An Evaluation of Conspicuity Tape on Trailers & Trucker Behaviors

An expansive study based on data from 194 trailers from 40 states and counting

By

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Background

- ~50% of all crashes take place after dark
- ~20% of all fatalities in large trucks are from Side-Impact and Rear-Enders
- Medium and heavy trucks were eight times more likely to be struck in the rear at night than in daylight

Regulations

- 1993: FMVSS No. 108 (S5.7.1): All Trucks manufactured from 1993 should br fitted with retroreflective tape
- 2009: All trucks wider than 80” required to have all conspicuity markings
- Minimum Standard: FMCSR 393.11

The Issues

- Currently only a “*when new*” standard for retroreflective tape
  - Retroreflective tape degrades over time
- No relevant regulations for law enforcement vehicle inspectors to deem vehicles unsafe
  - Except for if tape is present/not present
- No measurement protocol for law enforcement vehicle inspectors

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Trailer markings

About our Study

- Develop a minimum standard for safe on-road operation
- Development of a fast and standard protocol for inspection of retroreflective tape
- Determine the level of retroreflectivity is observed on trucks today
- Effect of dirt on retroreflectivity of tape

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The Data

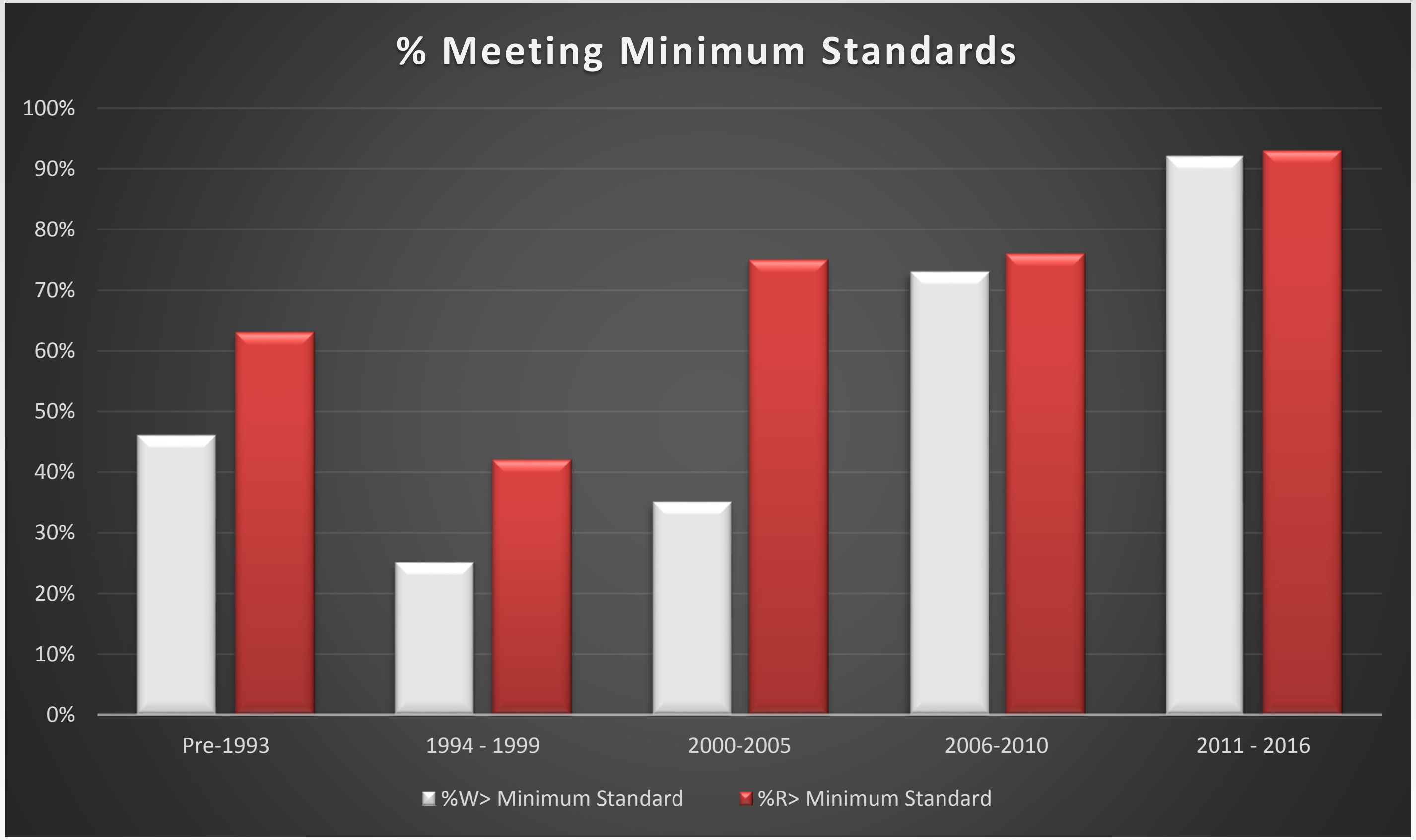
- No. of Trailers measured= 194
- States Represented= 40
- Test Locations: Colorado, Connecticut, California (Southern),Georgia, Pennsylvania and Massachusetts
- Trailers: Box Type (65%); Flatbed (12%); Tanker (8%); Lowboy, Intermodal, Grain, Car Carrier, Livestock (15%)
- Year of Manufacture: Median 2007; Range 1969-2013

Results

- As is vs. Clean
  - White: As is = 75% Clean
  - Red: As is = 76% Clean

- Meeting “when new” minimum standard
  - White: 33% failed to meet minimum standard
  - Red: 20.2% failed to meet minimum standard

Influence of Age



Future Direction

- Expand on the current study
  - Data collection from more states across the country
- Determine a minimum recognition threshold for retro reflective tape
  - Recognizable from minimum safe maneuver distance
- Develop published standards and protocol

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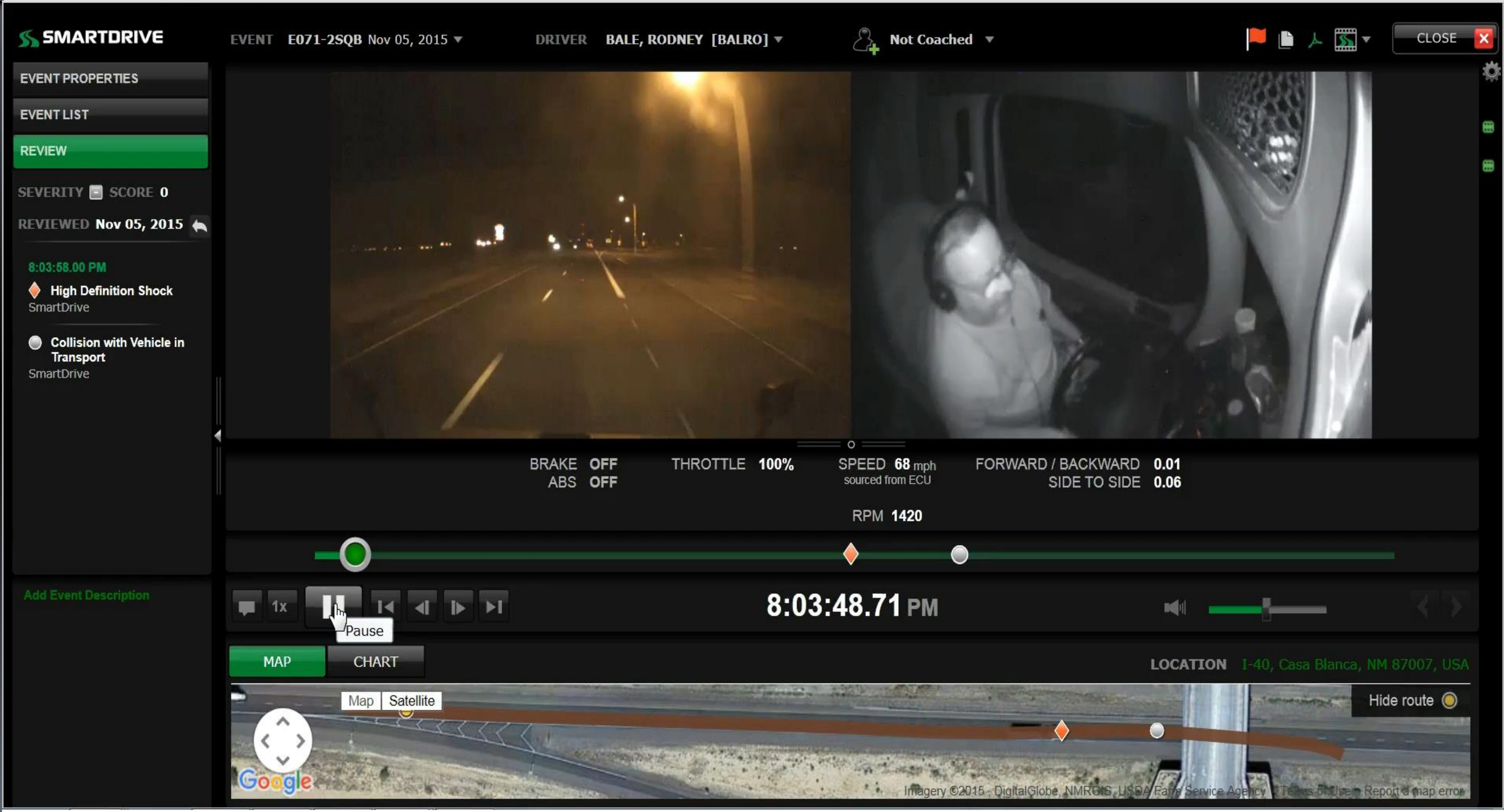
Jeffrey W. Muttart
Swaroop Dinakar

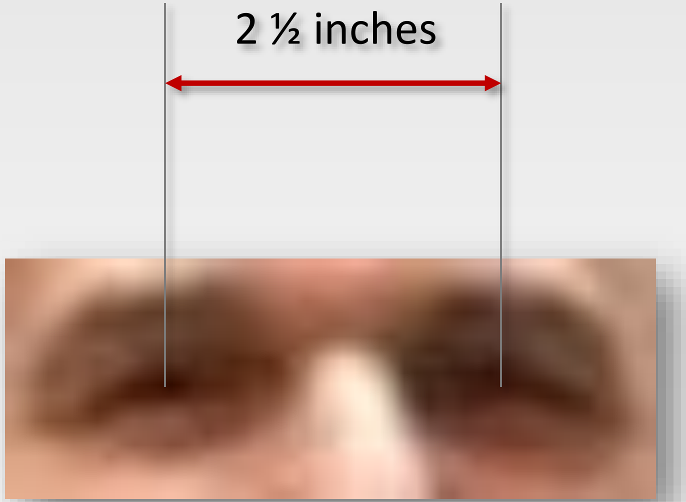
DRIVERS' ABILITIES TO RECOGNIZE CLOSING
- DRIVER RESPONSE BEHAVIORS
- COULD PATTERN & CONSPICUITY HELP?

Why do this research?: Stopped Vehicles on Highways Get Hit



Drivers are Ill-Suited to estimate…

- Longitudinal Distance,
- Velocity, Or
- Acceleration

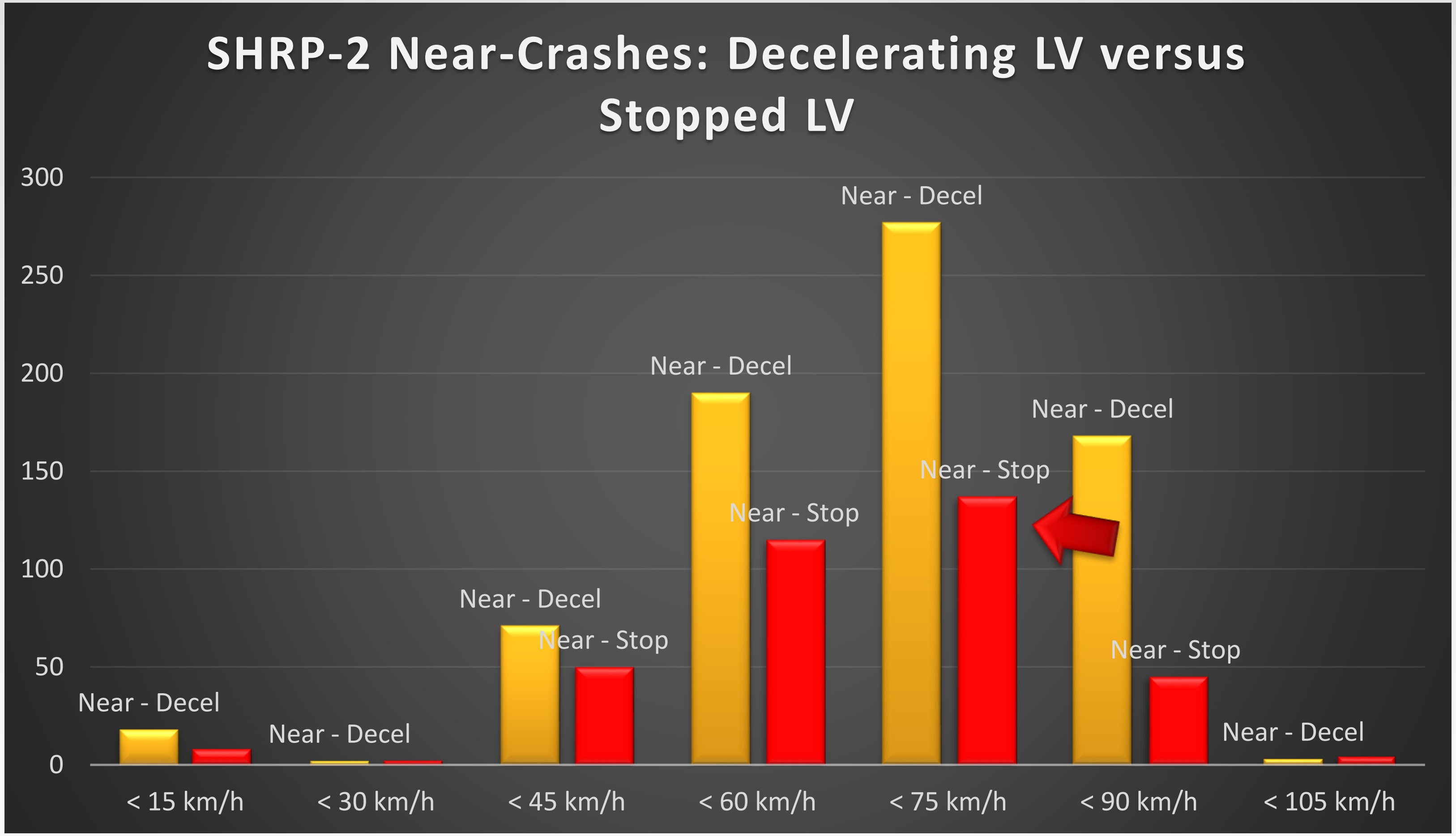


Gray, R., Regan, D., 1998. Accuracy of estimating time to collision using binocular and monocular information. Vision Res. 38 (4), 499–512.

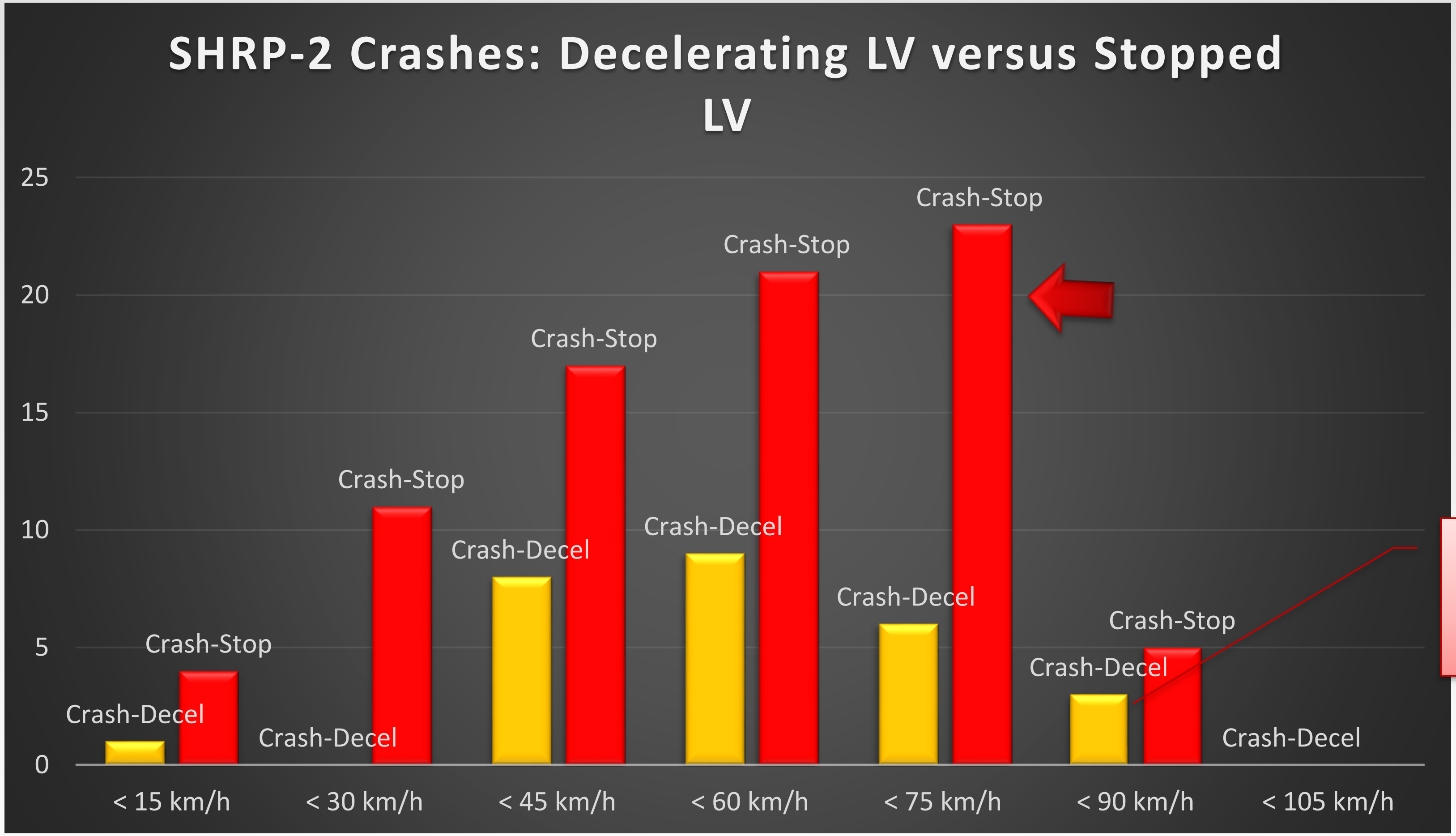
Michaels, R., 1963. Perceptual factors in car following. In: Proceedings of the 2nd International Symposium on the Theory of Road Traffic Flow, OECD, London, UK.

Michaels, R., Cozan, L., 1963. Perceptual and field factors causing lateral displacement. Highway Res. Rec. 25, 1–13

Decelerating LV: Not a clear story



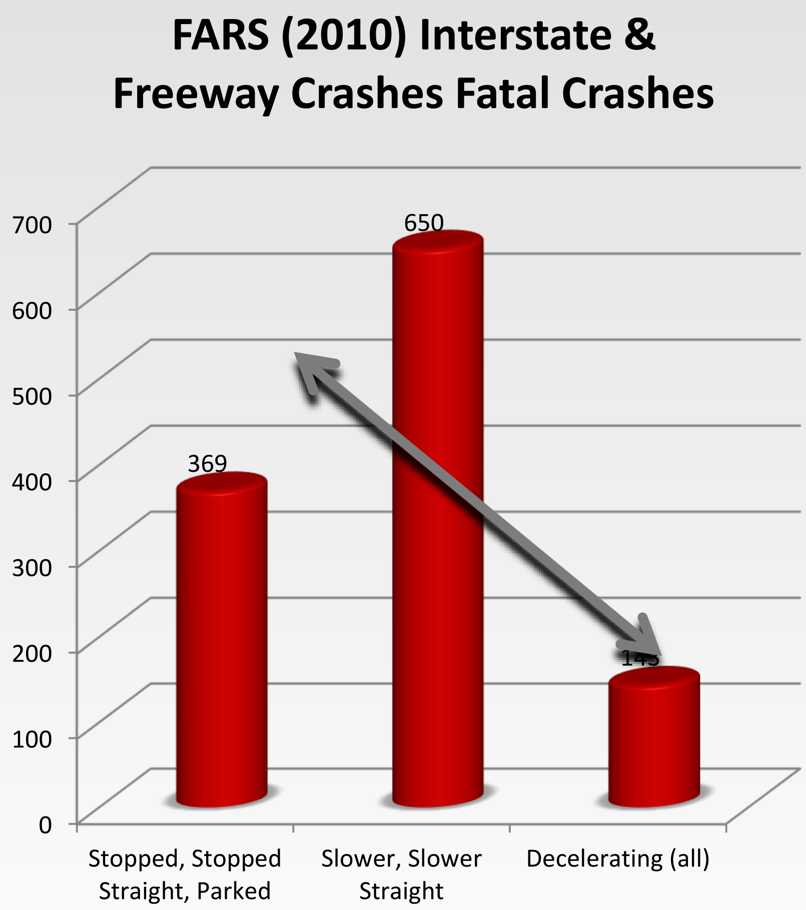
LV Stopped: As Speed increased, so did crashes

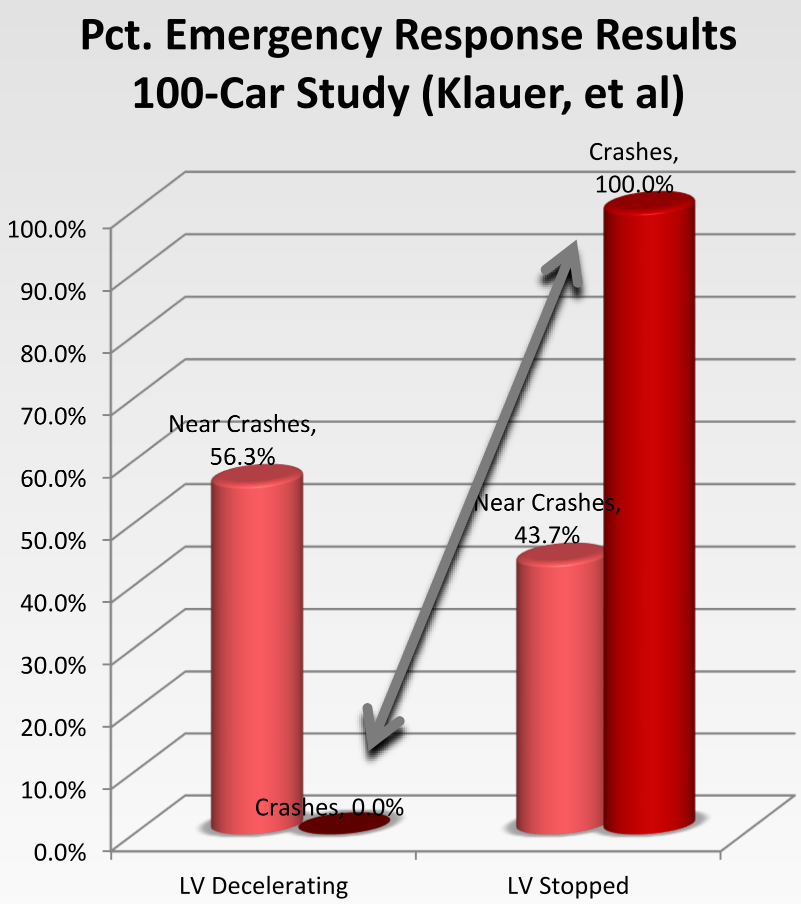


Less exposure when > 60 mph

70% of LVs are stopped or traveling less than 14 mph

McGehee et al., 1997; Knipling et al., 1993; Sorock, Ranney & Lehto, 1996; Dingus et al, 2006.





Detection of Relative Velocity

- Trucks 8 times more likely to be rear-ended at night (Sullivan et al, UMTRI, 2003)
  - "Discernible" width
  - Reflections of street lights and vehicle lights off hood & roof not available.
- Higher objects are perceived as further away (Myers 7th Ed. *Psychology)*
- Farm tractors rear end crash risk (Gerberich, 1998)
  - Day – 24%
  - Night – 65%

When within 500’ (150 m) drivers recognize closing

ROUTINE PASSING MIRROR GLANCE TIMES

Passenger Cars & SUVs

Average 2.5 head turns - 3 to 7 sec. depending on traffic

Henning, M. J., Georgeon, O. & Krems, J. F. (2007). The quality of behavioral and environmental indicators used to infer the intention to change lanes, *Proceedings of the Fourth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design,* 231

Finnegan, P., & Green P. (1990). The time to change lanes: A literature review. University of Michigan, *Transportation Research Institute* (IVHS Technical Report-90-13).

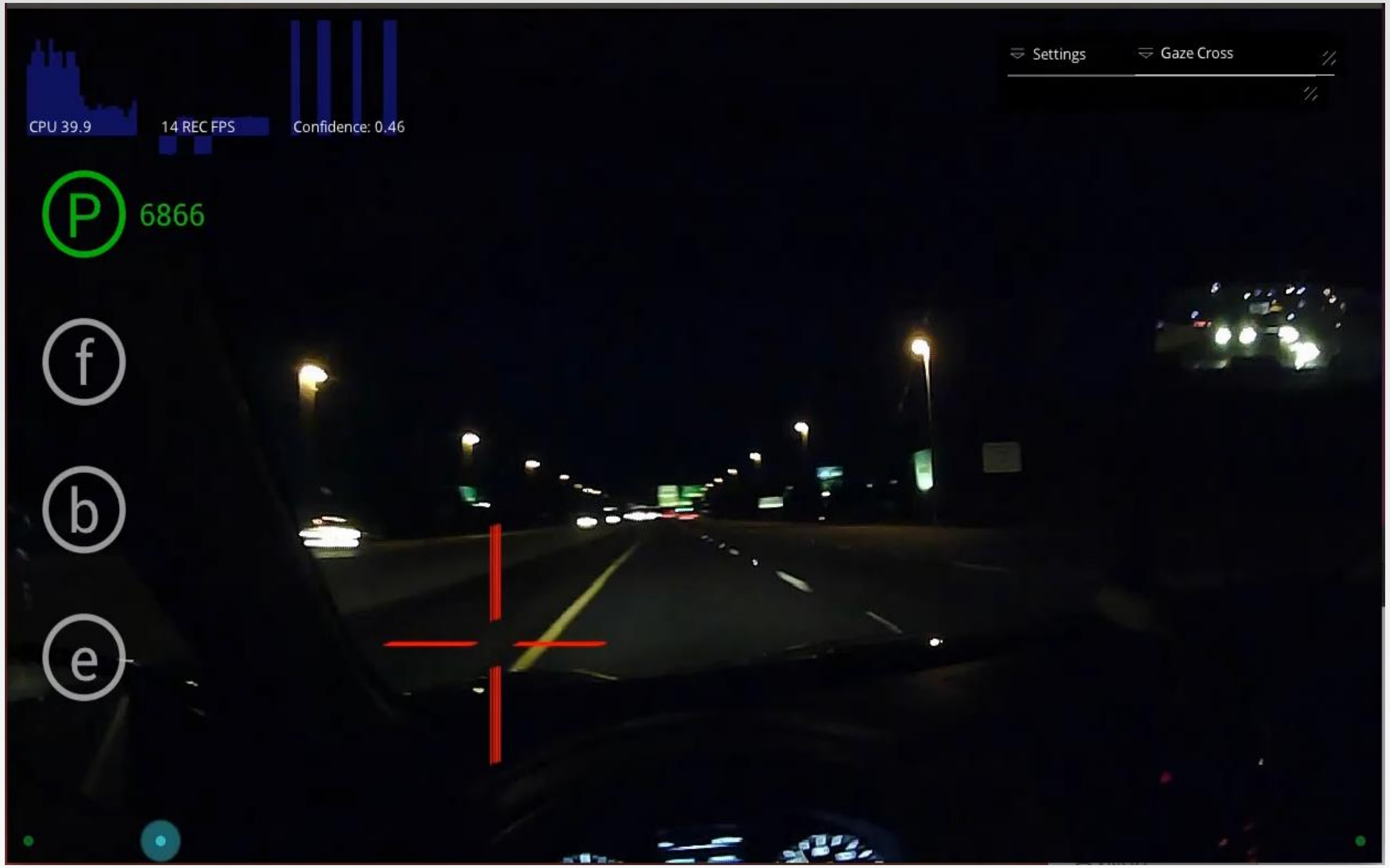
Fitch, G. M., Lee, S. E., Klauer, S., Hankey, J., Sudweeks, J., Dingus, T. (2009). Analysis of lane change crashes and near crashes, Washington, DC: NHTSA.

Lavalliere, M., Laurendeau, D., Simoneau, M., Teasdale, N. (2011). Changing lanes in a simulator: Effects of age on the control of the vehicle and visual inspection of mirrors and blind spot, Traffic Injury Prevention, 12, 191-200.

Robinson , G. H., Erikson, D.., Thurston, G., & Clark, R.. (1972). Visual search by automobile drivers, Human Factors, 14, 315-323.

Lane Change- Right - Average driver 2.5 head turns

2 glances (including shoulder check) in 7 seconds (w/ 1 car) - No LV



Consistent with:

Lavalliere, M., Laurendeau, D., Simoneau, M., Teasdale, N. (2011). Changing lanes in a simulator: Effects of age on the control of the vehicle and visual inspection of mirrors and blind spot, Traffic Injury Prevention, 12, 191-200.

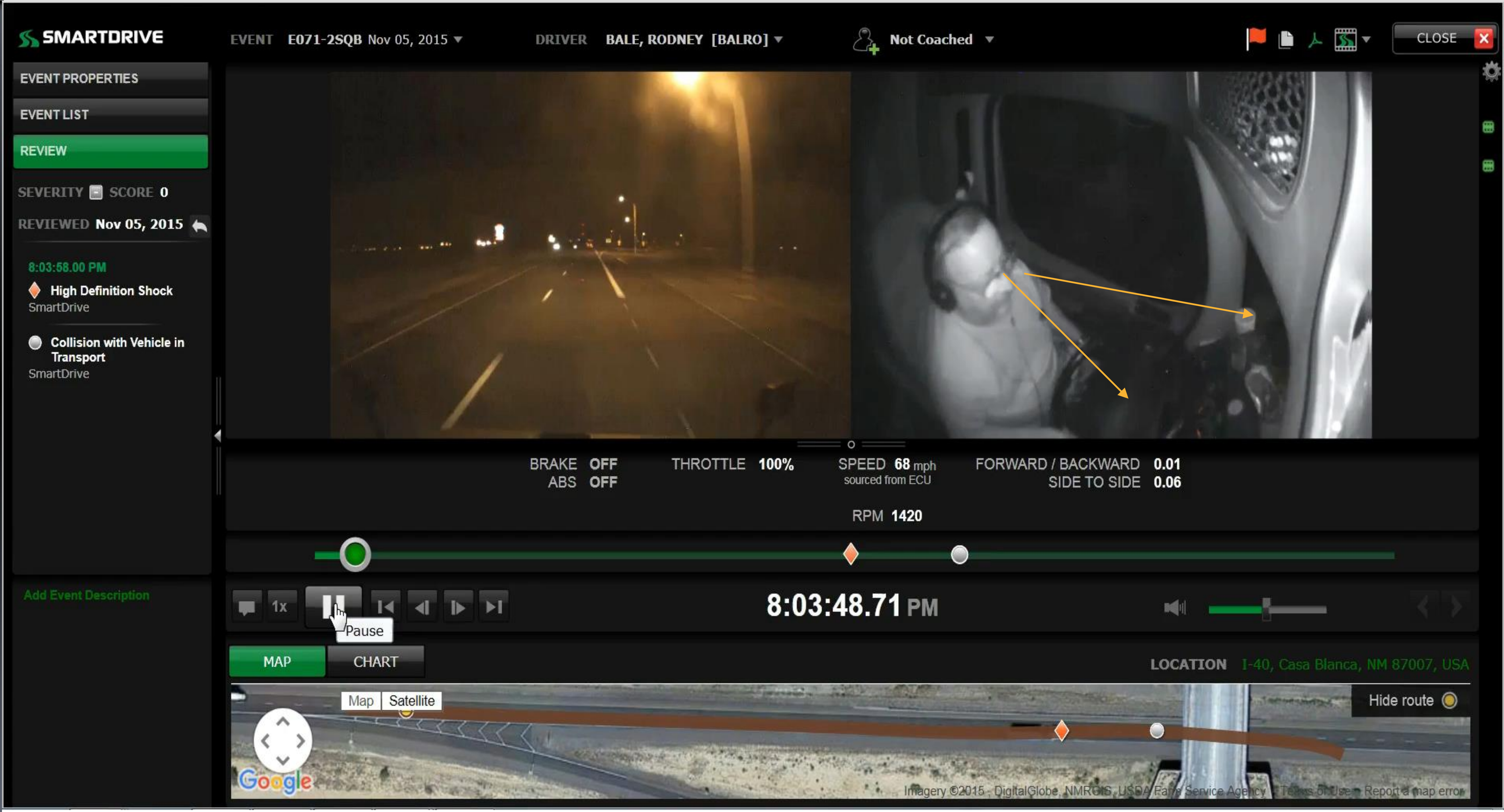
CDL driver in a large box truck

- Process took 9 seconds – 3 mirror glances – 1 over the shoulder glance
- truck 5 -Lane change.ogv

- 5 seconds - 2 mirror glances
- Truck 8 - Lane change.ogv

Truck drivers can look in only one place at a time

Mirror glance?



Next – Drivers closer before starting a lane change

- Close to within 124 feet (Mean or 96 ft. median)
  - Lee, Olsen, Weirwille, 2002, 2005
- Within 150 feet
  - Francher, et al (2001)

- Drivers do not slow when coming upon slower moving lead vehicle
  - Fitch et al (2009) – average acceleration = 0.0 g

Drivers Do Not Slow in Response to Routine Closing Instead they close to within 100-150 feet (31-46m)

Straight unchanging multi-lane road

0.0 Seconds

Noticeably closing on the lead vehicle

1.0 Seconds

2.0 Seconds

3.0 Seconds

4.0 Seconds

5.0 Seconds

6.0 Seconds

7.0 Seconds

8.0 Seconds

9.0 Seconds

10.0 Seconds

11.0 Seconds

12.0 Seconds

After 12 seconds following this unsuspecting driver starts to move left
Also note the distance is consistent with Lee, et al (X = 124')

13.0 Seconds

14.0 Seconds

Next - Factors Associated with Recognition of Closing speed

- The factors that influence a driver's response include
- Angular velocity (Michaels, 1963)

$$\frac{d}{dt}\theta_n t = -w\frac{\Delta V_n t}{(S_n(t))^2}$$

$$S_n = (8' \times \frac{(100\frac{ft.}{sec} - 0)}{0.006\, rad/sec})^2 = 365'$$

Or 3.6 seconds before impact

- *W – width*
- *ΔV (relative velocity)*
- *S – displacement*

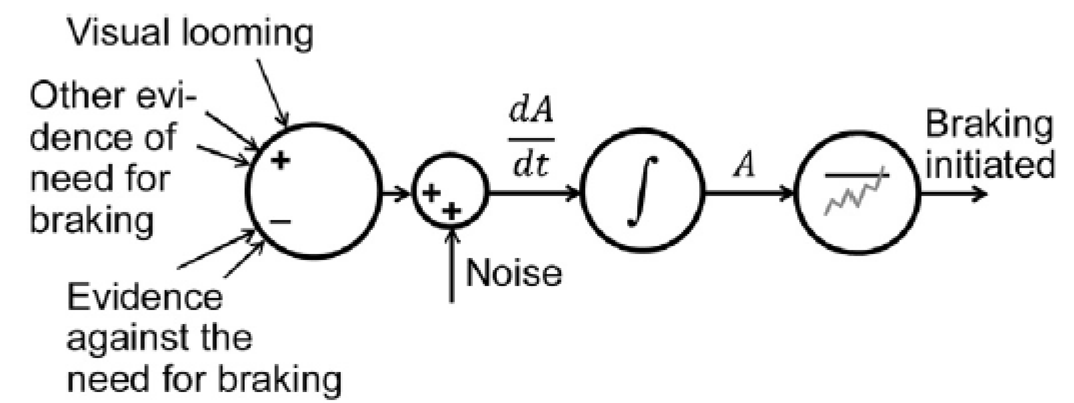


Fig. 12. An evidence accumulation account of brake timing. The rate of change of a quantity *A* depends on various sources of evidence for or against the need of braking, and braking is initiated once *A* exceeds a threshold. (Adapted from Markkula, 2014).

Michaels, 1963
Muttart, Messerschmidt, & Gillen (2005)
Fisher, Knodler, & Muttart, 2009

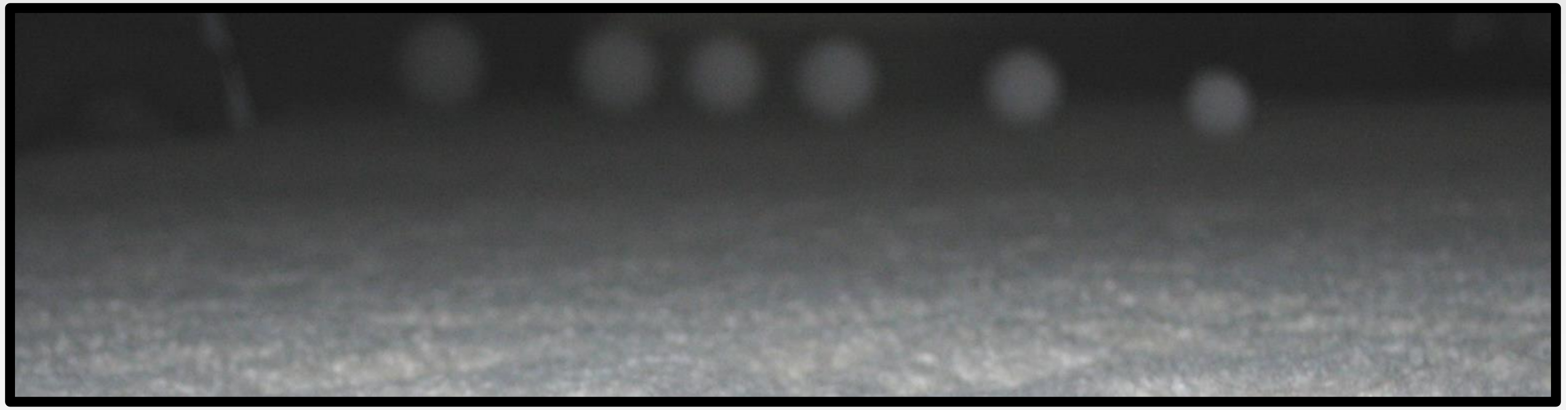
When within 500’ (150 m) drivers recognize closing

Solutions?

- Collision Avoidance/Mitigation Systems – in following vehicle

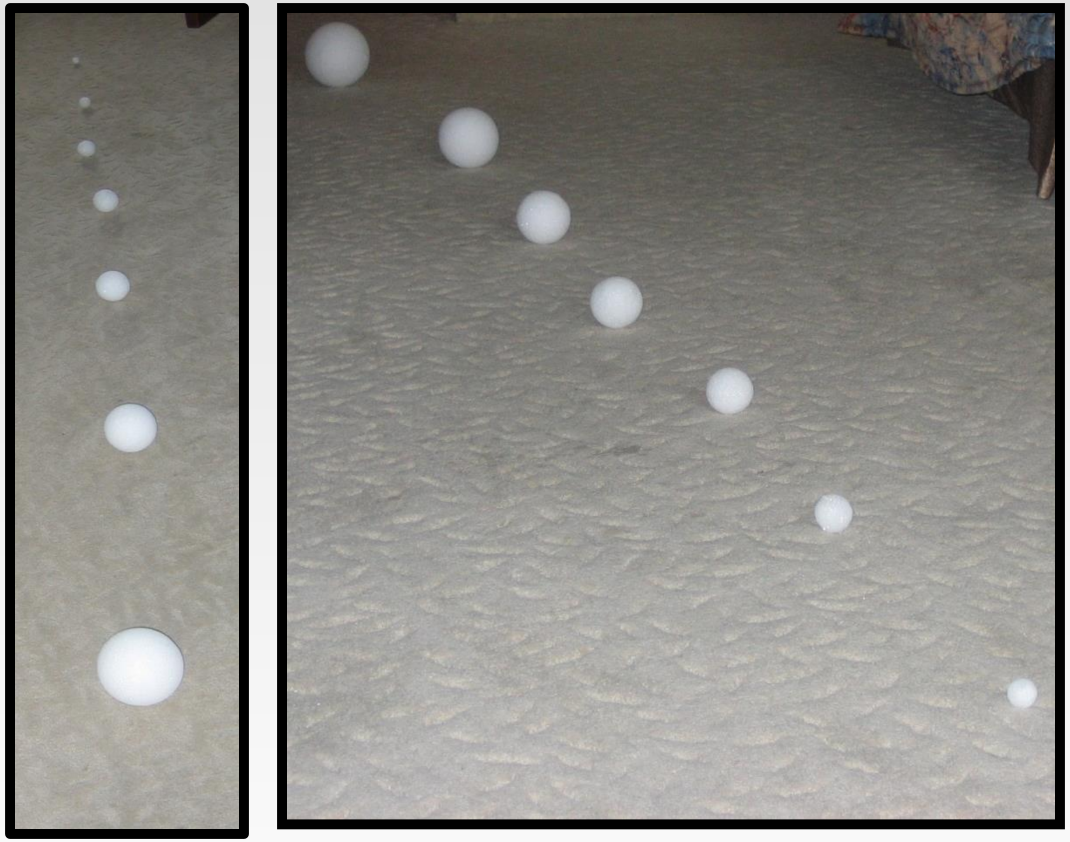
- Brighter, more defined, “lower” trailers – in stopped truck

Very Little Context:
Lacks Clarity
Depth
& Size information



Context:
More Clarity
But Lacks Depth & Size Detail

Better Perspective Offered Lighting, Clarity, & Brightness



We are now capable of accurately judging size and relative
Position which tells us the distance

Total extra cost = $55.60 if the best quality (10-year) Orafol
= $26.40 if purchased from ULINE

Shape = information

Bright = Closer

Lower = Closer

Questions

- Automacy: Are you concerned about the following?
  - Driver adaptation
  - Driver trust – what if system says 0.7 g and driver only accepts < 0.3 g
  - Driver fatigue / vigilance
  - Do safety features get to truck drivers last?
- Conspicuity
  - When is retroreflective sheeting of no value
  - Lighting and lighting laws – no good deed goes unpunished
  - What benefits are there for my trucking company to spend $50/truck?
- Response
  - Steering willingness
  - Braking willingness   (jackknife?)
  - Are CDL drivers' glances the same as passenger car drivers? Should it be better?

Thank you

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- Jeff Muttart, Ph.D.
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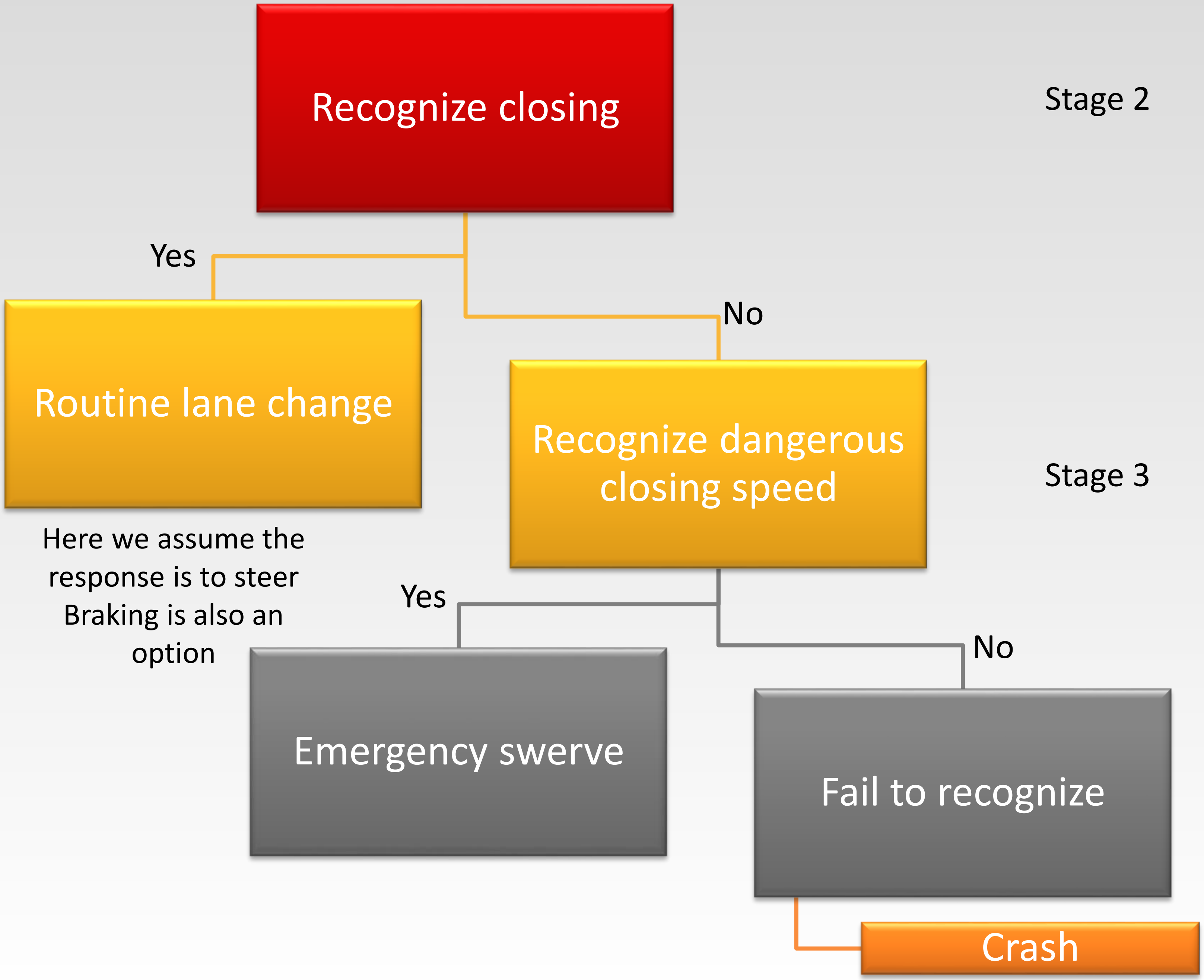
Issue			
Following within 2 seconds			Chisholm S. L., Caird, J. K., Lockhart, J. A., Teteris, L. E., & Smiley, A. (2006); Sivak & Olson, 1981; Chang, Lin, Fung, Hwang, & Doong, 2008; Fitch el al., 2009 (100-car study)
Approaching a stopped vehicle at an intersection			Muttart, 2003
Approaching slower moving traffic			


Recognize closing
Stage 2
Yes
No
Routine lane change
Recognize dangerous closing speed
Stage 3
Here we assume the response is to steer
Braking is also an option
Yes
No
Emergency swerve
Fail to recognize
Crash

Assumption: No typical cues associated with recognition of speed

<u>Sudden slowing by car ahead</u> – Cues include:

- Pitch of the LV --

-Immediate change in following distance

-Taillights flashing on --

<u>Car sideways</u>

- Cars do not travel 70 mph sideways!

(Assumes car is recognizable)

<u>Can see car ahead is not moving against immediate background</u>

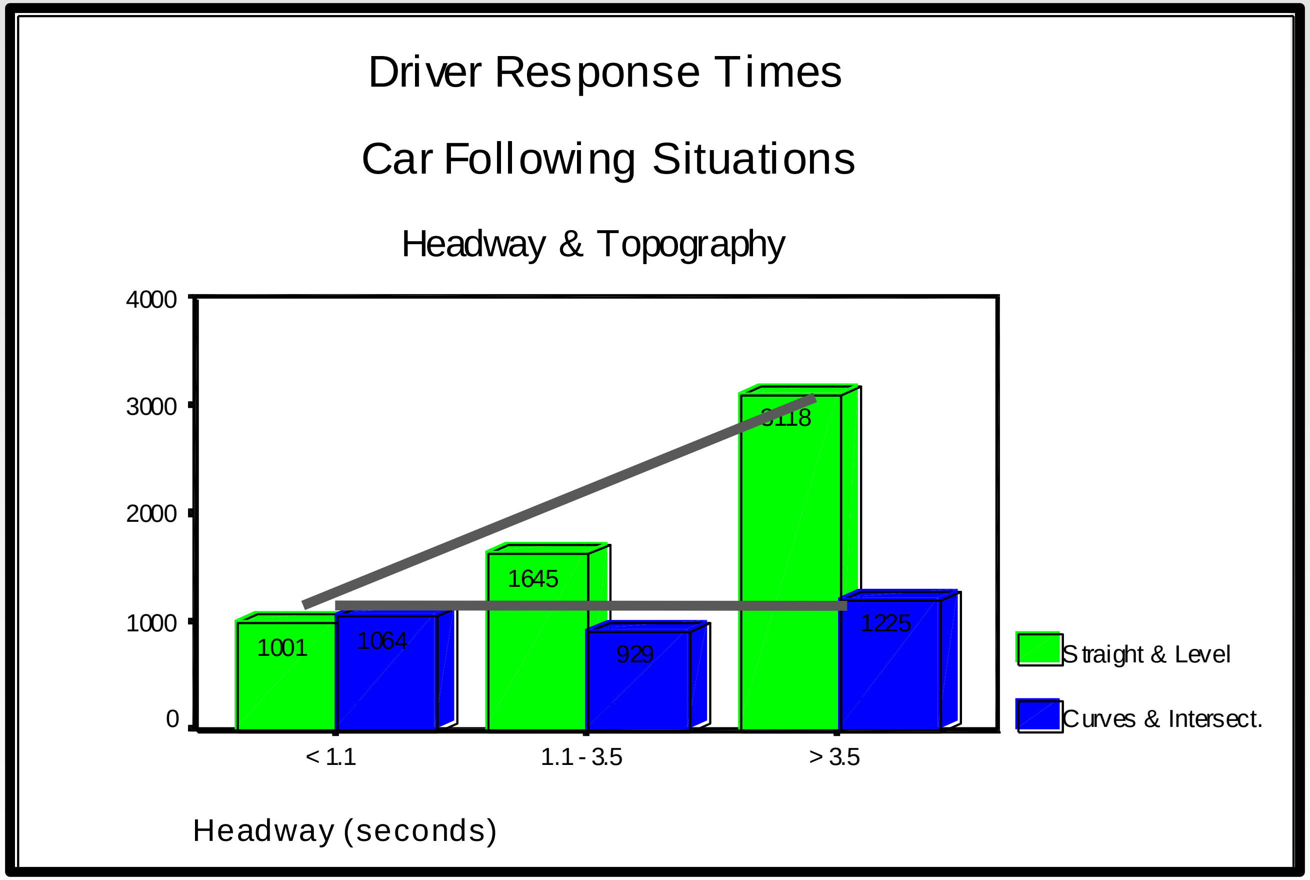
- Curves

- Pedestrian standing next to car

- Red traffic signal (Muttart, Messerschmidt, Gillen, 2005)

Yikes….

Closing Speed is not at issue at intersections



Exception
To
Additivity

Muttart, Messerschmidt & Gillen, 2005

Context: Closing speed analysis is not applicable

(Muttart, Messerschmidt, Gillen, 2005)

Adjacent vehicles
(same PRT – fewer fail to respond)

Samuel J. Levulis,
Patricia R. DeLucia
Daniel Oberfeld

Effects of Adjacent Vehicles on Judgments of a Lead Car During Car Following

Article · Jun 2016 · Human Factors The Journal of the Human Factors and Ergonomics Society

Crash Rate on a Bridge Incline

Crash History for this Site

- 42 reported crashes within 0.1 mile between 1/1/1999 and 12/31/2005.
- **<u>92%</u>** of 26 WB (in direction we are looking) crashes were rear end collisions.
- Only 18.8% of 16 EB (coming toward us in photo) crashes were rear end collisions
- Most occurred during nice weather and in daylight
- 70% of rear end crashes (18/26) involved a stopped LV
- 49 – 67% of crashes are rear enders on elevated expressways and tunnels (Deng, et al., 2011)

Deng, B., Chen, X., Wang, X. (2011). Shanghai 2020 Driving scenario models and traffic accident models development. General Motors, Shanghai.

OTHERWISE: Closing speed is not applicable at intersections or when following close behind

Author(s)		RT
Chisholm S. L., Caird, J. K., Lockhart, J. A., Teteris, L. E., & Smiley, A. (2006); Sivak & Olson, 1981; Chang, Lin, Fung, Hwang, & Doong, 2008; Fitch el al., 2009 (100-car study)	LV Decelerates suddenly	1.01 – 1.48 sec
Muttart, 2003	Sudden Stop Intersections	0.98 sec (SD = 0.3)

PRT ~ 1.0

Olson & Sivak did not control for following distance
Almost ½ the drivers did not respond
Hence, they reported times up to 1.48 s
Everyone else is near 1 s.

Looming isn’t only cue

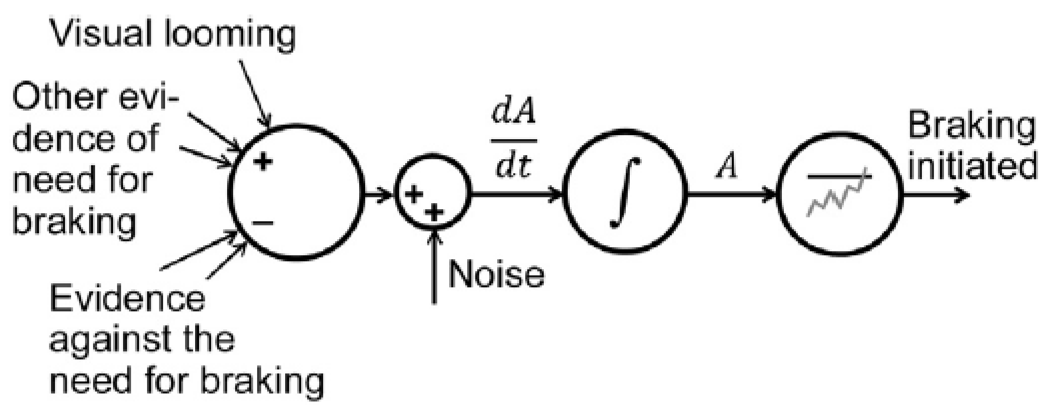


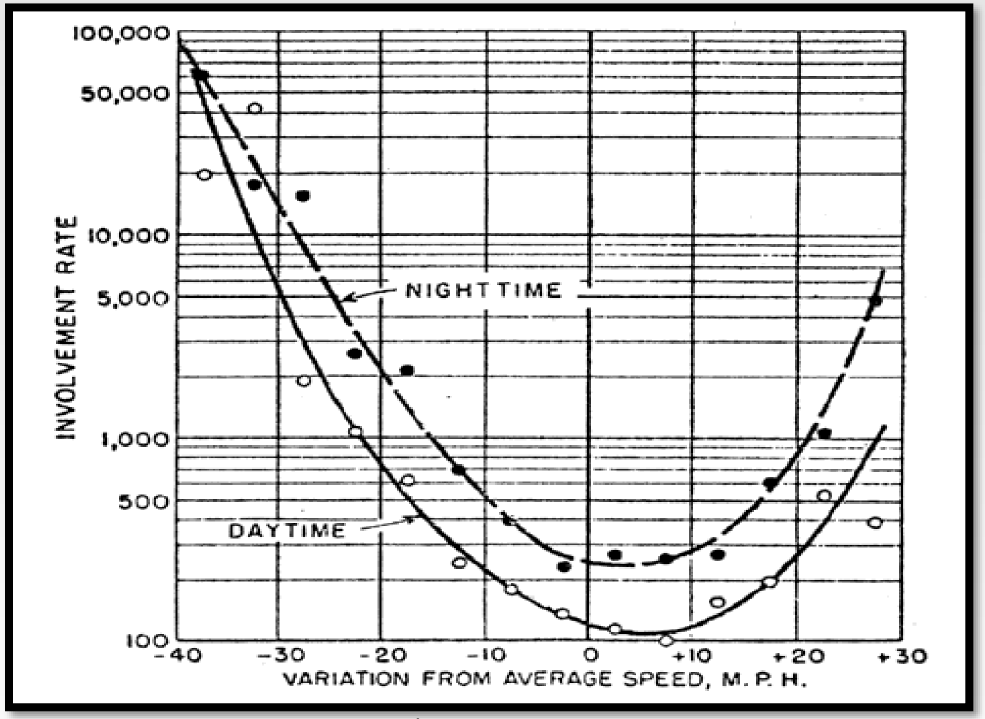
Fig. 12. An evidence accumulation account of brake timing. The rate of change of a quantity A depends on various sources of evidence for or against the need of braking, and braking is initiated once A exceeds a threshold. (Adapted from Markkula, 2014).

- Distance (closer is better)
- Closing speed (faster is better… to recognize)
- Width (larger is better)
  - Exception: Height – objects higher look farther away
- Exceptions:
  - Background information such as curves, intersections, standing pedestrians, and standing traffic.

Not Only Speed – Difference in Speed

- Decrease in speed variance leads to a lower crash rate.
- The largest crash rate is for vehicles traveling furthest from the average speed (higher or lower).

- Brehmer, B. (1990).
- Soloman (1964)
- Taylor et al (2008)



Brehmer, B. (1990). Variable Errors Set a Limit to Adaptation, Ergonomics, 33(10/11), 1231-1239.

Soloman, D. (1964). Crashes on main rural highways related to speed, driver and vehicle. In: Bureau of Public Roads, U.S. Department of Commerce. United States Government Printing Office, Washington, DC.

Taylor, M. C., Lyman, D. A., Baruya, A. (2000). The effects of drivers' speed on the frequency of road accidents. TRL Report No. 421. Transport Research laboratory TRL, Crowthorne, Berkshire.

III. Closing versus Separating

All vehicles are doing one or the other… What causes a response?

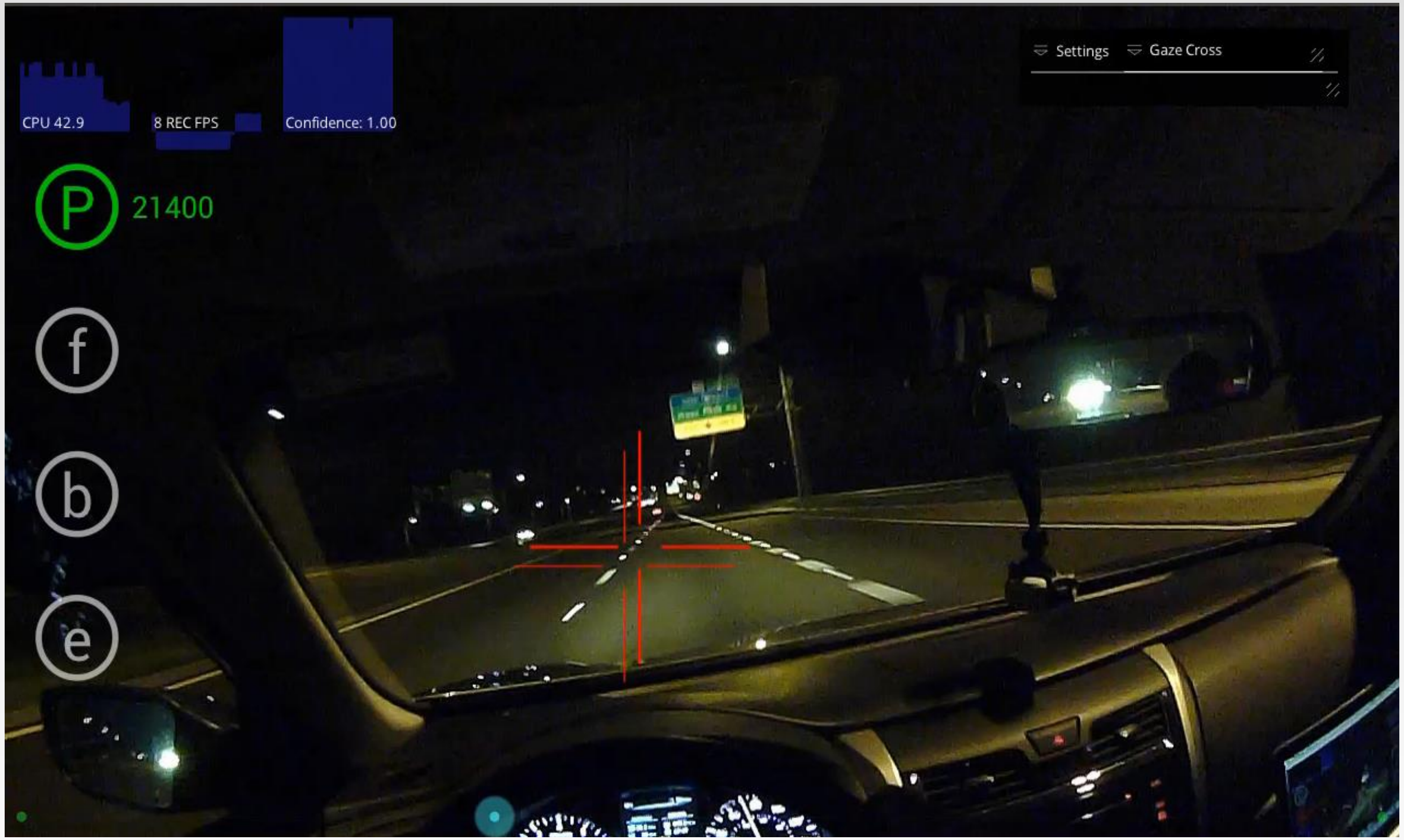
Lane Change- Left - Longer glance time when traffic is present

2 glances (including shoulder check) in 12 seconds (w/ 1 car) - Moves left ~ 240 feet – 75mph

Consistent with:
Finnegan, P., & Green P. (1990). The time to change lanes: A literature review. University of Michigan, *Transportation Research Institute* (IVHS Technical Report-90-13).

Lane Change- Left - Some drivers might make a longer single glance with no traffic

1 longer glance in 3.5 seconds (no traffic) -



Consistent with:

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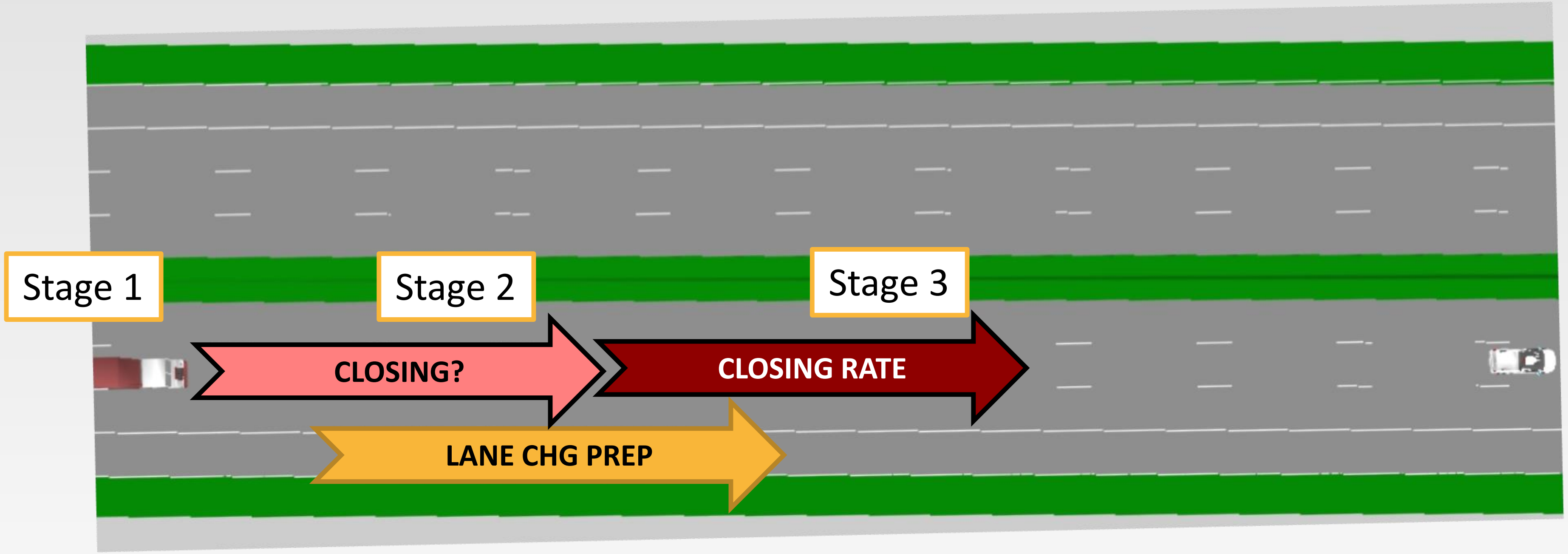
Progression of Events with Markkula's 3 stages



Analysis of a Response to a Lead Vehicle

Michaels, 1963; Hoffman & Mortimer, 1996; Muttart, Messerschmidt, & Gillen, 2005; Markkula et al., 2016

Cues to know LV is stopped or slow? [LV stopped on a curve or at signal]

Yes – Start PRT when LV becomes discernable immediate hazard

(You may use Chart for PRT)

No – Calculate the visual expansion rate of LV [when is LV an immediate hazard?] (able to recognize that they are closing dangerously fast)

$$d = \sqrt{\frac{w(V_A - V_L)}{\theta \quad rad/sec}}$$

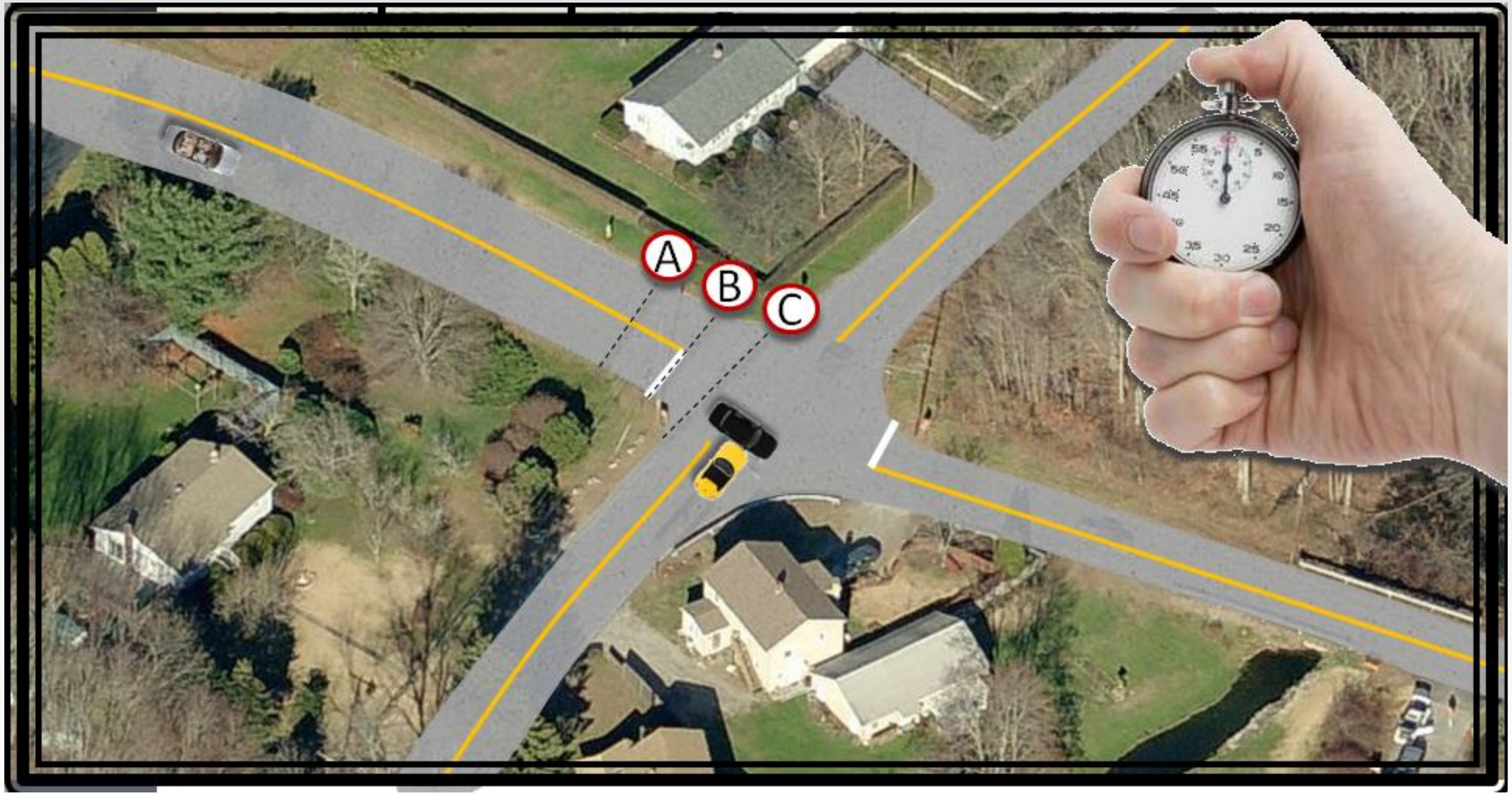
Where w is the discernable width of the lead vehicle, VF is the velocity of the approaching vehicle and VL is the velocity of the lead vehicle and 0.006 radians per second is the threshold at which drivers will likely be able to appreciate that they are closing dangerously fast.

θ = Threshold for detecting closing or Closing Rate (Larger number)

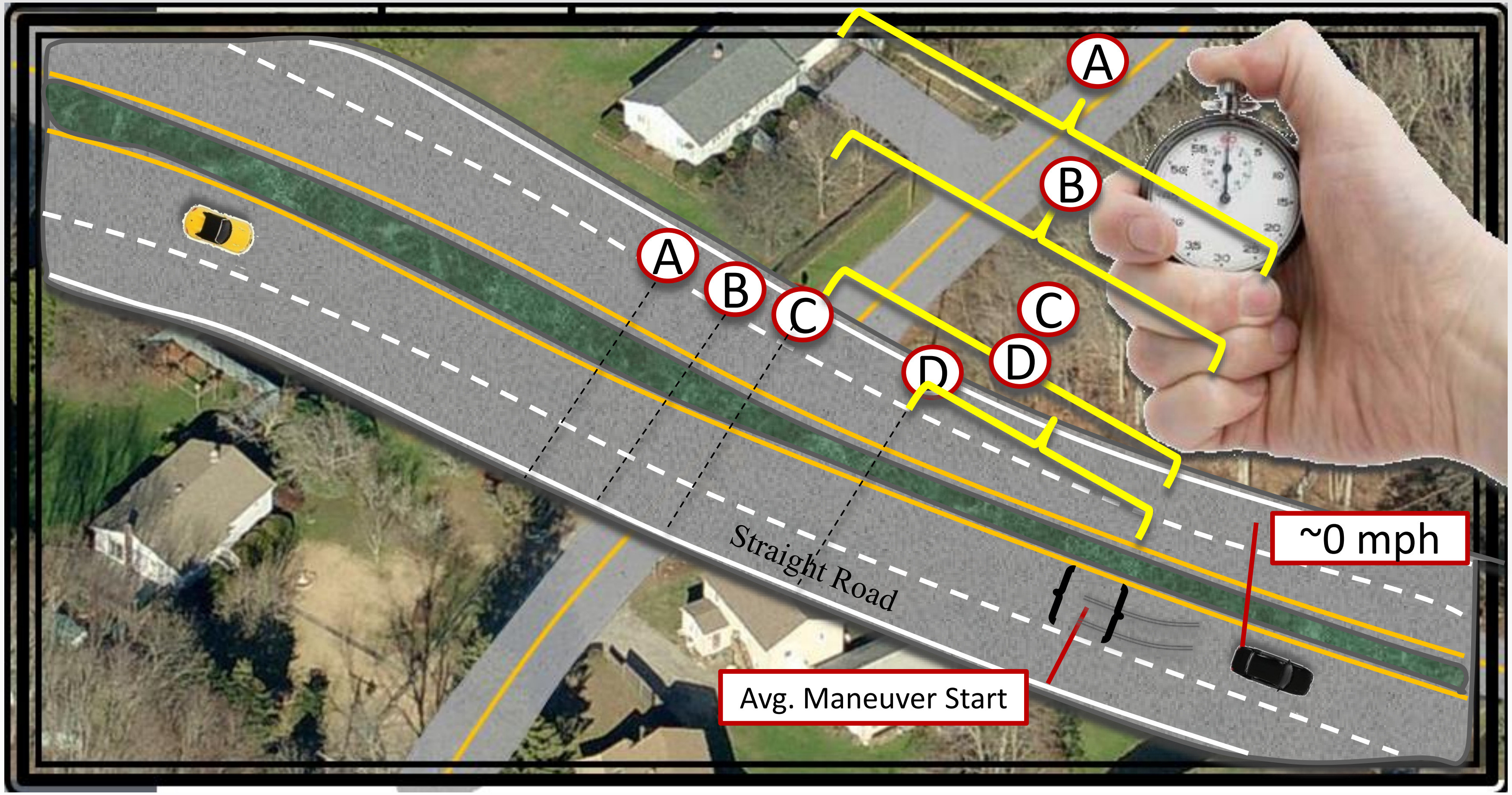
WHERE TO START AN ANALYSIS OF A DRIVER'S PERCEPTION RESPONSE TIME: RESPONSE TO LEAD VEHICLES

1. Go back in time
2. Start stopwatch as red car crosses "A" – stop clock as yellow car starts to skid
3. Start stopwatch as red car crosses "B" – stop clock as yellow car starts to skid
4. Start stopwatch as red car crosses "C" – stop clock as yellow car starts to skid

Will all "Perception-response times" be the same?

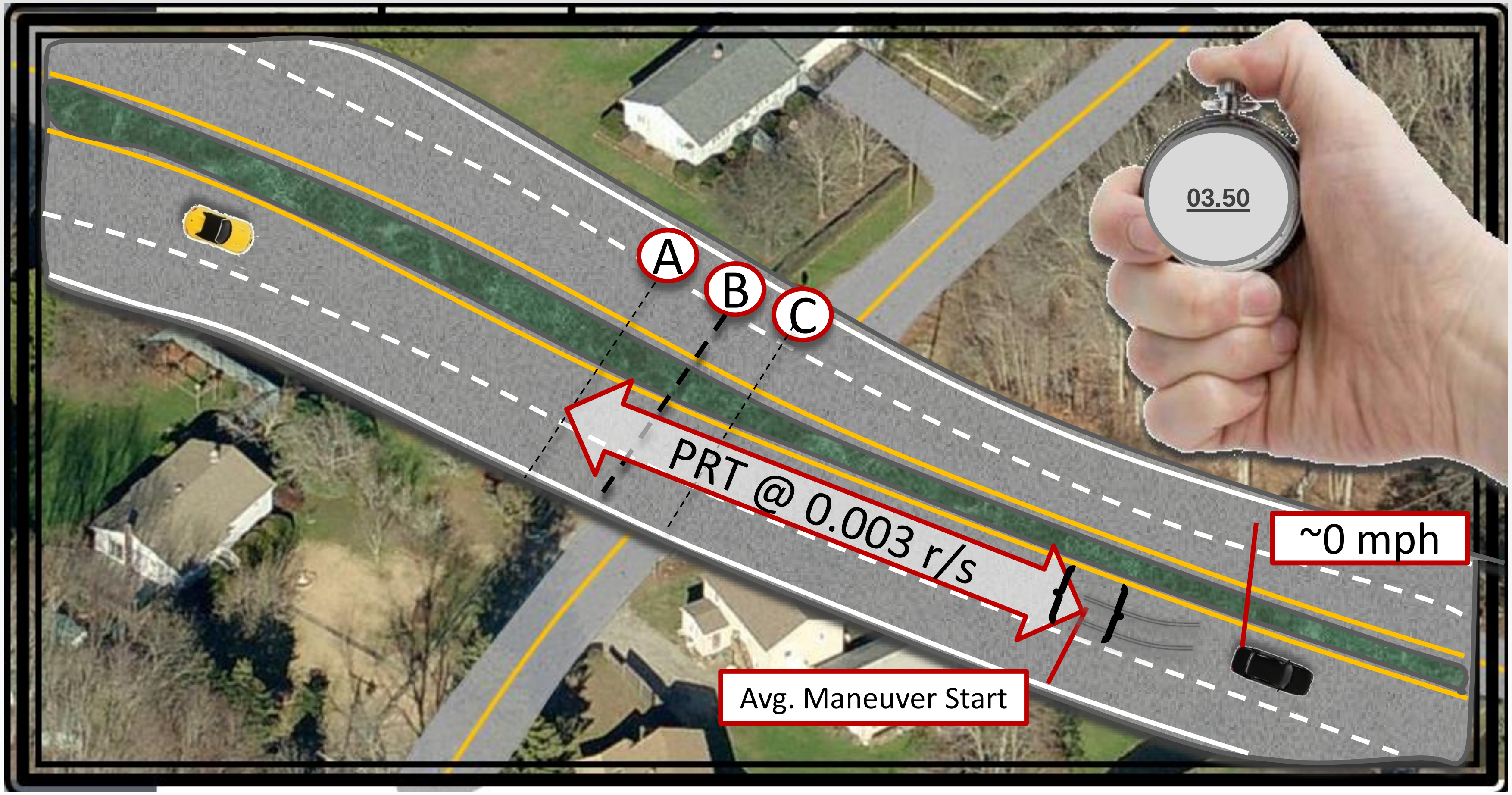


Similarly, will all PRTs be the same?
If… A = 0.003 radians / sec;
B = 0.006 radians / sec;
C = 0.01 radians / sec;
D = 0.02 radians/sec
… can you apply the same PRT to all locations?

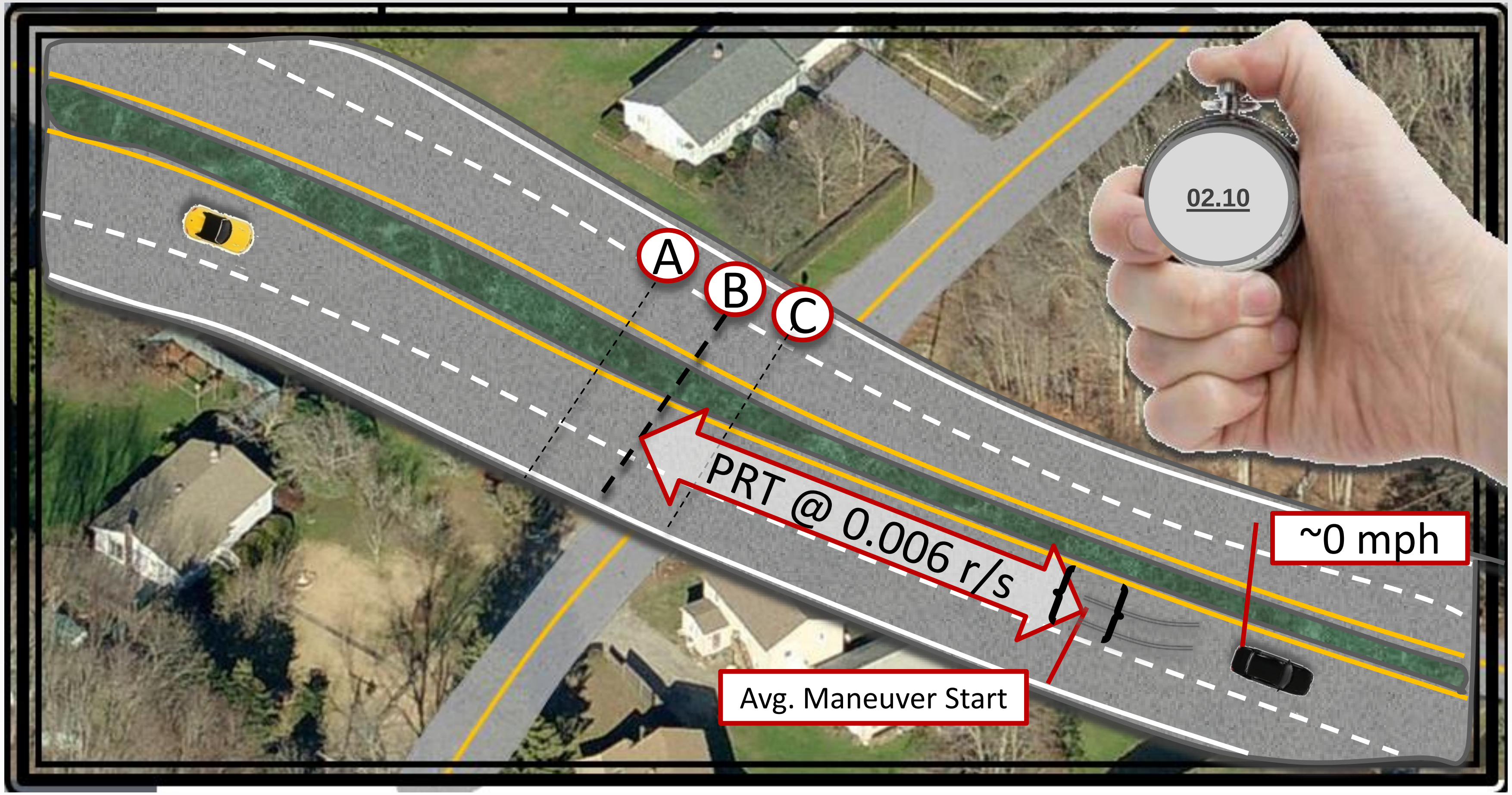


Measuring subtended angle "Looming"

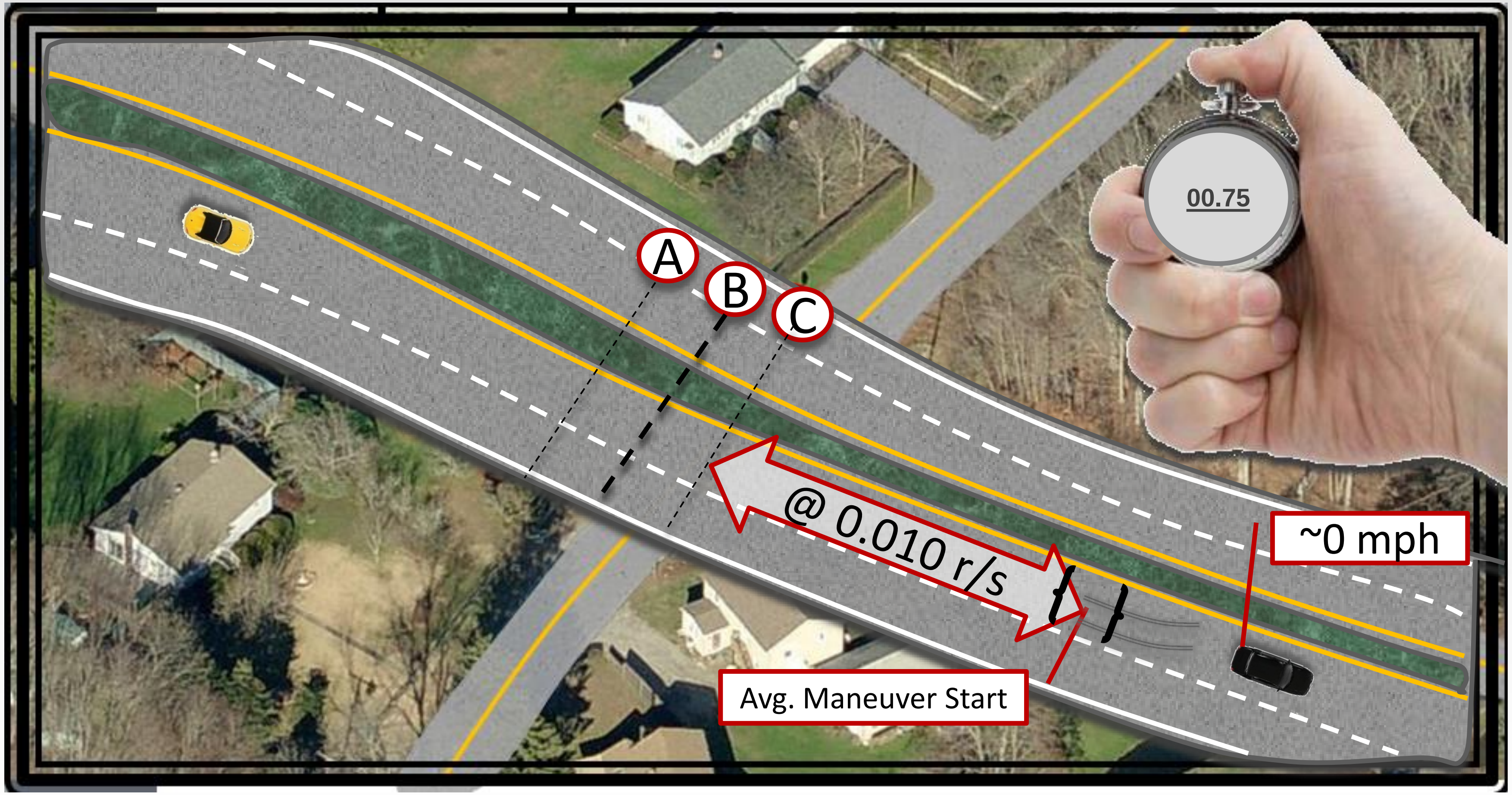
If you believe Hoffman & Mortimer's 0.003 radian/second threshold is best, the Perception-Response Time that best fits would be 3.5 – 4.5 seconds. (A)



If you believe Muttart, Messerschmidt & Gillen's or Fisher, Knodler & Muttart's 0.006 radian/second threshold is best, the Perception-Response Time that best fits would be 2.1 – 2.5 seconds. (B)



If you believe Maddox et al's 0.01 radian/second threshold is best, the Perception-Response Time that best fits would be a much faster response (C)



Markkula et al., Accident Analysis and Prevention, 95 (2016) 209-226. (SHRP-2)

MADDOX & KIEFER (2012)
- REANALYZED BY MUTTART (2013)

Method: Using the EDR results from M & K (2012) and their crash data (that they shared), steering distances were calculated using IDRR (STEER). Next the maximum maneuver distance (steer or brake) was compared to the results calculated by IDRR (LV).

Assumptions:

- 0.006 radians/second detection threshold and PRT adjusted (by program) to that threshold,
- At nighttime, M&K used width, not recognizable width which is typically 1.5 feet less than the overall width
- Drivers were looking ahead (0 degree eccentricity)
- Road experiment
- Response to one object (the LV)
- Driver, not passenger

							I.DRR STEER			I.DRR LV MANEUVER			
FV Speed (fps)	LV Speed (fps)	Closing Speed (fps)	Discern Width (ft.)	FLASH / BRAKE LTS	DAY/ NITE	Lateral Motion (ft.)	Avg Gs	Steer Time (s.)	Max Steer/ Brake (ft.)	AVERAGE (ft.)	85th %	DISCRIPT	PCT'ILE
80.7	0.0	80.7	5.83	YES	DAY	6	0.16	1.53	100	106	46	NORMAL	46%
66.0	4.4	61.6	8.5	NO	DAY	5	0.17	1.35	65	140	80	Below AVG.	11%
95.4	0.0	95.4	8.5	YES	DAY	0			59	151	75	Below AVG.	11%
80.7	36.7	44.0	6.0	NO	DAY	10	0.13	2.15	49	223	168	Below AVG.	0%
80.7	0.0	80.7	4.16	NO	DARK	0			90	61	0	NORMAL	68%
80.7	3.7	77.0	6.5	NO	DARK	4.15	0.18	1.19	82	110	43	NORMAL	34%
92.4	4.4	88.0	4.66	NO	DARK	6	0.16	1.53	111	79	11	NORMAL	68%
66.0	0.0	66.0	6.5	YES	DUSK	0			39	99	41	Below AVG.	15%
107.1	14.7	92.4	8.0	YES	DAY	5	0.17	1.35	107	158	85	NORMAL	24%
95.4	0.0	95.4	8.0	YES	DARK	9	0.14	2.00	151	139	63	NORMAL	56%
66.0	0.0	66.0	8.5	NO	DAY	6	0.16	1.53	78	126	64	NORMAL	22%
95.4	0.0	95.4	6.5	YES	DAY	9	0.14	2.00	151	121	51	NORMAL	66%
73.4	0.0	73.4	6.5	YES	DARK	8	0.14	1.85	143	116	45	NORMAL	65%
80.7	3.7	77.0	6.5	YES	DARK	8	0.14	1.85	88	143	78	NORMAL	20%

- Overall, most likely due to having drivers who crashed only (none who avoided), these data represent an average of a 38th percentile response.
- Yet, 71.4% of these real life drivers fall within the normal range offered by I.DRR (the most normal 2/3rds of drivers).

Maddox, M, Kiefer, A. (2012), Looming threshold limits and their use in forensic practice, Proceedings of the Human factors and Ergonomics Society 56th Annual Meeting. Boston, MA. 700-704.

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Long Headway Situations

LV	LV Speed	FV	10	9	8	7	6	5	4	3	2	1		Throttle off	Clutch on	Brake on		DIST	DRIVE3	D	Rd	Tp	S	C	E
passenger h=90'		truck tractor		41.5	22.0	22.0	20.0	21.0	18.0	11.0	6.0	2.0	1.0	9			5	79	90	1	1	1	1	1	0
SUV	10.0	truck tractor	18.0	18.5	19.0	19.5	20.5	21.5	22.5	23.0	23.5	13.5	3.5	2	4..1	0	2	40	158	1	3	1	1	1	0
passenger	0.0	passenger						35.0	14.0	7.0	9.0	7.0		5				70	111	2	3	1	1	1	0
Passenger	0.0	truck tractor	35.0	35.0	35.0	33.5	33.5	31.5	29.0	26.5	20.5	12.5	4.5	8	0.0	8	4	112	97	1	1	1	1	1	0
cable trailer	0.0	Passsenger						42.0	40.0	32.0	22.0	10.0		5		4	5	138	137	1	3	1	1	1	0
Passenger	0.0	Passsenger						48.3				48.3					1	106	114	2	2	1	1	1	0
	20.0	truck tractor						50.0	48.5	46.5	43.5	38.5				5	5	255	226	1	1	1	1	1	0
Tanker	0.0	Pickup						51.0	51.0	51.0	51.0	49.0		1		1	2	145	155	1	1	1	1	1	0
SUV	15.0	truck tractor	58.0	58.0	57.0	56.0	55.0	53.0	53.0	52.0	52.0	51.0	43.0	9		9	2	144	173	1	wz	1	1	1	0
Passenger	10.0	Passsenger						56.0	55.0	60.0	56.0	42.0		5		2	2	133	156	2	1	1	1	1	0
passenger	-28.0	truck tractor	57.0	57.0	56.0	52.0	40.0	29.0	14.0	7.0	5.0	1.0	0.0	5	4	9	9	229	195	2	3	1	1	1	0
Farm Tractor	11.0	truck tractor						57.5	58.0	58.5	59.0	59.5		1		0	1	87	173	1	1	2	1	1	0
	0.0	truck tractor						59.0	59.0	59.0	59.0	59.0		0.4		0.4	1	87	128	2	3	1	1	1	27
passenger	0.0	truck tractor	59.0	59.0	59.0	59.0	59.0	59.0	59.0	59.0	59.0	59.0	57.0			4	1	85	109	2	1	1	1	1	0
			61.0	61.0	62.0	62.0	62.0	62.0	62.0	62.0	62.0	62.0	61.0					90	160	2					
truck tractor	47.4	bus no clutch	68.5	68.5	68.0	68.0	67.5	61.5	38.0	34.5	27.5	17.5	7.5	6		**x144**	**6**	264	274	2	3	1	1	1	0
Passenger	10.0	Passsenger cell?						62.0	62.0	39.0	37.0	37.0		3			4	238	212	2	1	1	1	1	0
Towncar	0.0	truck tractor	65.0	65.0	65.0	65.0	65.0	65.0	65.0	64.5	54.0	43.5	9.5	4	1	3	4	292	119	2	1	1	1	1	0
passenger	17.1	truck tractor	76.0	76.0	76.0	73.5	67.5	66.0	**62.5**	58.0	56.5	52.0	43.0	6	1	7..1	1	149	170	1	1	1	1	1	0
	0.0							113.0	**114.0**	114.0	114.0	114.0		1		1		167	163	2	3	1	1	1	0
			55.3	54.0	51.9	51.1	49.0	47.7	43.9	40.8	38.6	34.4	23.1	4.3	1.6	3.6	3.2	142.3	156.0	1.5	1.9	1.1	1.0	1.0	1.4

Long Headways

17 of 21 within 41'

Short Headway Situations

14 of 15 have been 0.98 $\pm$ 0.4

(assumed impact occurred at 0.5 sec – C. Wilkinson, 2006)

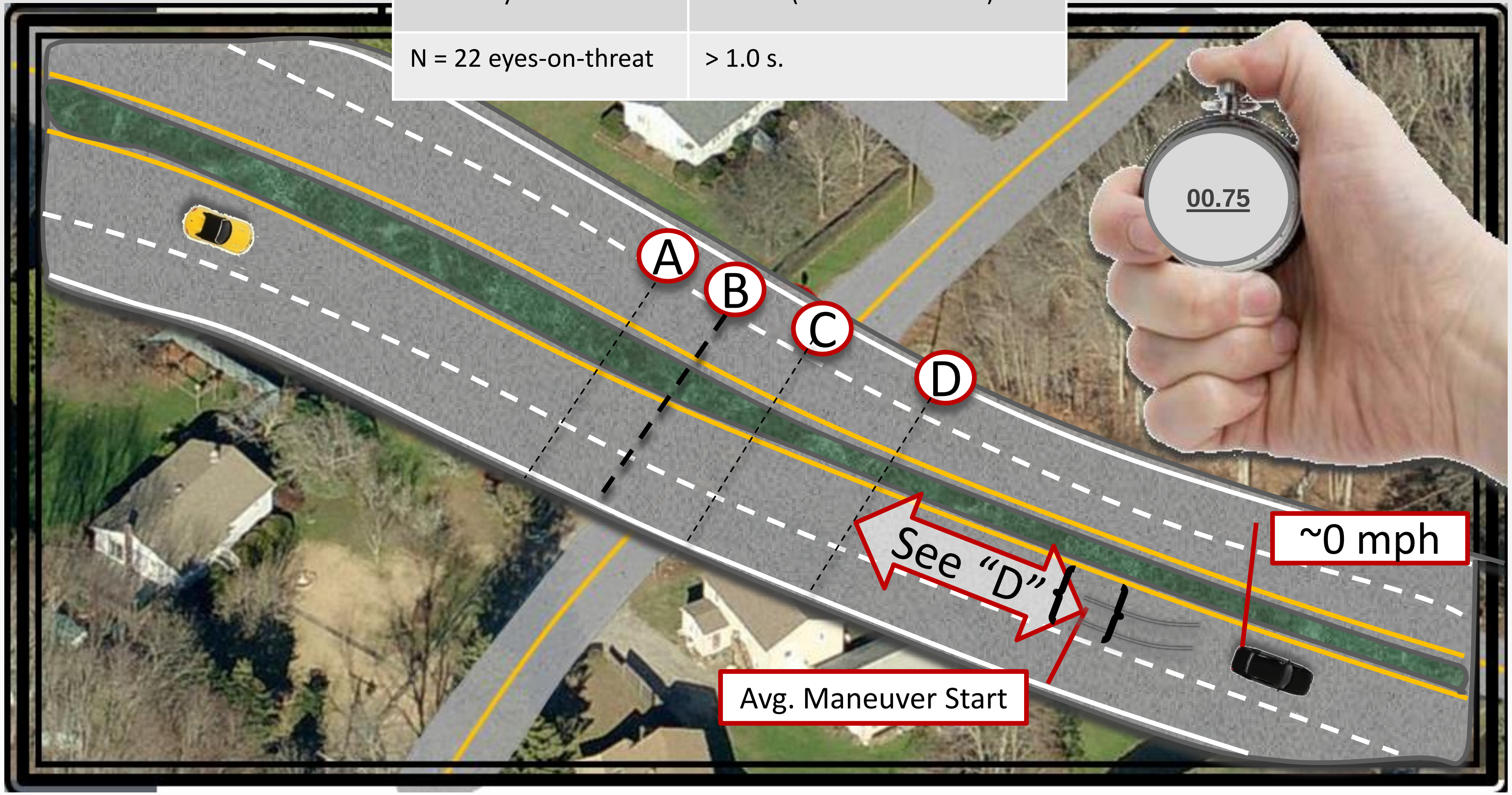
Including Maddox & Kiefer: 27 of 35 (77%) within range offered by IDRR

Overall LV 41 of 50 (82%) fall within range estimated by IDRR

If you believe Markkula's Brake threshold 0.02 radian/second (D) threshold is best,

Table D	Response Time relative to $1/\tau \geq 0.2\ s^{-1}$ (~0.02 r/s)
N = 141 eyes-off-threat	0.42 s.
N = 80 eyes-on-threat	< 1.0 s.
N = 20 eyes-on-threat	< 0.0 s. (before threshold)
N = 22 eyes-on-threat	> 1.0 s.

-Trucks and cars were similar responses
-LV brake lights on93%



Brake onset most often occurred within a second after the driver first saw visual looming above the approximate threshold of 0.2 s−1for −1(0.02 rad/s for θ. Markkula et al 2016 p. 221 Accident Analysis and Prevention, 95 (2016) 209-226. (SHRP-2)

Compare Muttart et al to Markkula et al

When does PRT end and Maneuver start?
Both methods yield distances within 8 feet (2.4 m)

Closing Speed			Recog. Thres. 0.006 r/s			Minus PRT			Recog. Thres. 0.02 r/s				
MPH	KPH		Feet	Meters	PRT	Feet	Meters		Feet	Meters	PRT	Feet	Meters
55	88.5		284	87	2.1	114.6	34.9		156	47	0.46	118.5	36.1
60	96.5		297	90	2.0	120.6	36.8		162	50	0.46	122.0	37.2
65	104.6		309	94	2.0	118.1	36.0		169	52	0.46	125.3	38.2
70	112.6		320	98	1.9	125.3	38.2		176	53	0.46	128.3	39.1
75	120.7		332	101	1.9	122.7	37.4		182	55	0.46	131.1	40.0

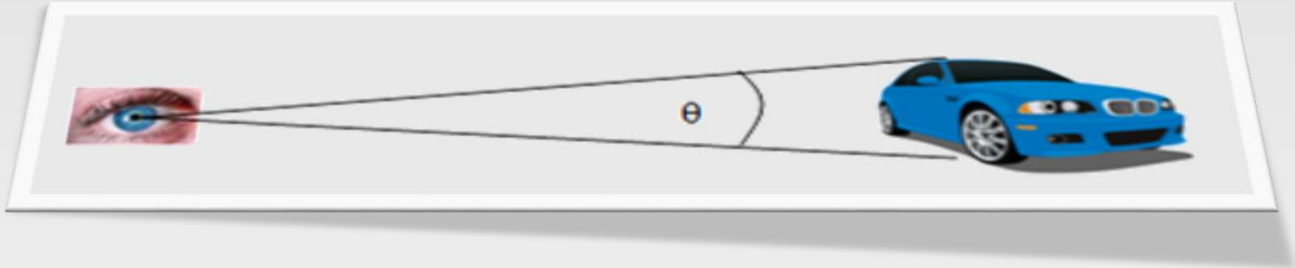
Assumption that LV was stopped and 6 feet (1.8 m) wide

Summary

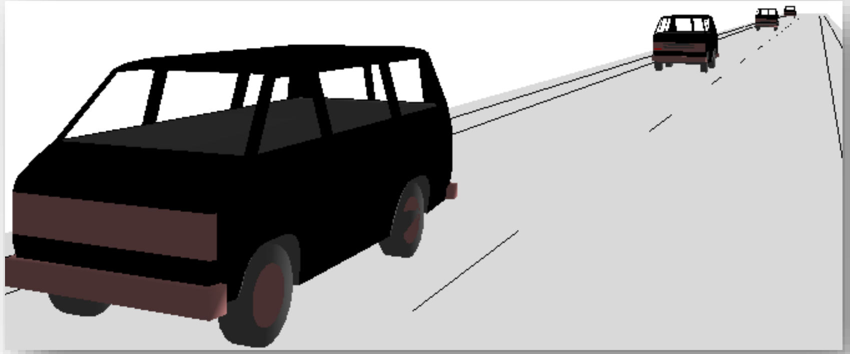
- We do not know when or where a driver perceived.
- Our goal:
  - Compare this driver's response (based upon the physical evidence)
  - With the response of others (Based from research).
- To do that –
  - Compare pre-impact maneuvers…
  - How long before impact did the maneuver start?
- Closing speed threshold is only a starting point (a landmark) from which we can apply how drivers have responded in research (both simulator & naturalistic).
- Ultimate goal is to compare maneuver distance of the crash driver with the maneuver distance of reasonable drivers.

Variables that Influence RT

- **Subtended angle**
  - The angle formed by the size of an object at a given distance.



- **Subtended angular velocity** (Looming Rate)
  - The rate change of the subtended angle over time.



Van shown at 0, 100, 300, 600 feet

Visual Expansion Rate [VER] is the *CHANGE* in the angle

Figure 1.3.3 Above, an example of subtended angle and below, how subtended angle changes, which is subtended angular velocity (or visual expansion rate)

AUTHORS	Vis Expan r/s
Michaels & Cozan 1963	0.0006
Brown 1960	0.00003 - 0.0061
Braunstein & Laughery 1964	0.0014 – 0.0024
Summala, Lamble & Laakso (1998)	0.0020 – 0.0045
Mortimer 1990	0.0021
Lamble, Laakso & Summala (1999) Ahead	0.0022 – 0.0038
Mortimer 1994	0.0027
Mortimer 1988	0.0028 – 0.0035
Farber & Silver 1967 (head on)	0.0030
Duckstein, Unwin & Boyd 1970	0.003 - 0.004
Mortimer & Hoffman 1996	0.0022 – 0.0052
Bierly 1963	0.0035
Terry, Charlton & Perrone, 2008	0.004 – 0.005
Muttart, Fisher, Knodler, 2007	0.0045 – 0.007
Muttart, Messerschmidt, & Gillen, 2005	0.0063- 0.0068
Lamble, Laakso & Summala (1999) 45 Deg.	0.007 – 0.0095
Lamble, Laakso & Summala (1999) 90 Deg.	0.013 – 0.015
Plotkin, 1974	0.0275
Maddox & Kiefer, 2012	0.007 – 0.05
Markkula et al, 2016	0.02
Caro, et al., 2007 (fog)	0.050 (only used)

Distance from LV

Further

Closer

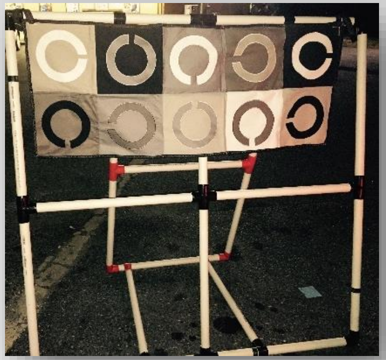
1 radian = 57.3 degrees

2Pi radians in a circle = 2 x 3.14 x 57.3 = 360 degrees

Ability to Recognize Closing Rate

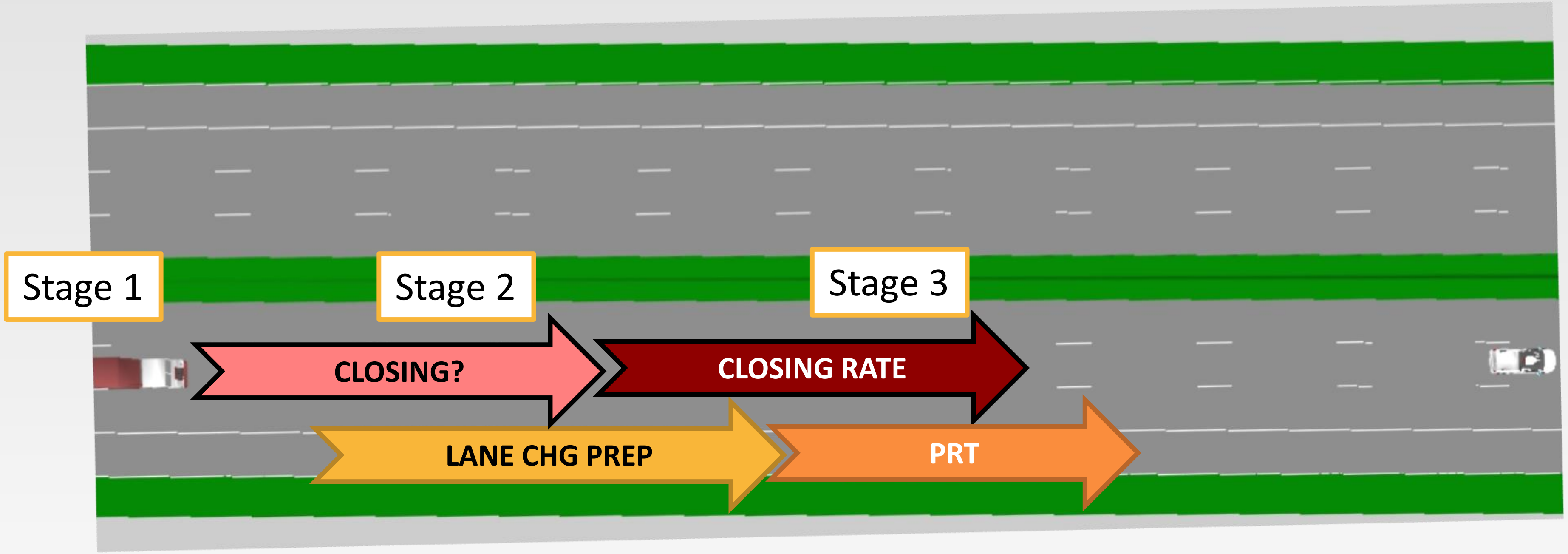
Authors	Methodology	Threshold
Summala, Lamble, Laasko, (1998)	Responded to LV at various eccentricities, two headways, brake lights on or off	Results - 0.0045 rad/sec
Muttart, Messerschmidt & Gillen (2005)	Part 1 – meta-analysis Part 2 – very low fidelity simulator	PRT remains high – levels off after 0.0063 rad/sec
Plotkin (1968-1974)	"Reconstructed" 5 crashes – applied "known" PRT = 0.75 sec	0.0275 radians/sec
Fisher, Knodler & Muttart, 2007	Part 1 – Fixed base -High fidelity simulator Part 2 – Field Part 3 – Simulator again	0.0045 to 0.006 rad/sec
Lamble, Laakso & Summala (1999)	45 degree eccentricity 90 degree eccentricity	0.007 – 0.0095 0.013 – 0.015
Caro, et al., 2007 (fog)	Simulator – in fog – threshold was up to braking (Do not add PRT)	0.050 (includes PRT)
Markkula et al, 2016	SHRP-2 Naturalistic data	0.02 radians/second (0.46 second "offset")

Break…

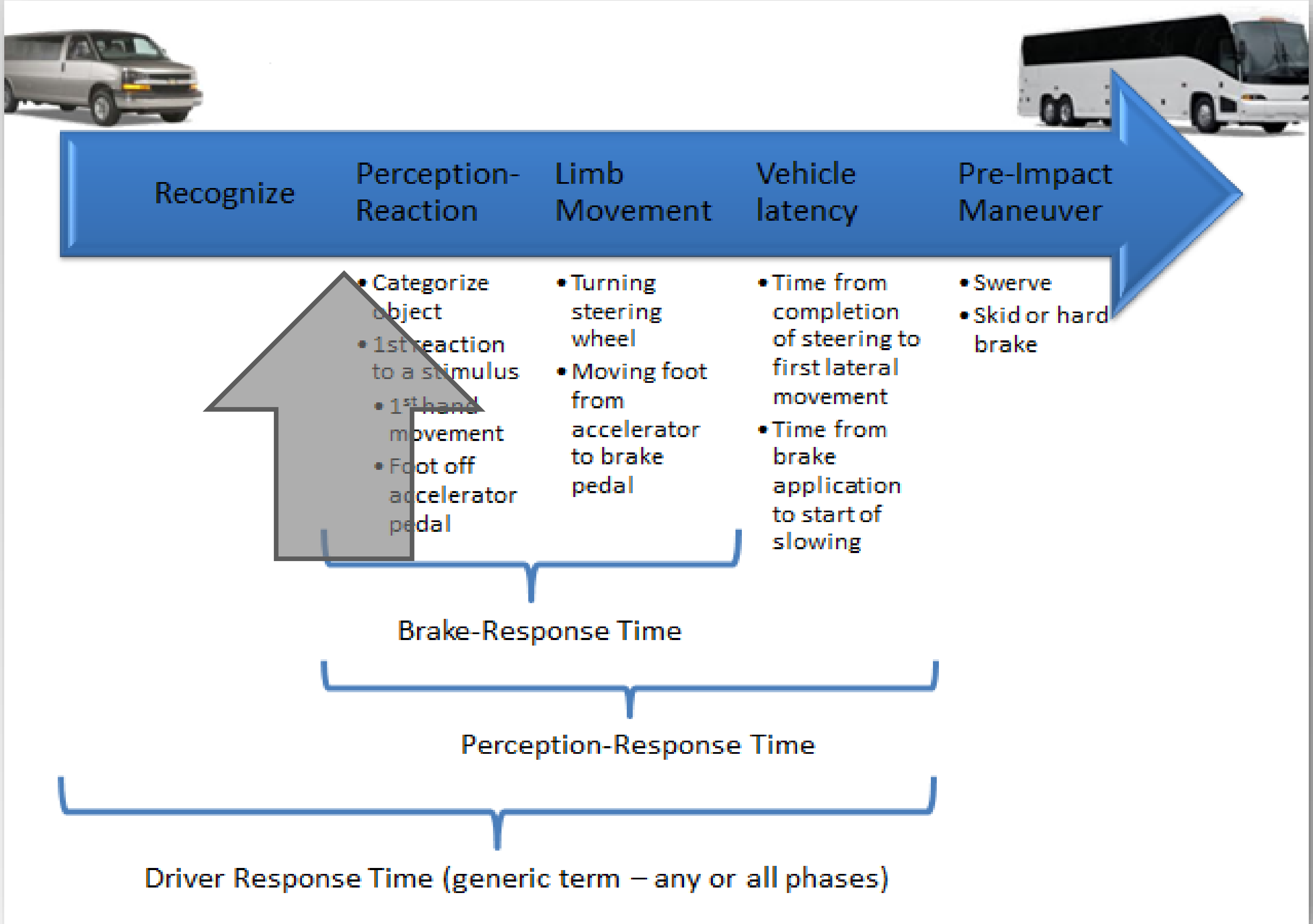


Contrast gradient

Progression of Events with Markkula's 3 stages



Starting Point for PRT



Perception-Response Time (PRT)

- Inherent in the term *perception*-response time is that a driver is PERCEIVING an immediate hazard that requires an emergency response

- **Perceive**
  - Something more than vision, perception is vision plus categorization, such as good or bad, hazardous or not, shoot or don't shoot; hazardous or non-hazardous.

Four Studies

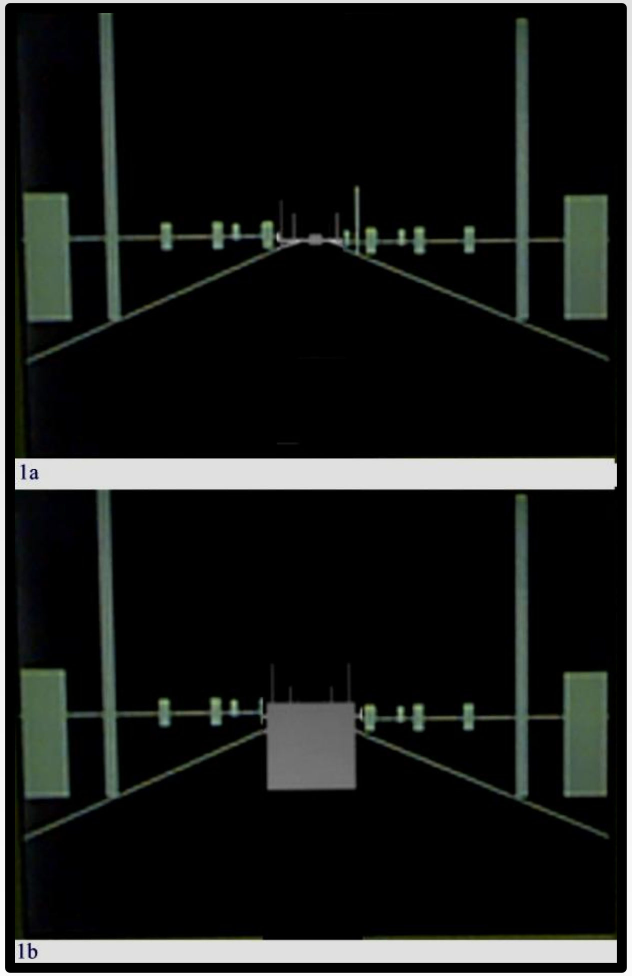
- Study 1 – Meta-analysis
  - Compared RT to Subtended angular velocity at start of RT.
  - Other variables – topography, pRT, BRT, or PRT?, eccentricity, day or night, flashing lights, brake lights.
- Study 2 – Low fidelity laptop simulation
- Study 3 – High fidelity simulator
- Study 4 – Field study

Two-Part Study (SAE 2005-01-0427)

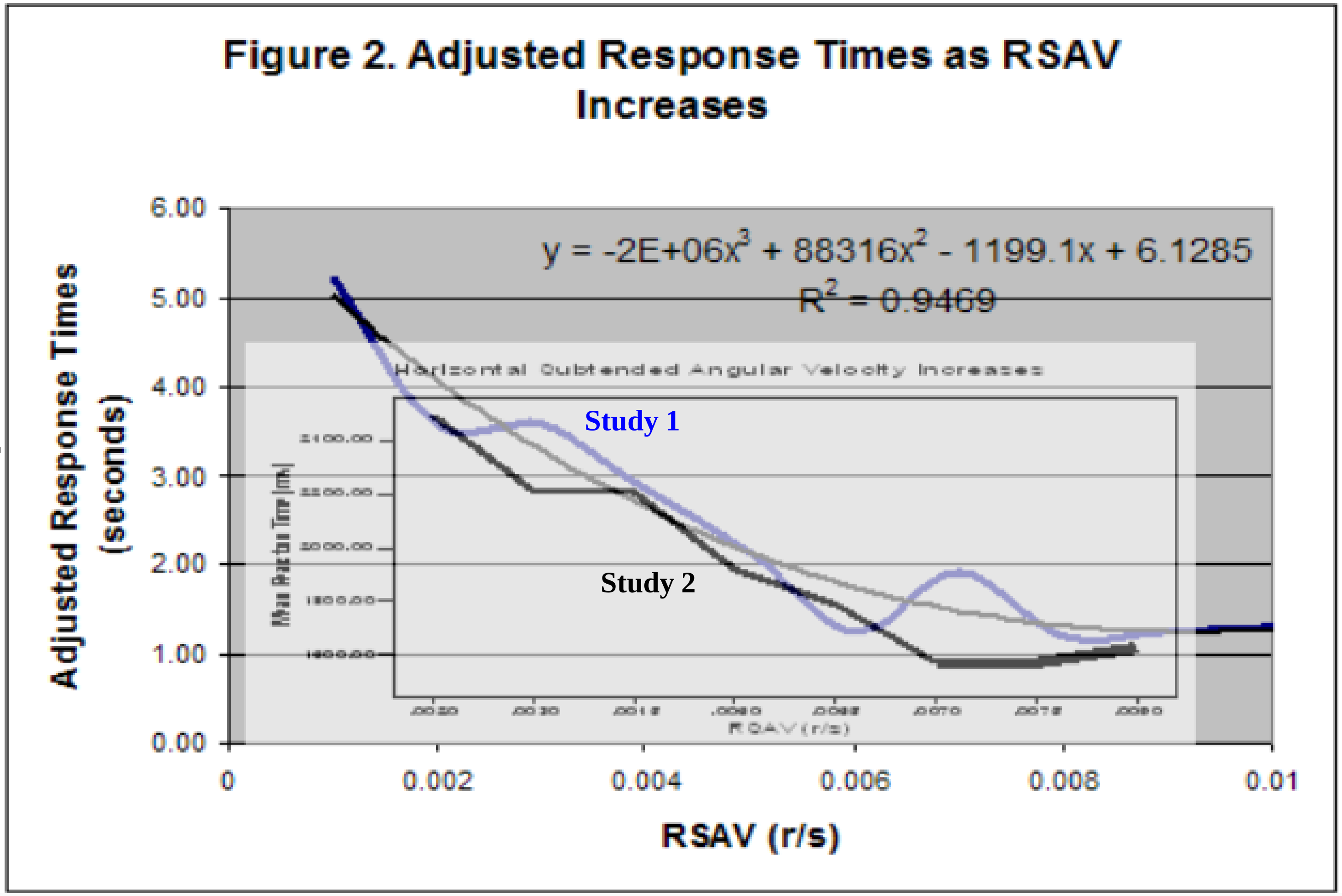
- 1st – Compared subtended angular velocity and reported response time in published research (Must compare like events).
- 2nd – A laptop simulator.
- Hypothesis:
    1. Response times remain high until…
    2. A lead vehicle is easily perceivable as an immediate hazard when…
    3. At which time the driver response times level off and remain constant.

Study II: Simulated Screen

- Screen 1a represents the size (subtended) of a ‘car’ at 0.002 radians per second,
- 1b shows a 2 m by 2 m ‘box’ at 0.01 radians per second.
- Also examined the influence of a object the size of a semi-trailer



Part I Meta-analysis
Part II Laptop Simulator



At 62 mph & 0.006 r/s = 301 ft. = $(6 \times 91 / 0.002)^{0.5}$

Need to determine when a driver start's a maneuver

Thus, a combination of threshold (i.e. – start line) and RT

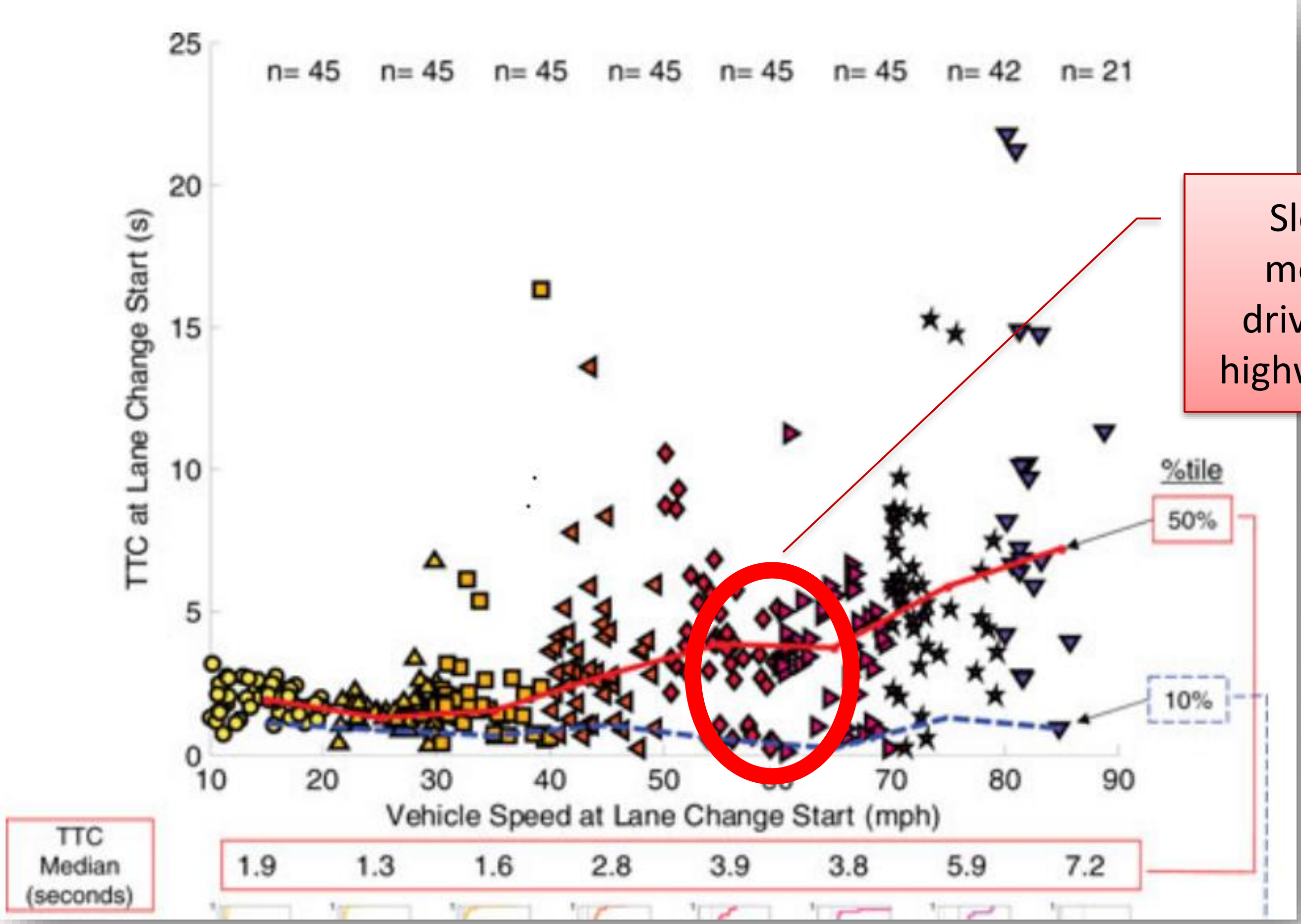
Table 4. Results of meta-analysis comparison of driver response times at various radians/second

Radians per second	Reported BRT	Adjusted PRT	Percent < 2 s.
< 0.0035	3.52 s	4.28 s	0%
0.0035 to 0.007	2.14 s	2.47 s	46%
> 0.007	1.16 s	1.29 s	94%

Markkula et al, 2016 (incl. braking ramp-up)

0.02 r/s 0.46 s ~0.75 ~99%

When > 70 mph drivers leave their lanes earlier – Problem at 55-70 mph

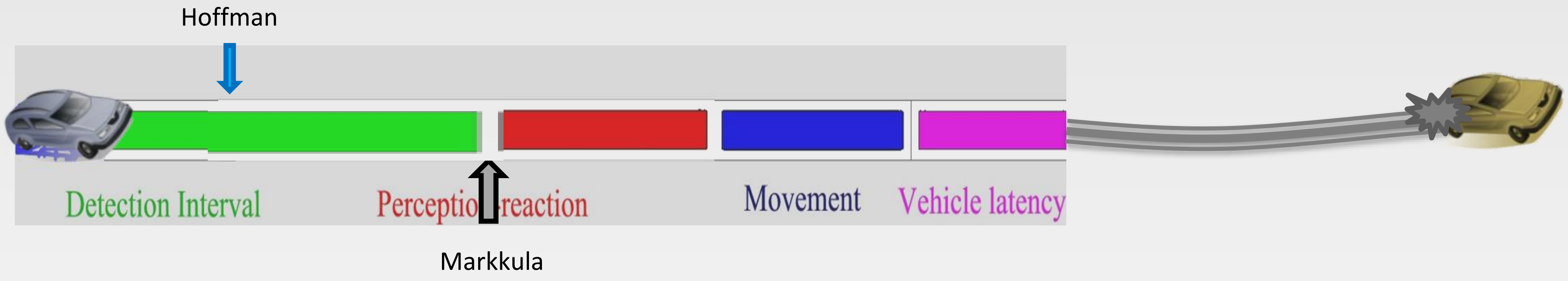


Slower moving drivers on highways???

CHEN, R., KUSANO, K.D. and GABLER, H.C., (2015). Driver Behavior During Overtaking Maneuvers from the 100-Car Naturalistic Driving Study, Traffic Injury Prevention,16, S176–S181

Visual Expansion Rate

- If Visual Expansion rate is small –
  - We are starting the stopwatch early
  - Approaching driver is further away
  - Approaching driver PRT will be longer

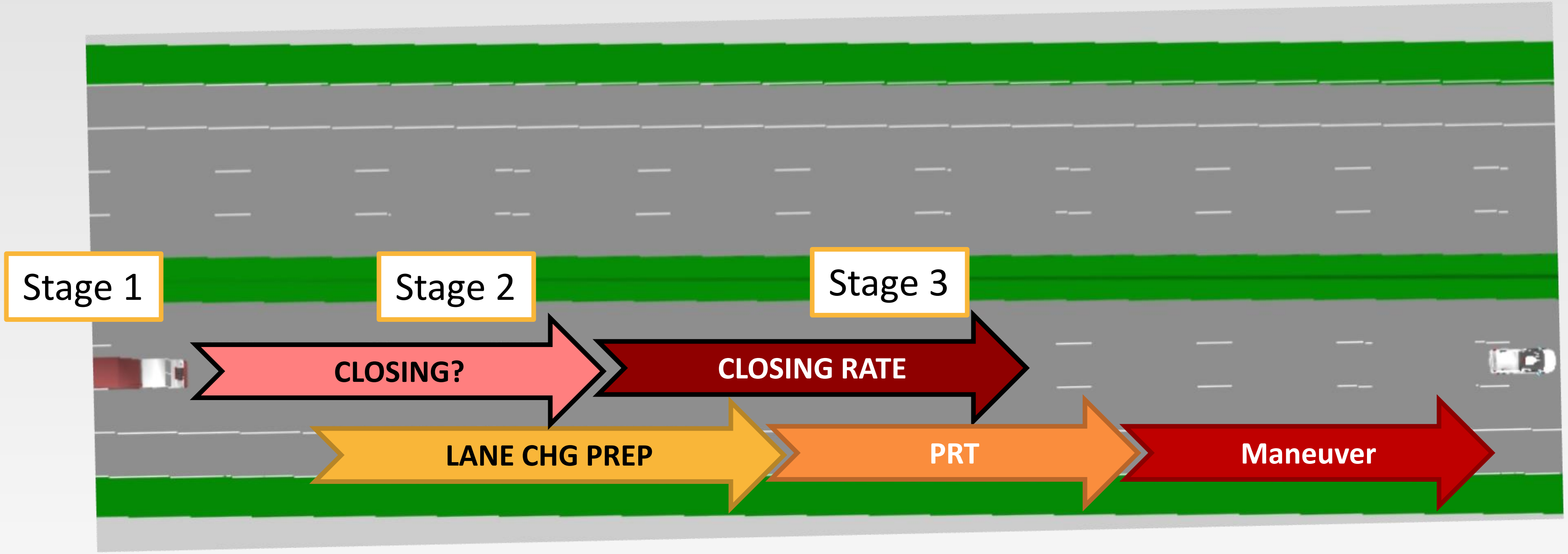


- If Visual Expansion rate is large–
  - We are starting the stopwatch late
  - Approaching driver is closer to impact
  - Approaching driver PRT will be shorter

- PRT must FIT with visual expansion rate

Figure 1.3.4 Theoretical progression of a drivers response and how detection of closing speed and PRT fit with one another.

Progression of Events with Markkula's 3 stages



Low Probability Event

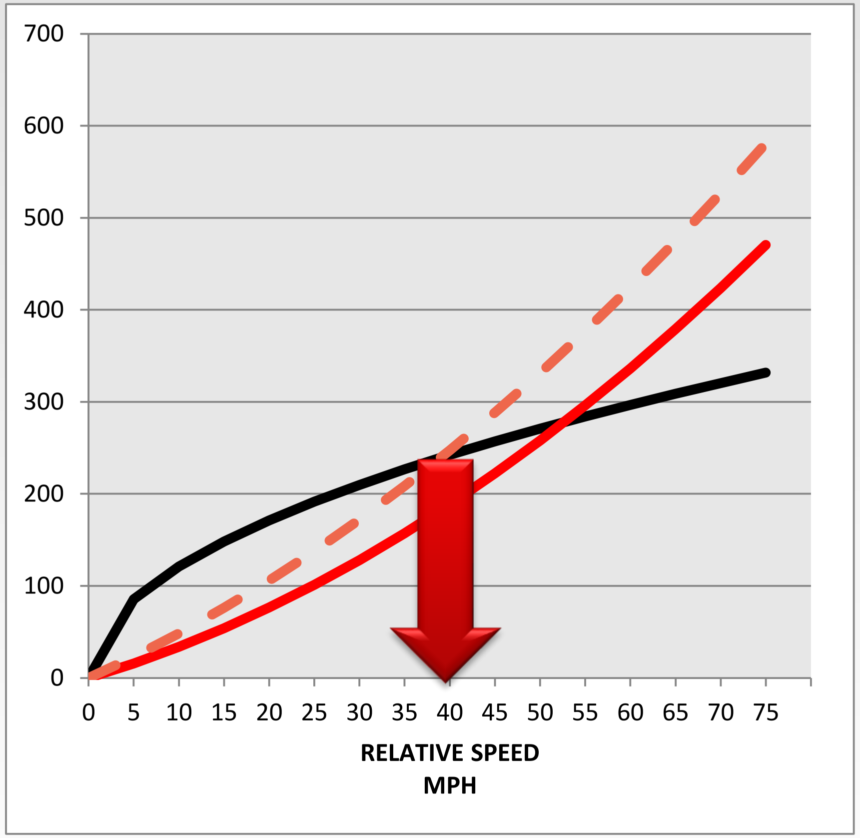
- Tijerina et al. (UMTRI)
  - 95% maintained a safety envelope of $\leq$ 20 feet per second (6.1 m/s) relative velocity in each direction.
  - Closure rates of greater than 44 feet per second (13.4 m/s) → low probability event.

Louis Tijerina

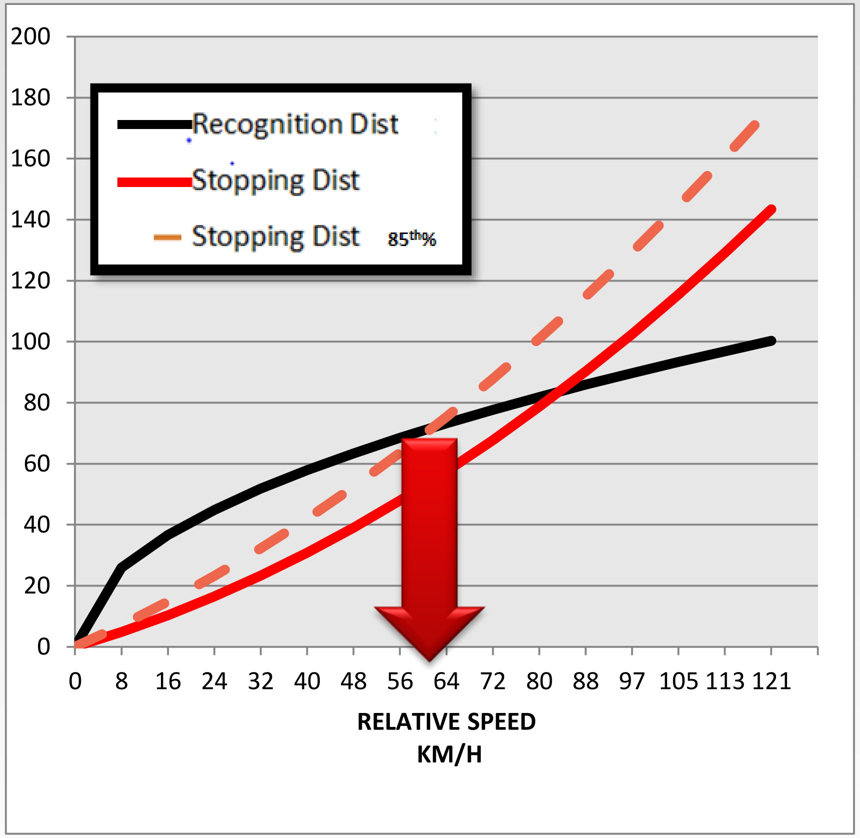
Tijerina L, Garrott WR, Stoltzfus D, Parmer E. Eye glance behavior of van and passenger car drivers during lane change decision phase. *Transp Res Rec. 2005;1937:37-43.*

Problem: When Closing Speed Recognition Distance is Less Than Stopping Distance

Imperial



Metric



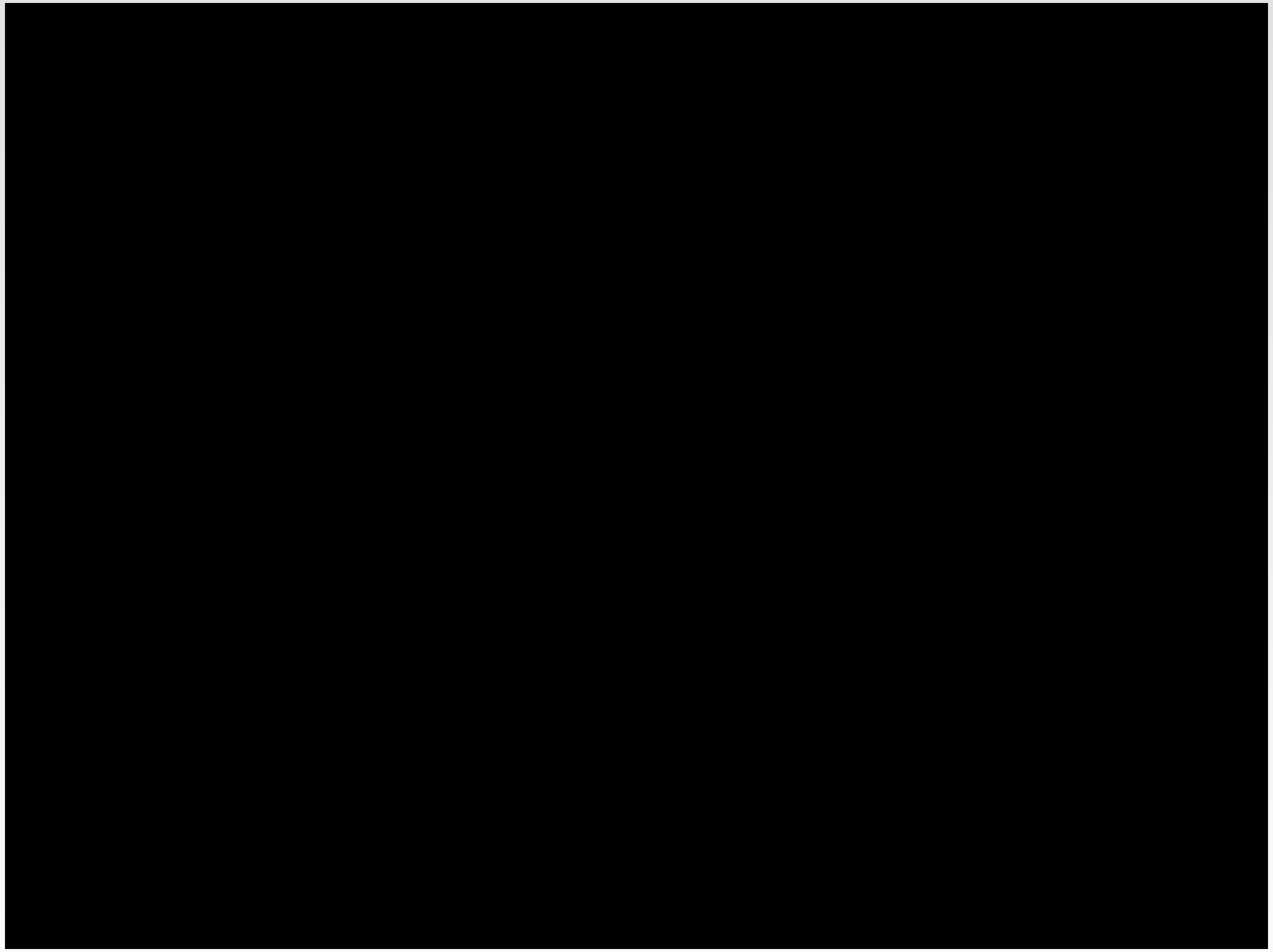
Closing at High Speeds is Rare

- Lee, Olsen, & Weirwille, 2002
- Probability
- **Average closing speed** **5.9 ft./sec** SD = 12.55 ft./sec
- 95^{th} percentile = 5.9 + 1.645 x 12.55 = 26.5 ft./sec

- Closing at 60 mph would be 1 in 33 billion
- 3 of 434 were closing at speeds between 40 and 50.5 mph (none closing at faster speeds)
- Median lane change start 96 ft. (Mean = 124 ft.)

- Francher, 1999
- Average closing speed is 4.1 ft./sec (SD = 10.0)
- Range 153.3 ft. (SD = 103.6 ft.)

Closing? Speed of LV?



CSRC CRASH SAFETY RESEARCH CENTER

J Muttart © CSS, LLC

Response to Lead Vehicle

Fl	0.No lights or only running lights
Ex	4. Road/HI Fidelity Sim ***DEFAULT***
O	1. Response to one object
E	0 deg (ahead)
Tp	1. Straight Road (Can't discern veh move relative to backgrou
Tr	Full Response (250 ms veh dela
D	1. Driving
Lt	2. Night

Check if Hovering brake

Hv

Vis. Expan. Thres. 0.0060 radian/s

Closing Speed Detection Threshold

Check Box if mobile phone usage

Sight Distance (ft) 1000

Init. Speed Appr Veh (mph)	55
Eyes-2-F. Bump(ft)	8
LV Initial Speed (mph)	0
Speed of LV at Imp (mph)	0
Discernable Width (ft)	7

Steering Response

Lateral Dist. Nec. To Avoid? (ft)	3
Avg. Lateral Friction (gs)	0.55

EXPECTED PRE-IMPACT MANEUVER

Average Pre-Impact maneuver 108 feet **85th %ile 39 feet**

			85th %ile	
AVG PER-RESP TIME	**2.4 sec**		**3.2 sec**	Individuals
Equation	**2.1 sec**	Min Avg	Max Avg	
Studies Adjtd	**2.6 Sec**	**2.4 Sec**	**3.1 Sec**	Scenarios

Visual Expan Threshold (ft)	306.8	HEADWAY	3.80 sec	93.2%
Distance to Impact at Vis Exp Thres (ft)	298.8		3.70 sec	follow closer

393 x H + 509 x O + 26 x E – 703 x Tp + (Tr & constant) + Brake adj + Adj to VER

393 x 3.8 + 509 x 1 + 26 x 0 – 703 x 1 + 1335 + 0 + -527

AVG. Response Dist. = ~ 2.4 x 55 x 1.467 = 190 feet	eq.3
Distance to Steer = 0.366 x 55 x x SQRT(3 / 0.55)	eq.4
Tot. Steering Distance = 190 feet + 47 feet =	eq.5
Time to steer = d / V = 0.58 sec	eq.6

TOT. STEERING DIST.	**237 feet**
AVG. Response Dist.	190 feet
85th percentile response Dist.	259 feet
Distance to Steer.	47 feet

85th percentile response

85th %ile STEER. DIST. **306 feet**

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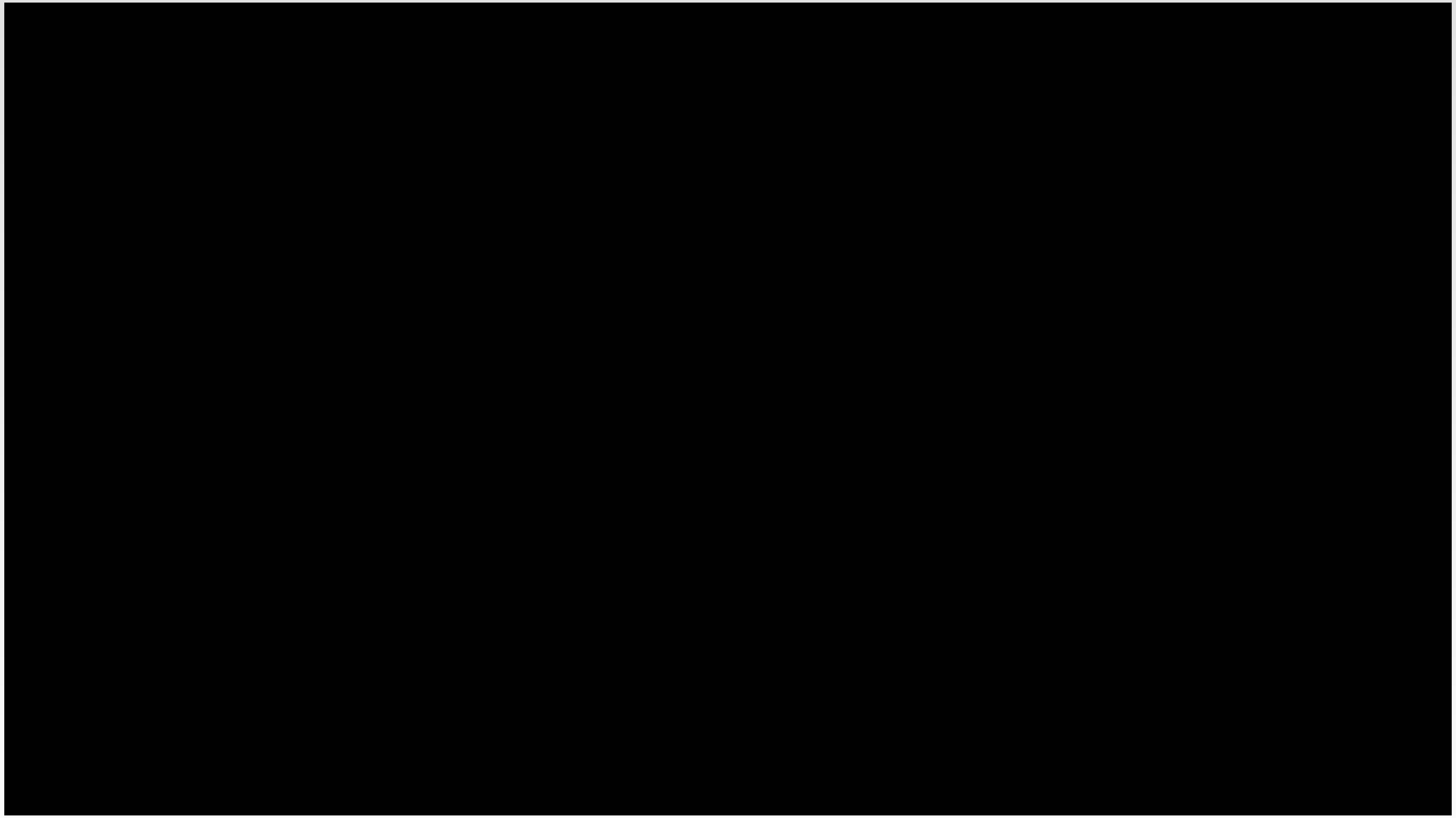
The Entire Event

Are you Closing or Separating?...
– 12% rule when applied too far away



12% rule when applied too close

My Related Research

- Muttart, J. W., Fisher, D. L., Pollatsek, A., & Knodler, M. (2007). *Driving Simulator Evaluation of Driver Performance during Hands-Free Cell Phone Operation in a Work Zone: Driving without a Clue* (Technical Paper No. 07-2873). Washington, DC: Transportation Research Board and Texas A&M Work zone Clearing House.
- Muttart, J. W., Messerschmidt, W., & Gillen, L. (2005). *Relationship between Relative Velocity Detection and Driver Response Times in Vehicle Following Situations* (Technical paper No. 2005-01-0427). Warrendale, PA: Society of Automotive Engineers.
- Muttart, J. W. (2004). Estimating Driver Response Times, (2004). *Handbook of Human Factors in Litigation* (Noy & Karkowski Ed.), (Ch. 14) Boca Raton, FL: CRC Press (Taylor & Francis) 14-1 – 14-24. http://www.crcnetbase.com/doi/abs/10.1201/9780203490297.ch14
- Muttart, J. W. (2003). Development and evaluation of driver perception-response equations based upon meta-analysis, *Transactions Journal of Passenger Cars - Mechanical Systems*, Society of Automotive Engineers.

Headway

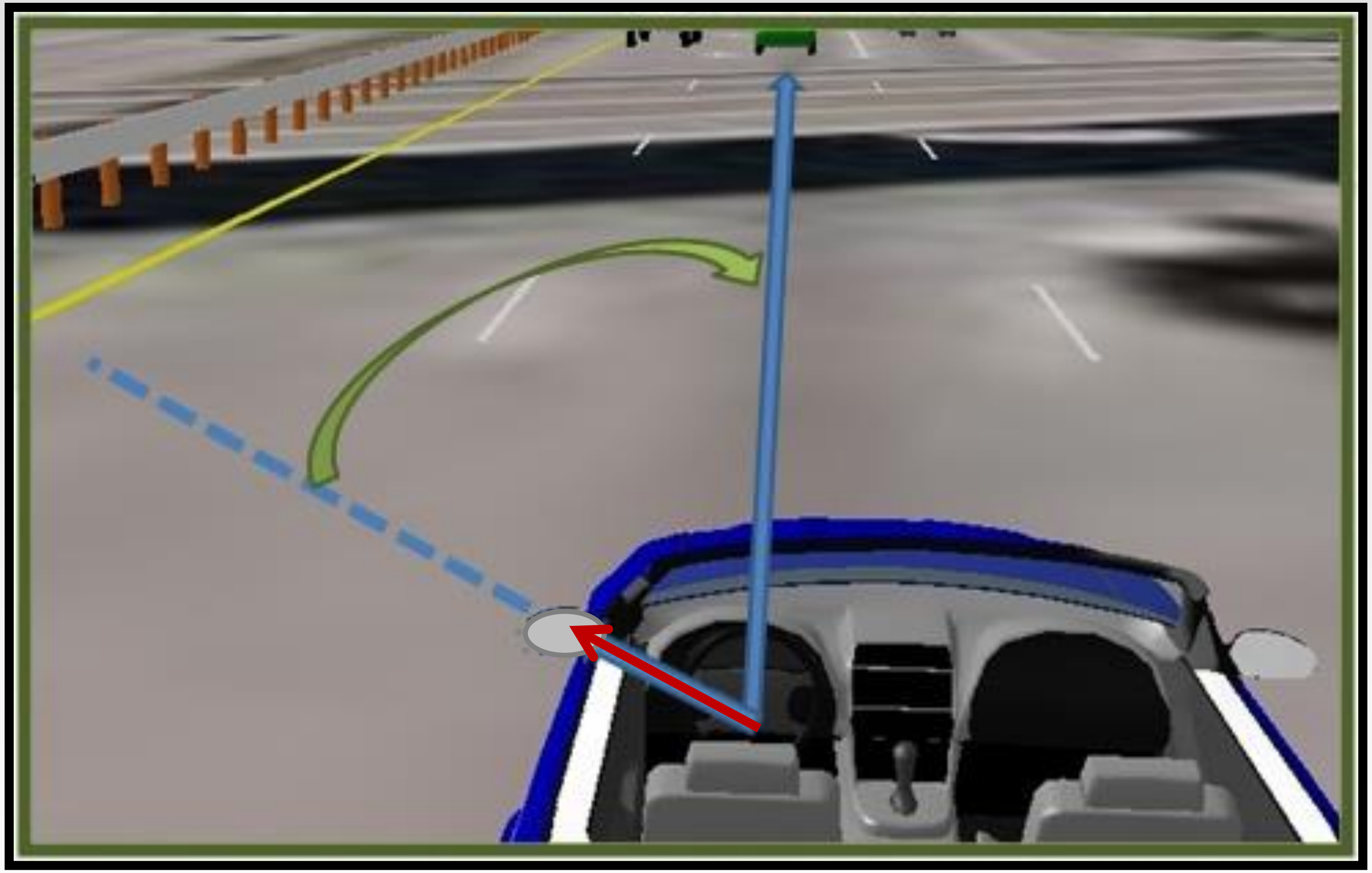
- Response time increases as headway increases & deceleration rate (LV) decreases.
  - Boer, 1999
  - Duckstein, Unwin, Boyd, 1970
  - Caro, Cavallo, Marendaz, Boer, Vienne, 2007
  - Muttart, 2003

- Smaller deceleration may not be associated with an emergency response event initially.

Flashing Lights?

- Presence lights - Fisher and Hall
  - Insignificant difference when detecting a change in headway.
- Brake lights - Summala et al
  - 0.3 second faster than without brake lights (Adjusted for Eccentricity – otherwise ~ 0.6 s)
  - Only one LV in the driver's forward field
  - Markkula et al., 2016
    - 59% had brake lights on all 6 seconds
    - 34% had brake lights on at some time
- Strobe lights – Schriener
  - Insignificant effect in Response to Lead Vehicles situations
- Flashing lights - Crawford - Boff & Lincoln
  - More difficult to detect if among other flashing lights (like transient brake lights)
  - flashing lights increase the likelihood of detection if there were no other flashing lights.

Eccentricity if Looking into Driver's Side Mirror



Relative Velocity Detection

Detect…

Detect Closing…

Detect RATE of Closing…

0.34 deg/sec

Subtended Angular Velocity
(Visual Expansion Rate)

- Hoffman & Mortimer (1996)
  - 50 % of *observers* were capable of detecting a relative velocity *greater than* 0.003 radians/sec.
  - Allowed 4 second observations in laboratory setting.
- Brown (1960, cited in Duckstein, et al, 1968)
  - Just noticeable difference for alerted subjects with "binary" choice was 0.002 rad/sec.
  - Alerted subjects with binary choice = drivers stopped at a stop sign!
- Plotkin (1968) – 0.0275 r/s based upon reconstruction.
  - Estimated vehicle speed
  - Assumed several factors including PRT.

Subtended Angular Velocity (Visual Expansion Rate)

- Lamble et al
  - 0.007 rad/sec with 45 degree eccentricity
- Muttart, Messerschmidt & Gillen (2005)
  - 0.006 r/s is when PRT levels off
  - 0.0045 r/s is threshold that best fits with PRT research
- Summala, Lamble & Laakso (1998)
  - Reported 0.002 to 0.003 rad/sec threshold
  - Findings support 0.0045 r/s
- Markkula et al 2016
  - 0.02 rad/sec threshold
  - Time after 0.02 r/s threshold where braking began = 0.46 s
  - Did not account for braking time but addressed "ramp up" deceleration

RSAV

- Hoffman & Mortimer (1996) calculated the subtended angular velocity [SAV] as follows:
  - Perceive relative speed:
    - $d\theta/dt = WV_r / D^2$
- Sixteen comparisons were presented twice to each of the subjects;
- The relative speeds of 0.54, 1.20, 3.25 and 5.43 m/s were compared with the 0.95, 2.21, 4.38 and 7.23 m/s conditions (P. 418).
- Eight film segments were shown, each with a mean headway of 28 m and having a 4 s exposure.
- Corresponding subtended angular velocities ranging from 0.0013 to 0.017 rad/s.
- Stationary observers, no driving task, no other glance location was necessary, did not address the added difficulty of a stopped LV from more than 300 feet (100 m) away.

Subtended angle threshold gets smaller

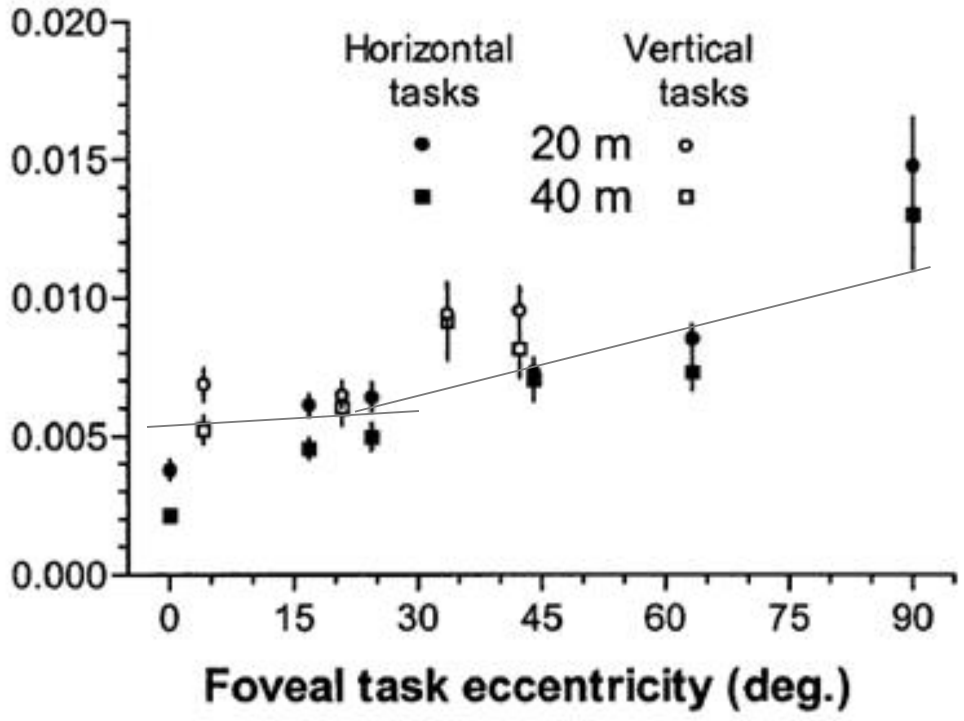
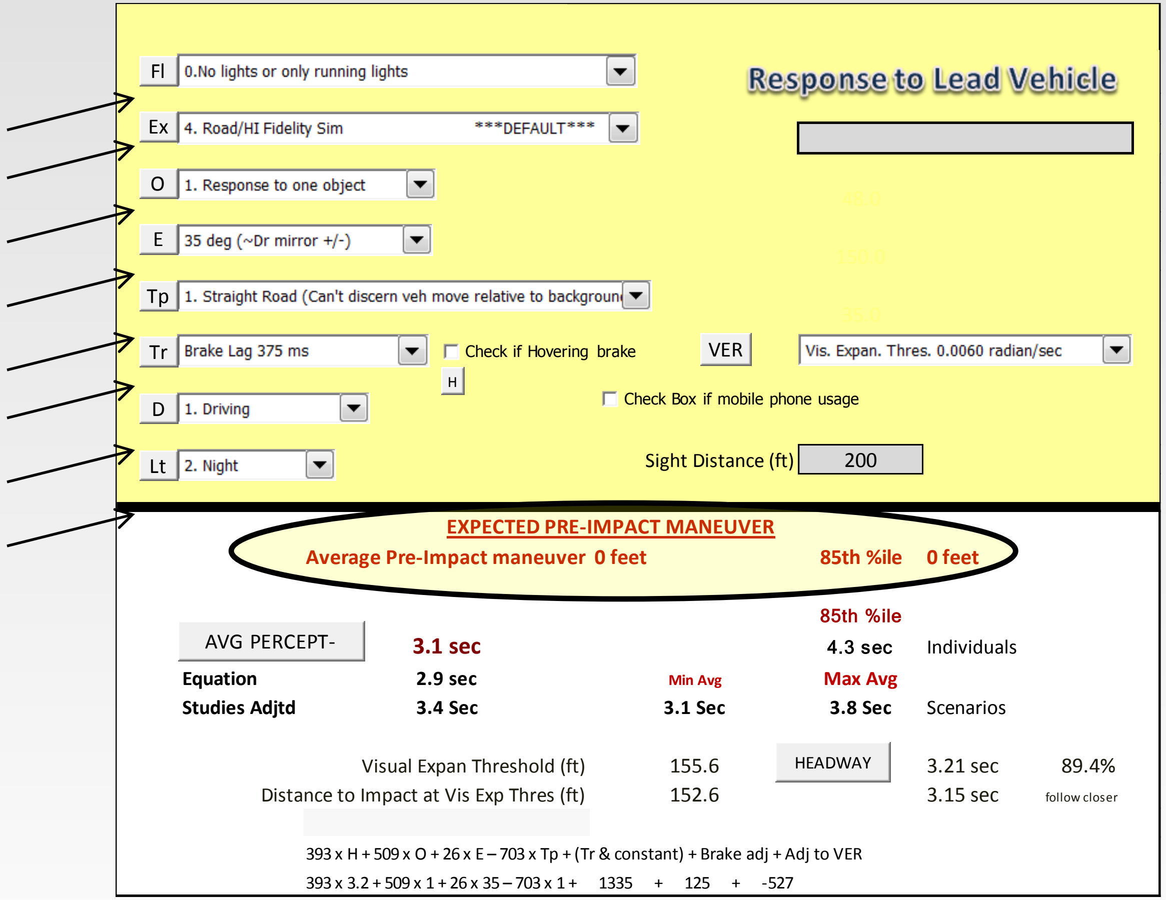


Figure 4. Angular velocity of expansion of the image of the vehicle ahead on the retina at the moment of detection for each position of the foveal in-car task.

Lamble et al 1999

Equation:

See Letters & Numbers Above



Muttart, 2003, 2004, 2005

Distance to Impact

EXPECTED PRE-IMPACT MANEUVER

	Average Pre-Impact maneuver 0 feet		85th %ile	0 feet	
			85th %ile		
AVG PERCEPT-	3.1 sec		4.3 sec	Individuals	
Equation	2.9 sec	Min Avg	Max Avg		
Studies Adjtd	3.4 Sec	3.1 Sec	3.8 Sec	Scenarios	
Visual Expan Threshold (ft)		155.6	HEADWAY	3.21 sec	89.4%
Distance to Impact at Vis Exp Thres (ft)		152.6		3.15 sec	follow closer

393 x H + 509 x O + 26 x E – 703 x Tp + (Tr & constant) + Brake adj + Adj to VER

393 x 3.2 + 509 x 1 + 26 x 35 – 703 x 1 + 1335 + 125 + -527

- **Distance to impact at Visual Expansion Threshold (DTI):**
- Vis. Exp Threshold Dist = (LV width x V_{rel} / DTI= Visual Exp. Rate)$^{1/2}$
- DTI = Vis. Exp Threshold x (V_f/ V_{rel})
  - Where:
    - Visual Expansion Threshold, 0.006 rads/sec
    - V_f is the Velocity of the following vehicle
    - V_{rel} is the relative velocity, calculated by V_{rel}=V_{ApprhV} – V_{LV}
    - Adjusts for distance from eyes to front bumper.

Influence of Size of Lead Vehicle on Response

Train Crashes

- "Leibowitz hypothesis,"
- Large objects seem to move slower
  - Two subsystems influence eye movement
    - Reflexive: without thought —
      - Triggered by seeing contours. Allows us to see things while we move
    - Pursuit eye movements. How we view moving objects. How we est. speed.
      - Effort necessary
      - The larger, the less our voluntary systems have to work, and the slower the object seems.

H.W. Leibowitz, "Grade Crossing Accidents and Human Factors Engineering." *American Scientist* Vol. 73, No. 6 November-December 1985, pp. 558-562.

Large Objects – Slower?

- Verified Leibowitz' hypothesis

- Subjects estimated speed of spheres coming toward them in computer simulation.
- Static posts and lines on the ground as helpful cues
- Observers reported smaller sphere was moving faster — even when the larger sphere was moving 20 mph faster.
- Not until the large sphere was 2 x faster were observers convinced the smaller sphere was moving faster.

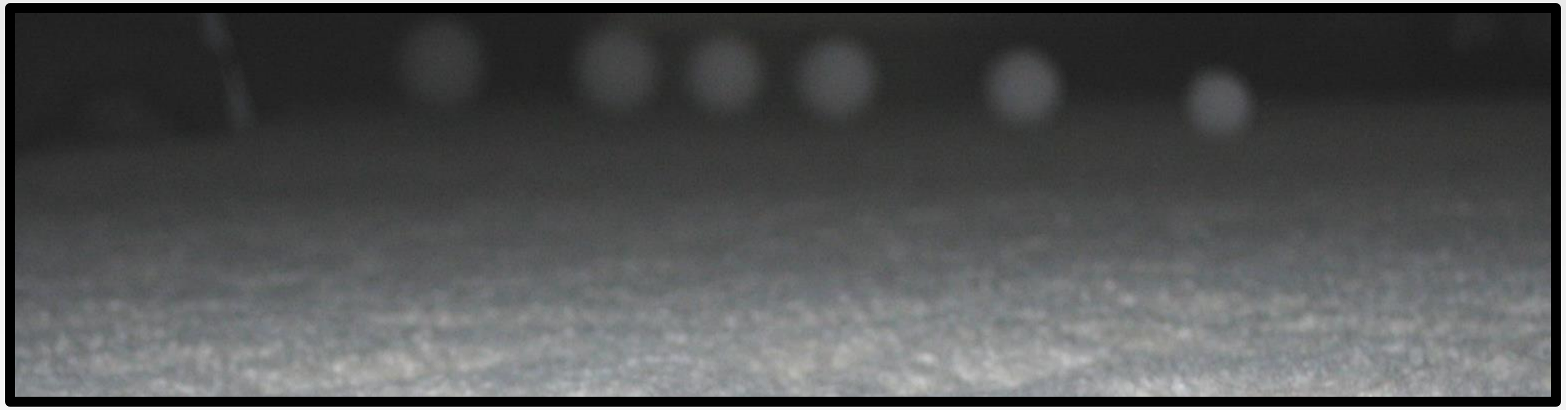
J.E. Barton and T.E. Cohn (2007). A 3D Computer Simulation Test of the Leibowitz Hypothesis, Transportation Research Board, Washington, DC.
[UC Berkeley Traffic Safety Center. Paper UCB-TSC-TR-2007-10.
http://repositories.cdlib.org/its/tsc/UCB-TSC-TR-2007-10]
Accessed May 14, 2012

Which is closing fastest?

DEPTH PERCEPTION: ESTIMATING DISTANCE & SPEED OF OBJECTS MOVING IN-LINE

If you do not know what it is (specifically its size, clarity or brightness), then you do not know where it is.

Very Little Context:
Lacks Clarity
Depth
& Size information



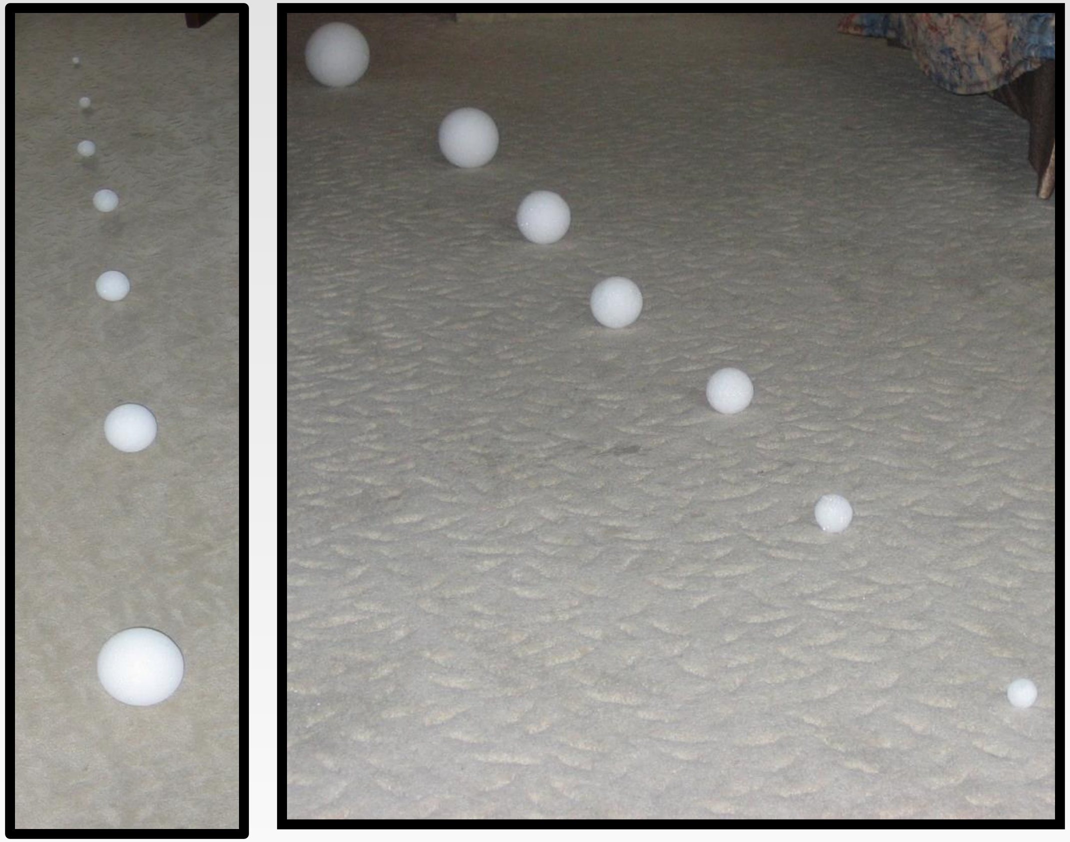
Context:

More Clarity

But Lacks Depth & Size Detail

CSRC
CRASH SAFETY
RESEARCH CENTER

Better Perspective Offered
Lighting, Clarity, & Brightness



We are now capable of accurately judging size and relative
Position which tells us the distance

Depth Perception Evaluation

- 2”, 4” & 6” squares
- Red C2, White C2 and aluminum sheeting
- At various heights
- Two trailer marker lights at approximately same distance
  - One powered by 6 volt battery
  - One powered by 12 volts

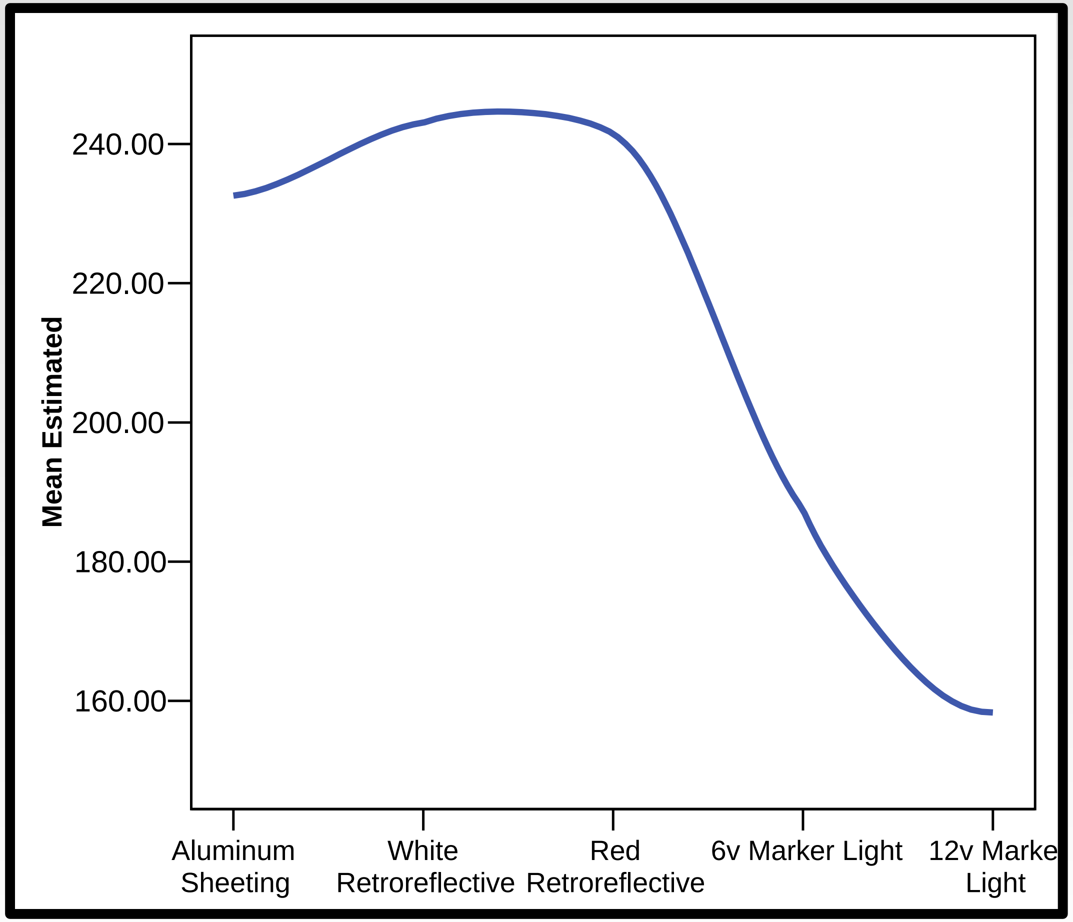
Height, Size & Perceived Brightness – Without Context

Photo by Gregory Vandenberg

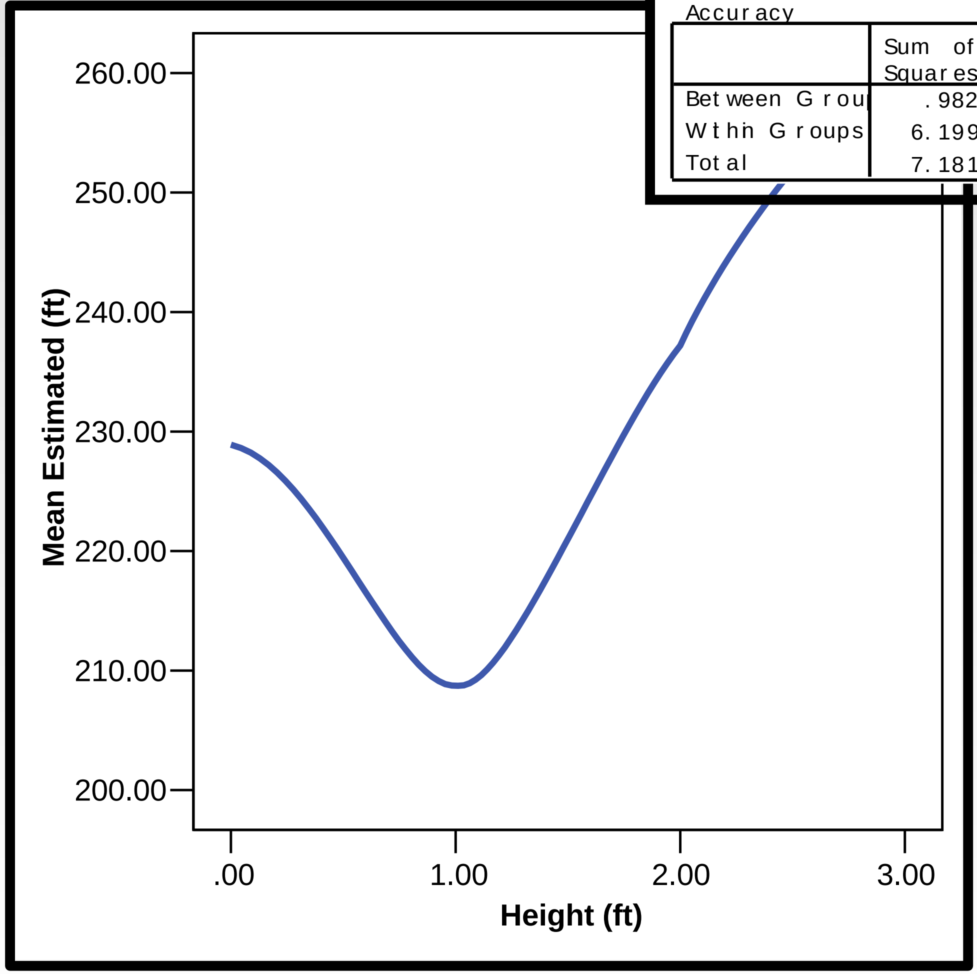
View from Within Vehicle

Photo by Gregory Vandenberg

Perception: Brighter is Closer; Dim is Further Away



Higher Objects Viewed as Further Away



ANOVA

Accuracy

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.982	12	.082	2.628	.003
Within Groups	6.199	199	.031		
Total	7.181	211			

Side Marker Light

6 v left & 12 v right

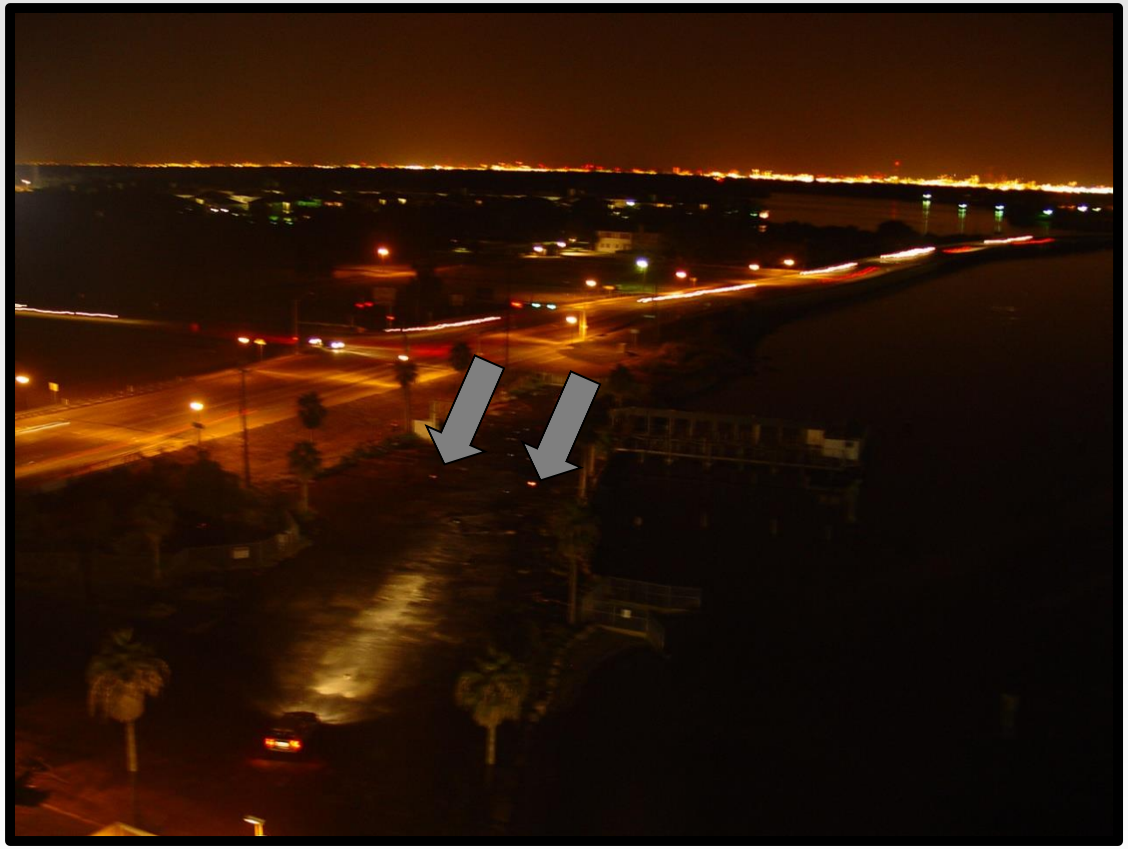


Photo by Gregory Vandenberg

Trailer Marker Lamps

	Actual	Estimated
Side Trailer Marker Light 6v power	205	185.0
Side Trailer Marker Light 12v power	203	160.0

Brighter light viewed as Closer

Discussion

- Features That Influence Depth Perception
  - Interposition
  - Linear perspective (vanishing lines of a road)
  - Clarity
  - Height
  - Size
  - Brightness (intensity)
  - TEXTURE

THE PROBLEM

Poor Context + Low Probability + Poor Grasp of Closing Speeds

IN THE NEXT SLIDES, I SHOW THE VIEW WHEN CLOSING AT VARIOUS SPEEDS AND FROM VARIOUS DISTANCES

UNDERSTAND – YOU KNOW WHERE TO LOOK AND WHAT TO LOOK FOR

IF YOU WERE
DRIVING
SCANNING
LOOKING AWAY… HOW WELL WOULD YOU DO?

YOU WILL BE SHOWN A SERIES OF PHOTOGRAPHS OF CLOSING ON A LEAD VEHICLE. YOU WILL BE ASKED QUESTIONS LATER?

TEST 1

CSRC CRASH SAFETY RESEARCH CENTER

CSRC CRASH SAFETY RESEARCH CENTER

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RESEARCH CENTER

CLOSING OR SEPARATING?

A – I 71

WHAT IS THE DISTANCE

- 900’
- 800’
- $\boxed{\text{700’}}$
- 600’
- 500’

RELATIVE SPEED

- CLOSING AT 25
- CLOSING AT 45
- $\boxed{\text{CLOSING AT 65}}$
- NOT CLOSING
- GAINING AT 20 MPH

Taillights 5.5 feet apart

TEST 2

CSRC
CRASH SAFETY
RESEARCH CENTER

CSRC
CRASH SAFETY
RESEARCH CENTER

CSRC
CRASH SAFETY
RESEARCH CENTER

TAILLIGHTS 5.5 FEET APART

What is the distance

- 900’
- 800’
- $\boxed{700’}$
- 600’
- 500’

A – I 73

Relative speed

- Not closing
- $\boxed{\text{Closing at 25}}$
- Closing at 45
- Closing at 65
- Gaining at 20 mph

TEST 3

CSRC CRASH SAFETY RESEARCH CENTER

CSRC
CRASH SAFETY
RESEARCH CENTER

CSRC
CRASH SAFETY
RESEARCH CENTER

TAILLIGHTS 5.5 FEET APART

A – I 62

What is the distance

- 900’
- 800’
- 700’
- 600’
- 500’

Relative speed

- Not closing
- Closing at 25
- Closing at 45
- Closing at 65
- Gaining at 20 mph

TEST 4

CSRC
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CSRC
CRASH SAFETY
RESEARCH CENTER

CSRC
CRASH SAFETY
RESEARCH CENTER

CSRC
CRASH SAFETY
RESEARCH CENTER

CSRC
CRASH SAFETY
RESEARCH CENTER

CSRC
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RESEARCH CENTER

TAILLIGHTS 2.5 FEET APART

A – I 62

What is the distance

900’
800’
700’
600’
500’

Relative speed

Not closing
Closing at 25
Closing at 45
Closing at 65
Gaining at 20 mph


VISION VERSUS
PERCEPTION
JEFFREY W MUTTART

1. Dingus, T. A., Klauer, S. G., Neale, V. L., Petersen, A., Lee, S. E., Sudweeks, J., Perez, M. A., Hankey, J., Ramsey, D., Gupta, S., Bucher, C., Doerzaph, Z. R., Jermeland, J., and Knipling, R. R. (2006). The 100-Car Naturalistic Driving Study, Phase II - Results of the 100-Car Field Experiment DOT HS 810 593. National Highway Traffic Safety Administration, USDOT. http://www.nhtsa.dot.gov/staticfiles/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/Driver%20Distraction/100CarMain.pdf
2. Knipling, R., Mironer, M., Hendricks, D., Allen, J., Tijerina, L., Everson, J., & Wilson, C. (1993, May) Assessment of IVHS countermeasures for collision avoidance: Rear-end crashes. Final Report (Report No. DOT HS 807 995). Washington, DC: National Highway Traffic Safety Administration.
3. McGehee, D.V., T. Brown, and T. Wilson (1997). Examination of drivers' collision avoidance behavior in a stationary lead vehicle situation using a front-to-rear-end collision warning system. USDOT/NHTSA Office of Crash Avoidance Research Technical Report. Contract DTNH22-93-C-07326.
4. Sorock, G. S., Ranney, T. A., Lehto, M. R. (1996). Motor vehicle crashes in roadway construction work zones: an analysis using narrative text from insurance claims, Accident Analysis and Prevention, 28, 131-138.