unsuspecting Driver (Unexpected Event) | N | Ages | Distraction-Involved? | Mean (sec.) | Std. Dev (Sec.) | 85th Pct. (Sec.) | 95th Pct. (Sec.) | Stimulus |
|---|---|---|---|---|---|---|---|---|
| **Field Collection (Drivers were unaware of being observed)** | | | | | | | | |
| Sivak et al., 1982 | 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 | 49 | Young | No | 0.72 | 0.11 | 0.95 | 1.11 | Anticipated object |
| Olson, Sivak, 1985 | 15 | Old | No | 0.73 | 0.10 | 1.00 | 1.29 | Anticipated object |
| Fambro et al., 1997 | 26 | Mix | No | 0.59 | 0.19 | / | / | Anticipated object |
| Fitch et al.. 2010 | 64 | Mix | No | 0.78 | 0.03 | / | / | Anticipated barricade |
| Fitch et al.. 2010 | 64 | Mix | No | 0.55 | 0.02 | / | / | Anticipated auditory alarm |

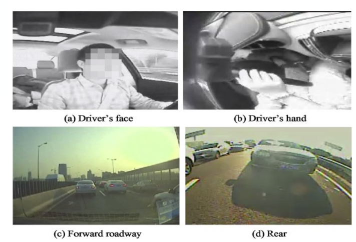
# SHRP2 Naturalistic Driving Study (NDS): Investigating Reaction Times and Deceleration Rates

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



- Roadway Information Database (RID)
  - 12,500+ miles of roadway information
    - Horizontal and vertical alignment
    - Cross-sectional characteristics
    - Historical data from DOTs



(a) Driver's face (b) Driver's hand

(c) Forward roadway (d) Rear

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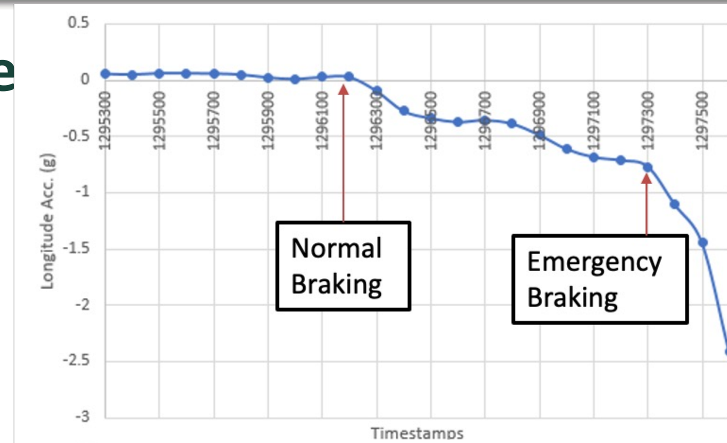
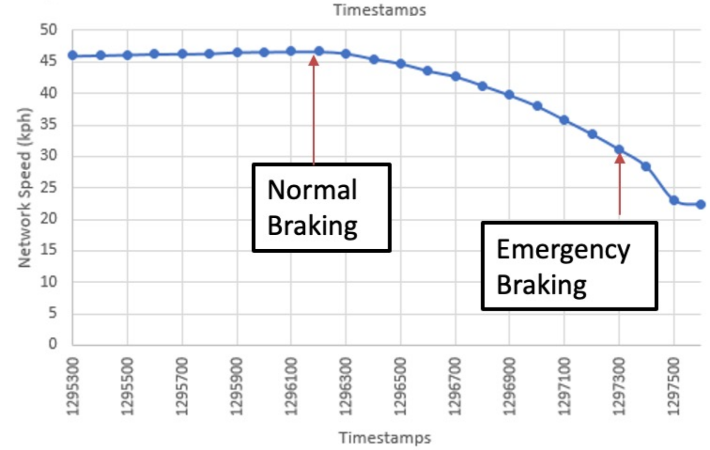
# Sample Event


Event Start = 1295300;
Onset of Normal Braking = 1296200;
Onset of Emergency Braking = 1297300;
Impact Time = 1297600;



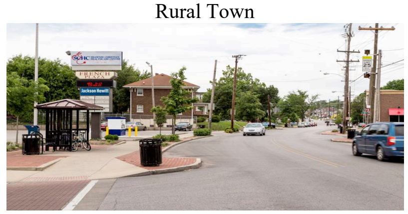



# NDS Contextual Information

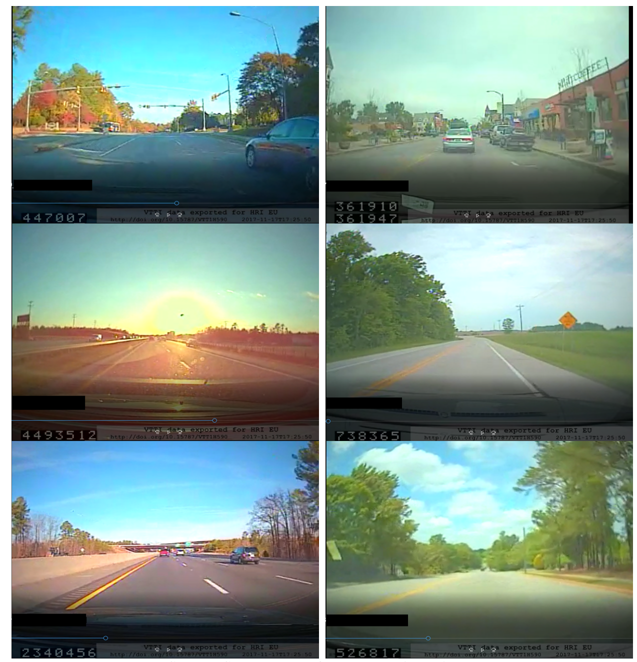

Rural


Rural Town


Suburban


Urban


Urban Core


**Sample Screenshots of Forward-View Video**

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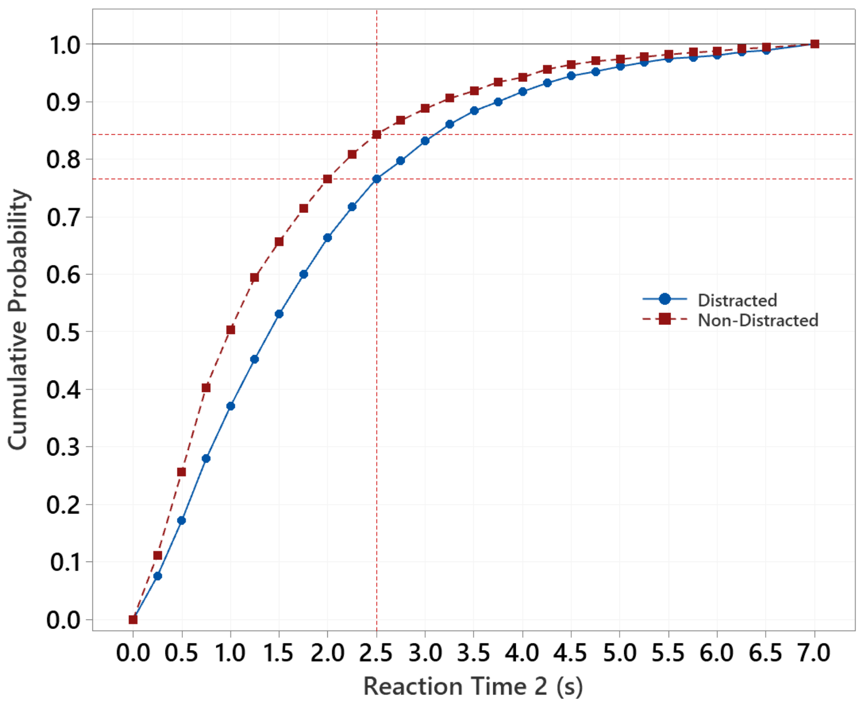
# NDS Reaction Time Data



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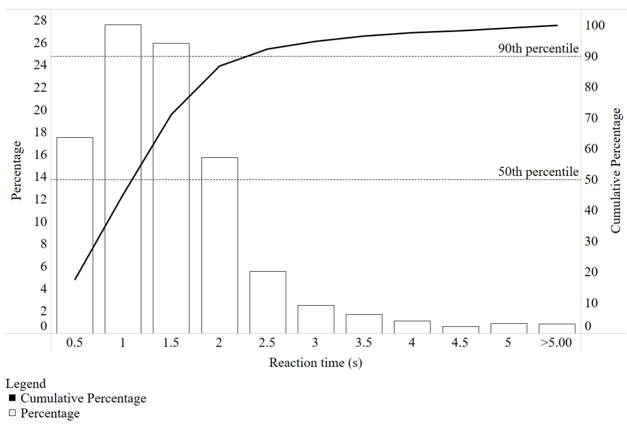
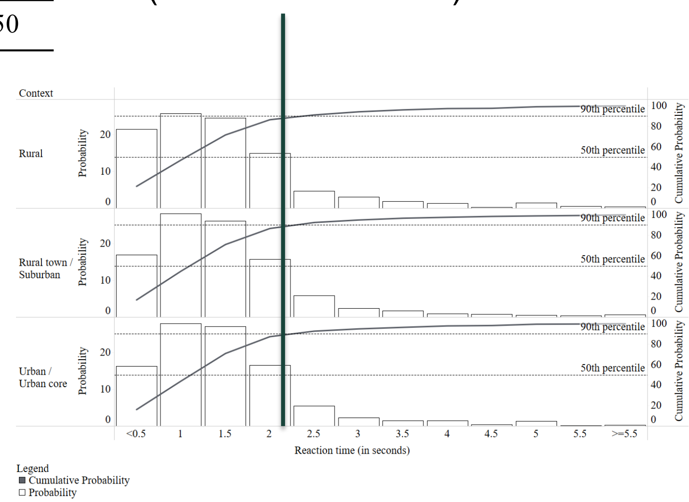
# NDS Reaction Time Results

| 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 |

90th percentile reaction time = 2.2 s (across all contexts)



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# 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 barricad |
| 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 | |

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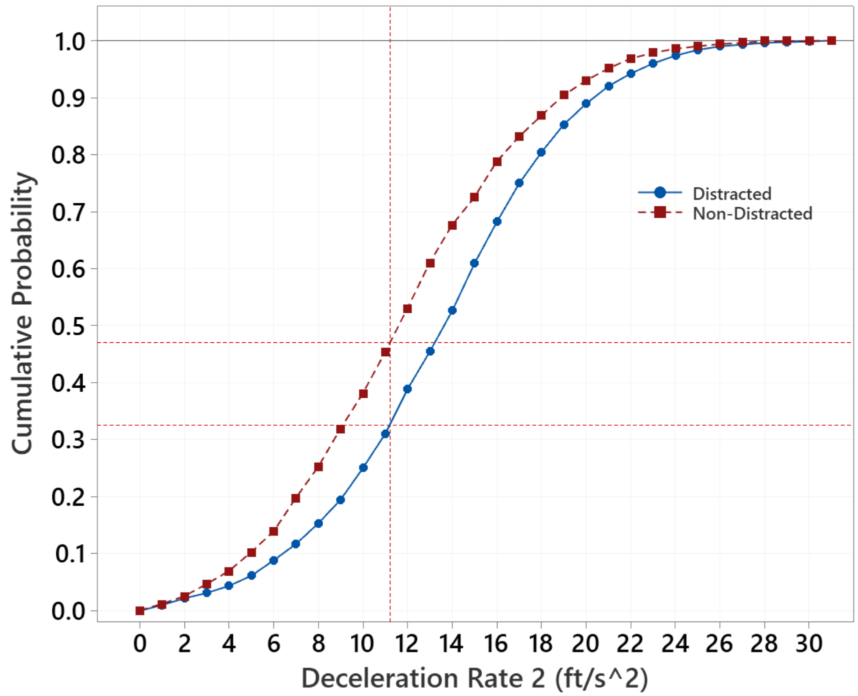
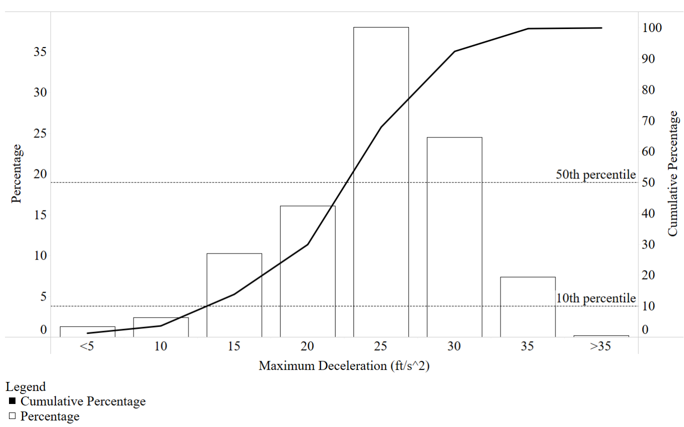
# NDS Deceleration Rate Data

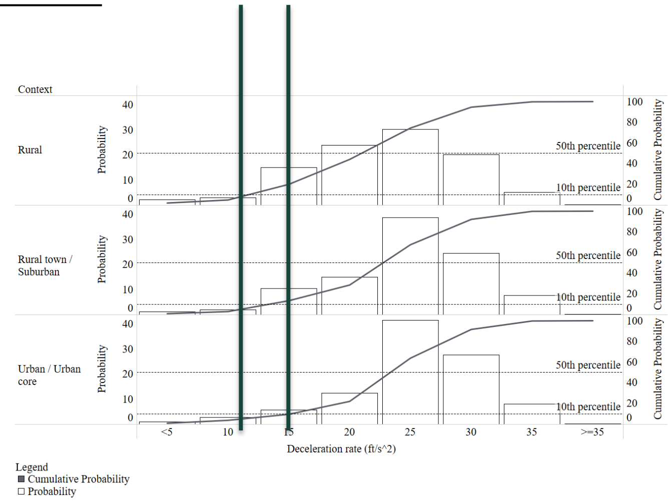


# NDS Deceleration Rate Results

| Scenario | Deceleration Rate (ft/s²) | |
|---|---|---|
| | 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 |

10th percentile reaction times:
Rural setting = 11.8 $ft/s^2$
Urban setting = 15.0 $ft/s^2$



# Summary – SHRP 2 NDS Studies

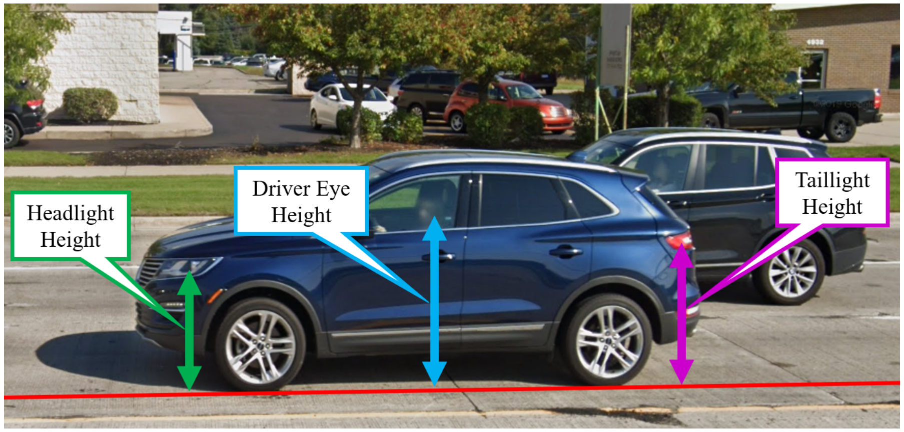
- Perception-reaction time
  - Mean and 90th-percentile reaction times were 1.3 s and 2.2 s, respectively.
- Deceleration rate
  - 10th-percentile and average deceleration rates were 13.4 $ft/s^2$ and 22.0 $ft/s^2$, respectively.
  - Rates were lower in higher-speed contexts (e.g., rural areas), where the 10th-percentile and average deceleration rates were 11.8 $ft/s^2$ and 20.4 $ft/s^2$, respectively.
  - Rates were higher in lower speed contexts (e.g., urban areas), where the 10th-percentile and average deceleration rates were 15.0 $ft/s^2$ and 22.8 $ft/s^2$, respectively.

# Evaluation of Characteristics of Vehicle Fleet

# Data Collection – Driver Eye Height and Vehicle Headlight/Taillight Height

- Vehicle measurements obtained through direct measurement of parked vehicles.

- Driver eye height estimated to center of vehicle headrest.
  - Accuracy of ~ 0.1 ft



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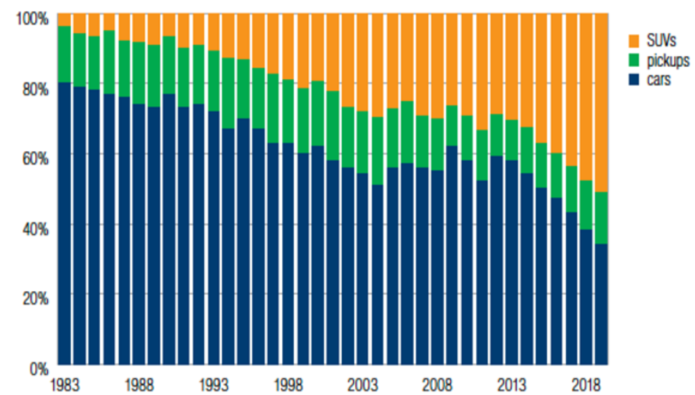
# Comparison with NCHRP Report 400 – Passenger Vehicles

| 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 |




Vehicle Type Distribution

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## Summary of Parking Lot Studies

- Driver eye heights
  - 90% driver eye heights exceed 3.75 ft for all passenger vehicles (slight increase compared to NCHRP 400)
  - No significant change in truck driver eye height
- Headlight height
  - No significant change compared to NCHRP 400
- Taillight height
  - Increased by 0.5 ft for passenger cars and multipurpose vehicles compared to NCHRP 400
  - However, no change is recommended to object height

# Recommended Changes to 2018 AASHTO Green Book

# 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
  - Deceleration rate to be updated to 11.8 ft/s$^2$ in rural contexts or high speed contexts (greater than 45 mph)
  - Deceleration rates to be updated to 15.0 ft/s$^2$ in urban and urban core context or low speed contexts (less than or equal to 45 mph)

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# 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) | 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) | 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 |

## 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.
  - No change in truck driver's eye height (7.6 ft).
  - Object height for SSD scenarios should remain the same (2 ft).

- These updates will also result in updating object height criteria for passing sight distance (PSD) and intersection sight distance to 3.75 ft

# 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 remain at 2.0 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 to 7.6 ft for truck eye height
  - Object height should be increased to 3.0 ft for taillights of a vehicle

## But……

## What are the impacts of SSD on crash risk?

## The Relationship between SSD and Crash Risk

- SSD is one of the ten controlling criteria for design and documentation of design exceptions. Applicable for horizontal and vertical alignments, except for sag vertical curves.
- The extant research literature has generally not shown that locations with insufficient SSD experience higher crash risks across most contexts.
- An exception is crest vertical curves on two-lane highways where a hidden curve, intersection, ramp, or driveway is present [Fambro et al., 1997; Harwood et al., 2014].
- Why?

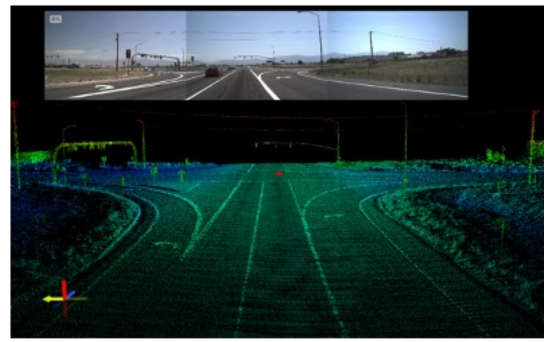
# Factor of Safety Inherent in SSD Model

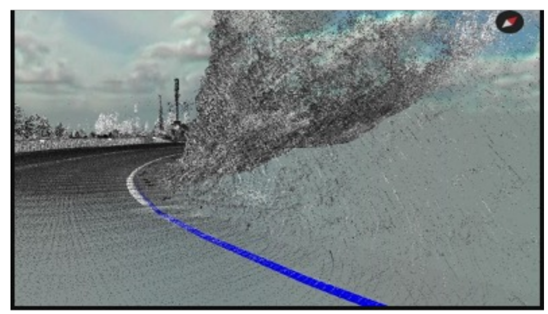
- Conservative design assumptions for each parameter (e.g., crest vertical curve case):
  - $90^{th}$ percentile brake reaction time (2.5 s)
  - $90^{th}$ percentile speed (design speed)
  - $10^{th}$ percentile deceleration rate (11.2 $ft/s^2$)
  - $10^{th}$ percentile driver eye height (3.5 ft)
- Assuming independence, probability of conditions being met simultaneously = 0.0001.
- Probability of conditions being met AND a stopping scenario arising $\ll$ 0.0001.

- SSD has also been resource-intensive to measure historically.

# SSD – Safety Analysis

- High-fidelity LiDAR data were utilized to assess relationship between available sight distance and crashes.
- Data from the Utah DOT were analyzed for freeways (80 mph speed limit) and two-lane highways (speed limits ranging from 30 mph to 65 mph).
    - Follow-up work in Michigan on two-lane highways posted at 55 mph or 65 mph.

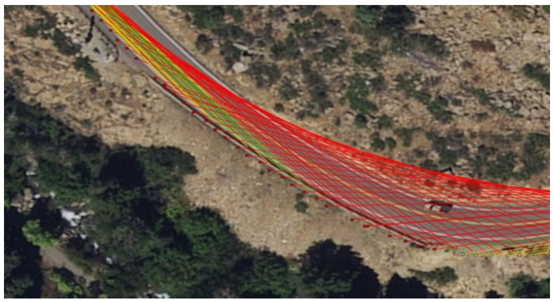




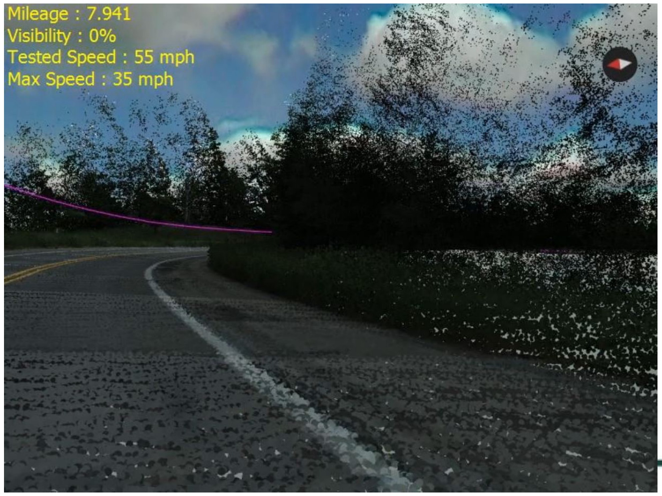

Mileage : 9.7097
Visibility : 50%
Tested Speed : 55 mph
Max Speed : 55 mph


Mileage : 8.3653
Visibility : 20%
Tested Speed : 55 mph
Max Speed : 70 mph

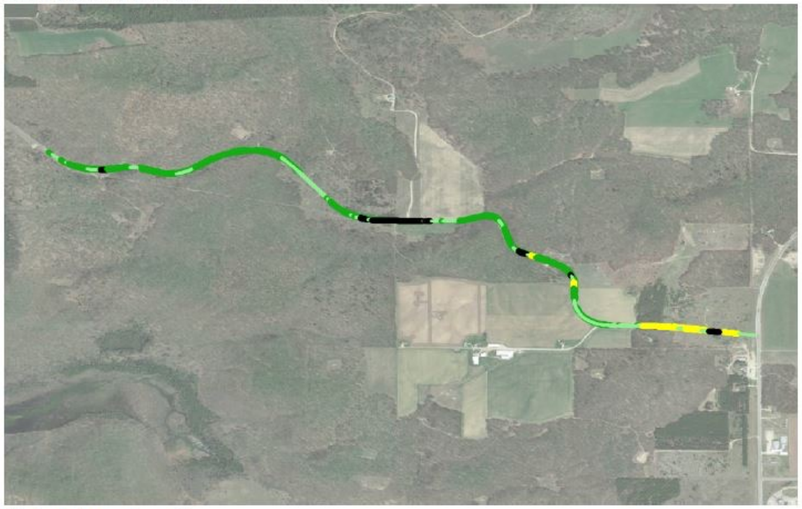
# Sample Output from LIDAR Tool



| ID | RName | Direction | PathCode | PathID | ConfType | Mileage | TSpeed | MaxSpeed | Slope | Visibility | Cycle | Classify | Action |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.1514 | 40 | 35 | -4.569184303 | 6.666666985 | 2017 | Terrain | Engineering redesign |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.1533 | 40 | 30 | -5.955739498 | 0 | 2017 | Terrain | Engineering redesign |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.1552 | 40 | 30 | -4.998222828 | 0 | 2017 | Terrain | Engineering redesign |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.1571 | 40 | 30 | -5.361332417 | 0 | 2017 | Terrain | Engineering redesign |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.159 | 40 | 30 | -5.660354137 | 0 | 2017 | Terrain | Engineering redesign |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.1609 | 40 | 30 | -5.131266117 | 0 | 2017 | Terrain | Engineering redesign |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.1628 | 40 | 30 | -4.799786568 | 0 | 2017 | Terrain | Engineering redesign |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.1646 | 40 | 35 | -4.301214218 | 0 | 2017 | Terrain | Engineering redesign |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.1665 | 40 | 35 | -3.8682127 | 0 | 2017 | Terrain | Engineering redesign |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.1684 | 40 | 35 | -3.739371777 | 0 | 2017 | Terrain | Engineering redesign |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.1703 | 40 | 35 | -4.498730659 | 0 | 2017 | Terrain | Engineering redesign |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.1722 | 40 | 35 | -3.274622917 | 0 | 2017 | Terrain | Engineering redesign |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.1741 | 40 | 35 | -4.10327816 | 0 | 2017 | Terrain | Engineering redesign |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.176 | 40 | 35 | -3.472764015 | 0 | 2017 | Terrain | Engineering redesign |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.1779 | 40 | 35 | -3.408043623 | 1.769911528 | 2017 | Vegetation | Maintenance vegetation |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.1798 | 40 | 40 | -3.969248295 | 66.66667175 | 2017 | | |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.1817 | 40 | 40 | -3.573226929 | 92.10526276 | 2017 | | |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.1836 | 40 | 40 | -3.108936787 | 92.98246002 | 2017 | | |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.1855 | 40 | 40 | -3.404061556 | 92.10526276 | 2017 | | |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.1874 | 40 | 40 | -3.937189817 | 93.85964966 | 2017 | | |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.1893 | 40 | 40 | -4.070704937 | 88.59649658 | 2017 | | |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.1912 | 40 | 45 | -4.434724808 | 92.10526276 | 2017 | | |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.1931 | 40 | 45 | -4.002924919 | 88.59649658 | 2017 | | |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.1949 | 40 | 45 | -4.763065815 | 90.56604004 | 2017 | | |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.1968 | 40 | 45 | -4.867936611 | 91.50942993 | 2017 | | |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.1987 | 40 | 45 | -5.094794273 | 90.47618866 | 2017 | | |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.2006 | 40 | 30 | -5.3622756 | 0.952381015 | 2017 | Vegetation | Maintenance vegetation |
| 9/2/21 13:33 | 190 | Negative | CL | 190-CL-N | SSD | 3.2025 | 40 | 30 | -5.362917423 | 0 | 2017 | Vegetation | Maintenance vegetation |

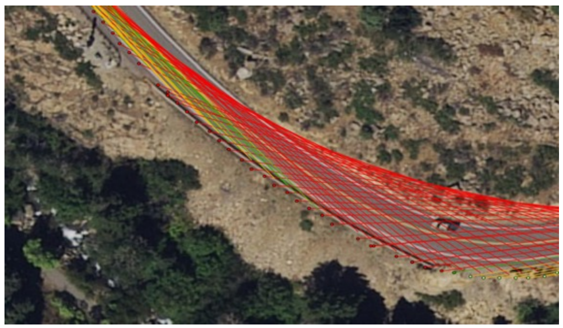

Stopping Sight Distance - By Classification



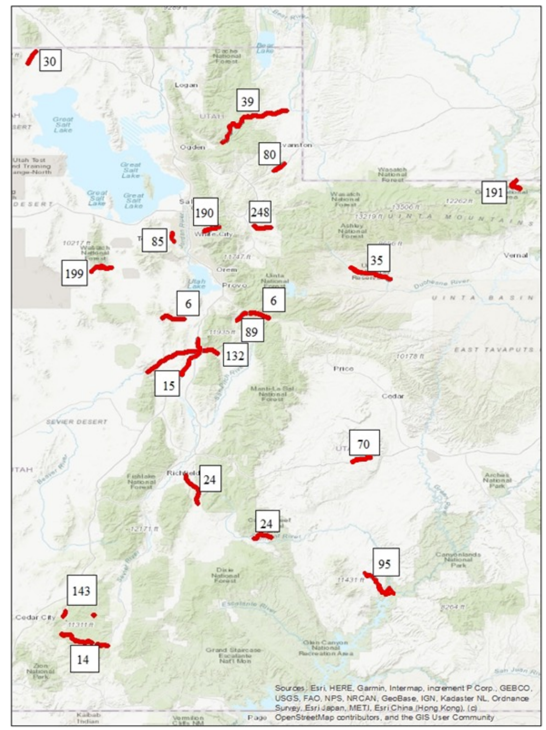
Obstacle types (count)

- SSD Position Classification
  - **MICHIGAN_0032-1-LL-P_SSD_Position**
    - Vegetation [499]
    - Vertical curvature [96]
    - Vehicles [135]
    - Visible [477]
  - **MICHIGAN_0032-1-LL-N_SSD_Position**
    - Vegetation [632]
    - Vertical curvature [79]
    - Visible [498]

# SSD – Safety Analysis for Utah Data

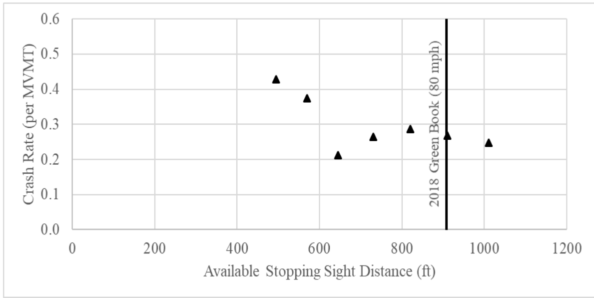


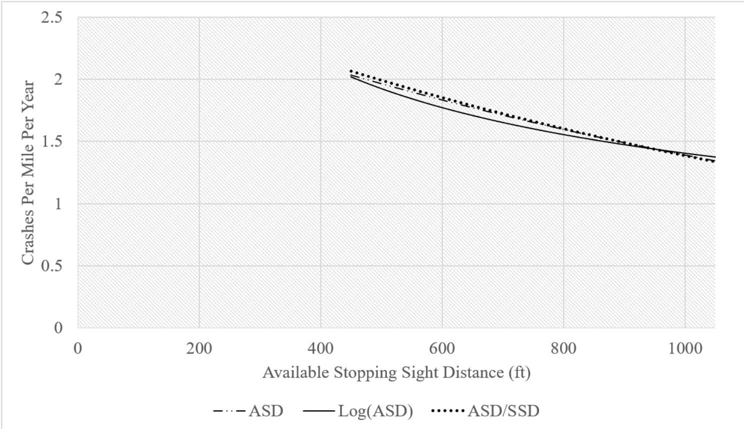
| Variable | Freeway Number | Freeway Percent | Non-Freeway Number | Non-Freeway Percent |
|---|---|---|---|---|
| **Crashes by Severity Level** | | | | |
| K | 2 | 0.6 | 19 | 1.1 |
| A | 8 | 2.6 | 83 | 5.0 |
| B | 22 | 7.1 | 200 | 12.1 |
| C | 33 | 10.6 | 182 | 11.0 |
| O | 246 | 79.1 | 1,174 | 70.8 |
| **TOTAL** | **311** | **100.0** | **1,658** | **100.0** |
| **Manner of Collision** | | | | |
| Not Applicable/Single Vehicle | 238 | 76.5 | 1,218 | 73.5 |
| Front to Rear | 25 | 8.0 | 164 | 9.9 |
| Sideswipe Same Direction | 39 | 12.5 | 64 | 3.9 |
| Sideswipe Opposite Direction | 0 | 0.0 | 61 | 3.7 |
| Parked Vehicle | 5 | 1.6 | 29 | 1.7 |
| Head On (front-to-front) | 0 | 0.0 | 19 | 1.1 |
| Angle | 4 | 1.3 | 99 | 6.0 |
| **TOTAL** | **311** | **100.0** | **1,658** | **100.0** |



# Freeway (Utah)

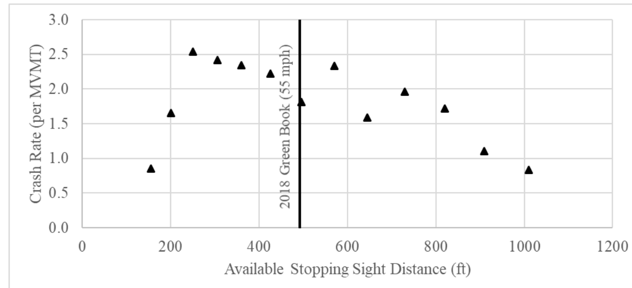
| Minimum Available SSD (ft) | No. of Segments | No. of Miles | Avg. AADT | Total MVMT | Total Crashes | Crash Rate per MVMT |
|---|---|---|---|---|---|---|
| ≤495 | 72 | 7.14 | 18702 | 242.76 | 104 | 0.43 |
| 570 | 13 | 1.26 | 17468 | 40.02 | 15 | 0.37 |
| 645 | 34 | 3.41 | 15550 | 94.65 | 20 | 0.21 |
| 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 |

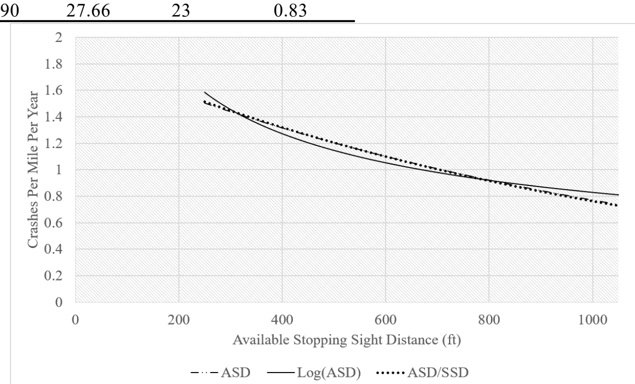


# Non-Freeway (Utah)

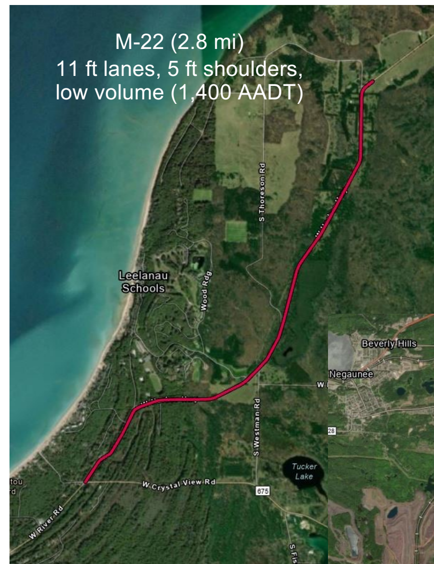
| Minimum Available SSD (ft) | No. of Segments | No. of Miles | Avg. AADT | Total MVMT | Total Crashes | Crash Rate per MVMT |
|---|---|---|---|---|---|---|
| ≤155 | 53 | 5.01 | 1,054 | 9.41 | 8 | 0.85 |
| 200 | 56 | 5.28 | 881 | 8.45 | 14 | 1.66 |
| 250 | 95 | 8.84 | 1,237 | 19.31 | 49 | 2.54 |
| 305 | 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 |

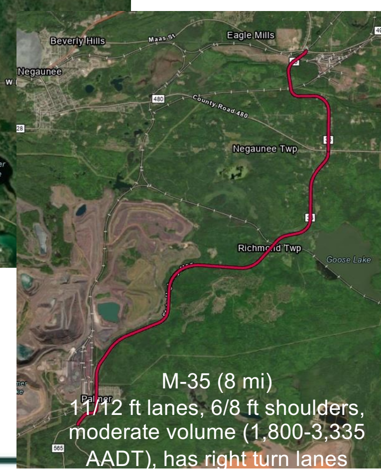


# SSD – Safety Analysis for Michigan Data

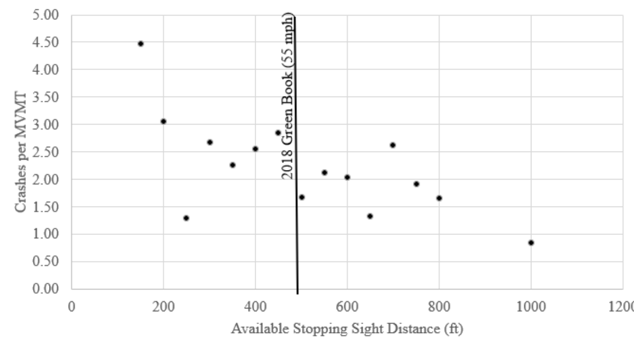
- Analysis carried out for smaller road network.
- 21 miles of rural two-lane highways posted at 55/65 mph were identified
  - Frequent occurrence of curvature
  - Varying traffic volume and geometry

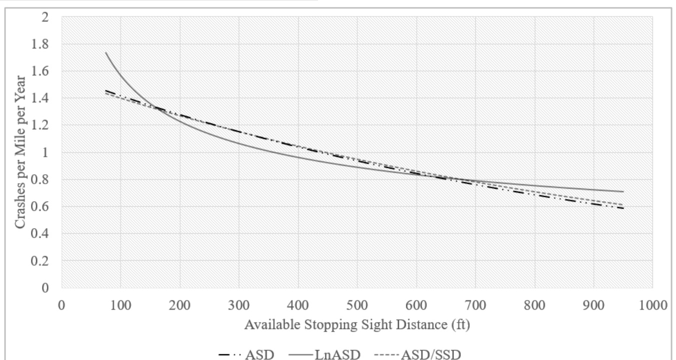


# Non-Freeway (Michigan)

| Minimum Available SSD (ft) | No. of Segments | No. of Miles | Avg. AADT | Total MVMT | Total Crashes | Crash Rate per MVMT |
|---|---|---|---|---|---|---|
| <150 | 30 | 3.06 | 1,793 | 10.04 | 40 | 4.47 |
| 200 | 28 | 2.83 | 1,737 | 9.04 | 26 | 3.06 |
| 250 | 17 | 1.76 | 1,562 | 4.99 | 6 | 1.29 |
| 300 | 16 | 1.60 | 1,817 | 5.31 | 14 | 2.68 |
| 350 | 16 | 1.60 | 1,680 | 4.91 | 11 | 2.26 |
| 400 | 10 | 1.00 | 1,931 | 3.52 | 9 | 2.56 |
| 450 | 16 | 1.60 | 2,282 | 6.66 | 18 | 2.86 |
| 500 | 12 | 1.20 | 2,148 | 4.70 | 9 | 1.67 |
| 550 | 7 | 0.73 | 2,015 | 2.69 | 6 | 2.12 |
| 600 | 11 | 1.10 | 2,332 | 4.68 | 9 | 2.04 |
| 650 | 12 | 1.20 | 2,365 | 5.18 | 7 | 1.33 |
| 700 | 5 | 0.50 | 2,130 | 1.94 | 5 | 2.62 |
| 750 | 7 | 0.77 | 2,288 | 3.22 | 7 | 1.92 |
| 800 | 11 | 1.10 | 2,280 | 4.58 | 7 | 1.66 |
| 1000 | 16 | 1.60 | 2,320 | 6.78 | 6 | 0.85 |



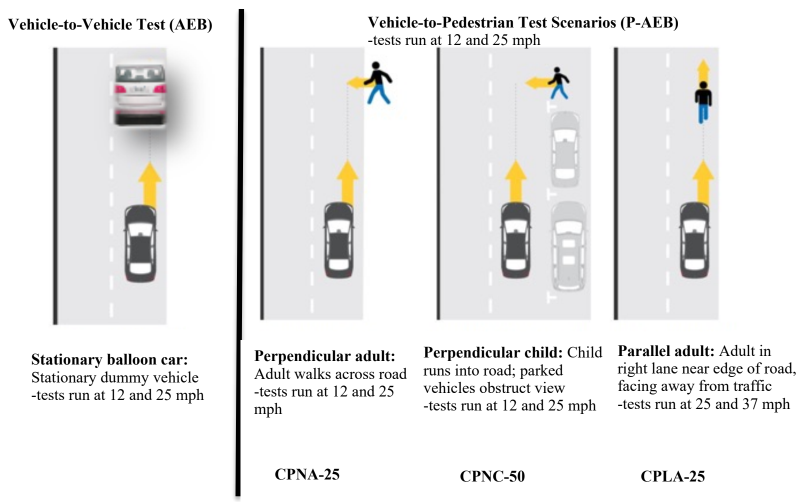
# The Future: What about Advanced Driver Assistance Systems (ADAS) and Automated Driving Systems (ADS)?

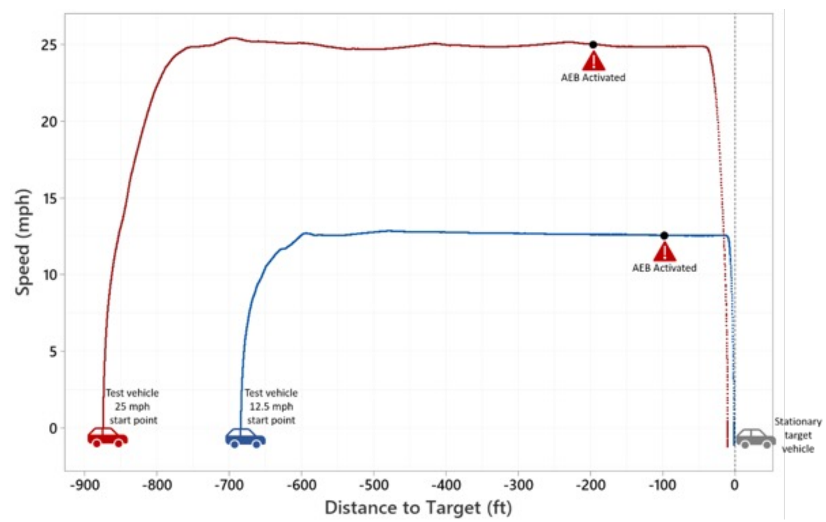
# SAE J3016™ LEVELS OF DRIVING AUTOMATION

| | SAE LEVEL 0 | SAE LEVEL 1 | SAE LEVEL 2 | SAE LEVEL 3 | SAE LEVEL 4 | SAE LEVEL 5 |
|---|---|---|---|---|---|---|
| What does the human in the driver's seat have to do? | **You <u>are</u> driving** whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering | | | **You <u>are not</u> driving** when these automated driving features are engaged – even if you are seated in "the driver's seat" | | |
| | **You must constantly supervise** these support features; you must steer, brake or accelerate as needed to maintain safety | | | When the feature requests, you must drive | These automated driving features will not require you to take over driving | |
| | These are driver support features | | | These are automated driving features | | |
| What do these features do? | These features are limited to providing warnings and momentary assistance | These features provide steering OR brake/ acceleration support to the driver | These features provide steering AND brake/ acceleration support to the driver | These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met | | This feature can drive the vehicle under all conditions |
| Example Features | • automatic emergency braking<br>• blind spot warning<br>• lane departure warning | • lane centering<br>OR<br>• adaptive cruise control | • lane centering<br>AND<br>• adaptive cruise control at the same time | • traffic jam chauffeur | • local driverless taxi<br>• pedals/ steering wheel may or may not be installed | • same as level 4, but feature can drive everywhere in all conditions |

# Analysis of Automatic Emergency Braking (AEB) Data

- Data from the Insurance Institute for Highway Safety (IIHS) were obtained for automatic emergency braking (AEB) systems.

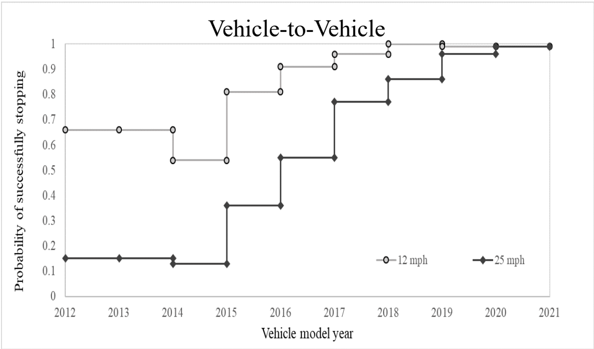


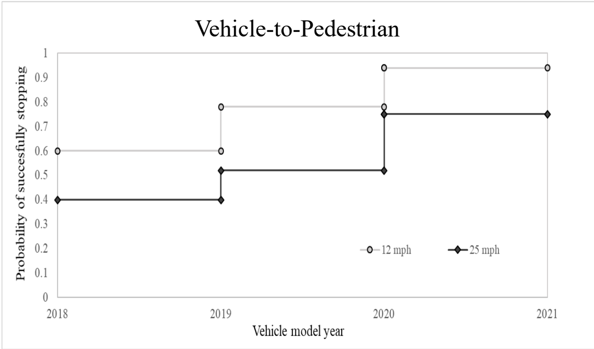




Source: HLDI, 2019

# 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 |



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

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

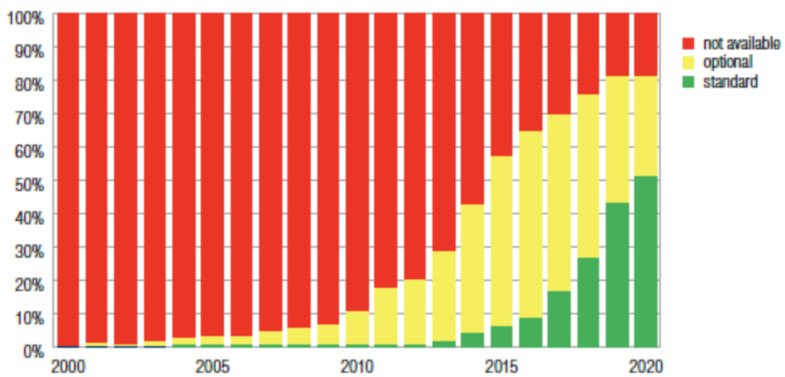
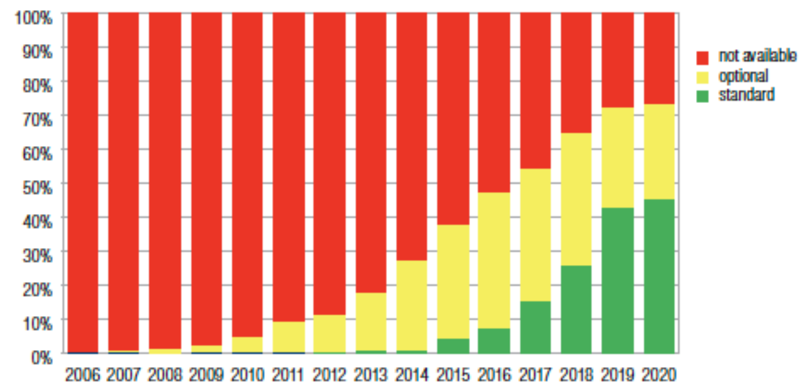



**Figure 7: Proportion of vehicle series with forward collision warning with autobrake, 2006–20 model years**



# Fleet Penetration for Forward Collision Warning and Automatic Emergency Braking

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

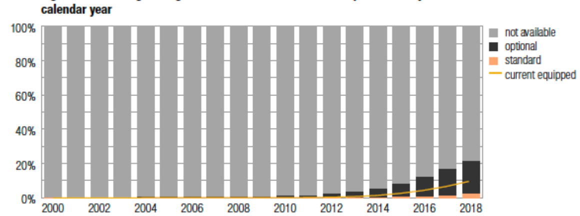



Figure 8 shows the percentage of registered vehicles by calendar year with either standard or optional front crash prevention. In 2006, front crash prevention had become standard on less than 1 percent and optional on less than 1 percent of registered vehicles. By 2018, front crash prevention was standard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

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

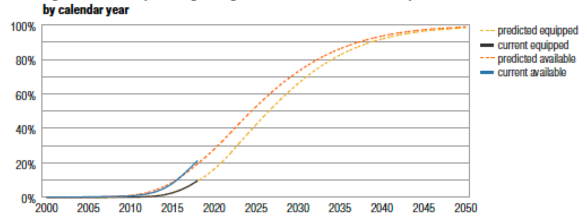



Figure 9 takes into account a voluntary commitment by many manufacturers to make front AEB standard on most of their vehicles by 2022. It shows the predicted registered vehicles by calendar year with front crash prevention. One prediction is for vehicles with front crash prevention available (standard 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 11: Percentage of registered vehicles with front automatic emergency braking by calendar year**

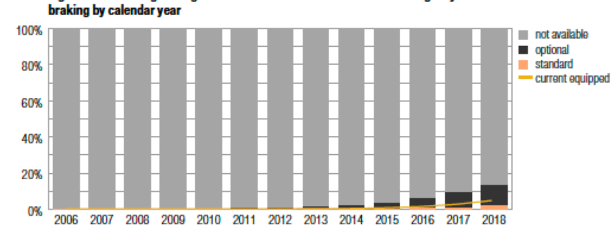



Figure 11 shows the percentage of registered vehicles by calendar year with either standard or optional front AEB. In 2012, AEB had become standard on less than 1 percent and optional on 1 percent of registered vehicles. By 2018, AEB was standard or optional on 13 percent of registered vehicles but estimated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

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

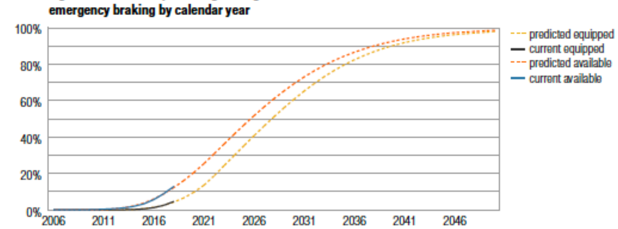



Figure 12 takes into account the 2022 voluntary commitment and shows the predicted registered vehicles by calendar year with front AEB. One prediction is for vehicles with AEB available (standard or optional) and the other prediction is for vehicles equipped (standard or optionally equipped) with AEB.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

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## Areas for Future Research

- Additional investigation into the relationship between crash risk and available stopping sight distance (e.g., crash modification functions).
- Probabilistic design in consideration of the distributions of reaction time, deceleration rate, and crash risk.
- Incorporation of the effects of automatic emergency braking systems into design criteria.

# Thank You!

# Questions?
# Comments?

Peter T. Savolainen, Ph.D., P.E.
MSU Research Foundation Professor and Chairperson
Department of Civil and Environmental Engineering
Michigan State University
428 S Shaw Ln, Room 3546C
East Lansing, MI 48824
Phone: (517) 432-1825
E-mail: pete@msu.edu

MICHIGAN STATE UNIVERSITY

# Michigan State University
# Department of Civil and Environmental Engineering:
# An Overview

**Presentation to National Technical University of Athens (NTUA)**
**November 11, 2024**

Peter T. Savolainen, Ph.D., P.E.
MSU Research Foundation Professor & Chairperson
Department of Civil & Environmental Engineering
Michigan State University

# Introduction

- MSU
  - founded in 1855, first land-grant institution
  - > 50,000 students
  - 5,300 faculty members and academic staff
  - 17 colleges, 200 degree programs
- College of Engineering
  - 6000 undergraduate, 1000 graduate students
  - 200 faculty members
  - 8 departments, 9 graduate/10 undergraduate degree programs

# Introduction

- Department of Civil and Environmental Engineering
  - BS, MS and PhD degrees in Civil Engineering and Environmental Engineering
  - 31 core faculty members
  - 600 undergraduate students
  - 130 graduate students
  - 43 undergraduate courses and 36 graduate courses offered
  - > 50 active research projects
  - > $11 million annual research expenditures

# Civil and Environmental Engineering Faculty

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## Research Specialty Areas

- Renewable Energy, Environmental Conservation, Recycled Materials
- Public Health, Water Quality, Microbiology, Environmental Chemistry
- Design, Construction, and Environmental Sustainability of Geotechnical and Pavement Systems
- Hydrology, Climate Change, and Water Resource Systems Modeling
- Structural Engineering, Mechanics, and Materials
- Transportation Safety, Human Factors, Travel Demand Modeling, Connected/Automated Vehicles, Sustainable Transportation

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## Graduate Degree Programs

- MS – 30 credits
  - Option A – 24 course credits; 6 thesis credits
  - Option B – 30 course credits

- PhD – 36-48 credits
  - 12 course credits
  - 24-36 dissertation credits

- Dual PhD – TBD