Safely and Effectively Communicating Non-Connected Vehicle Information to Connected Vehicles

August 22, 2019

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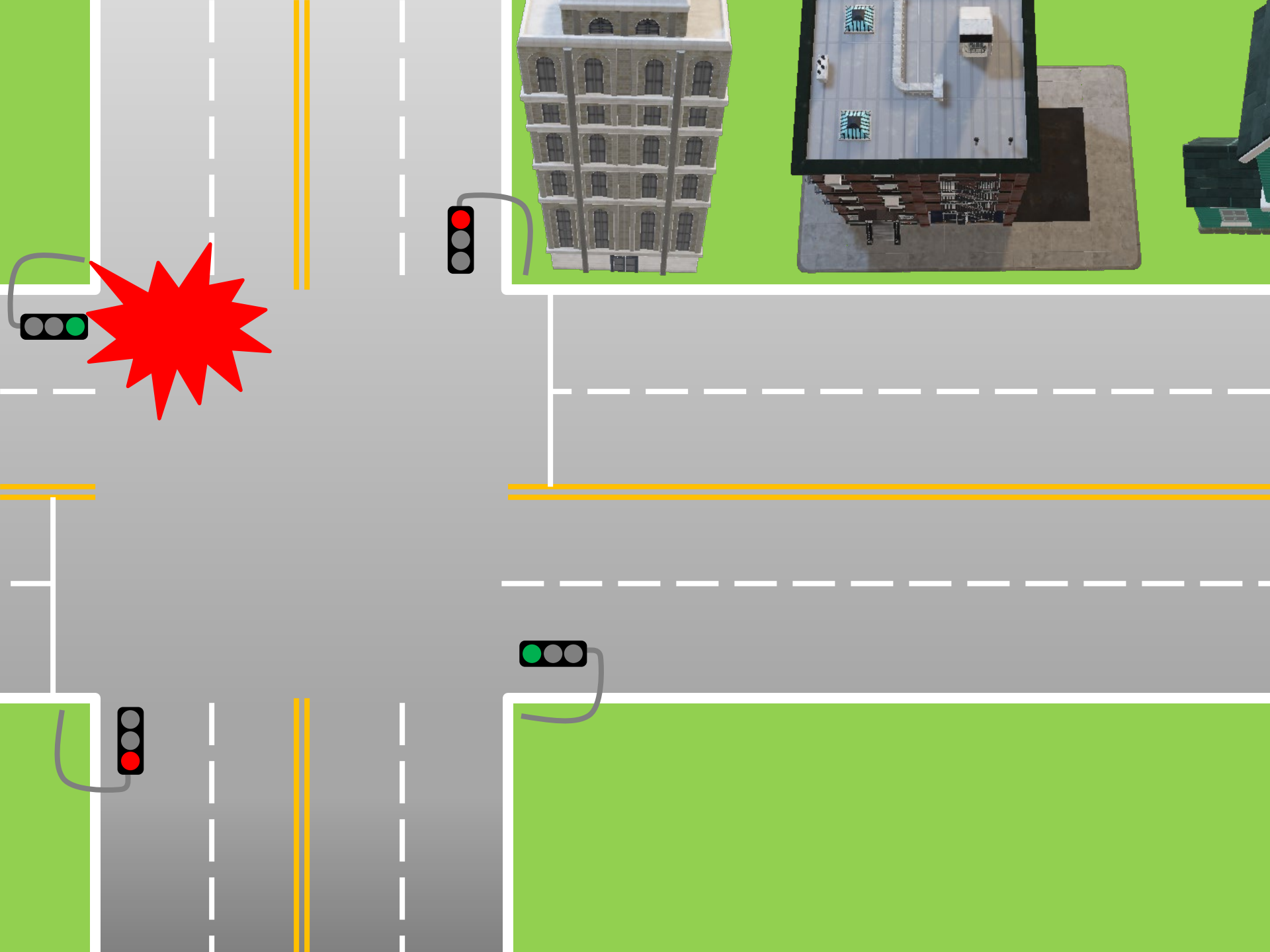
Presentation Outline

- Introduction
- Objective
- Literature Review
- Experimental Design
- Results
- Conclusion
- Future Work

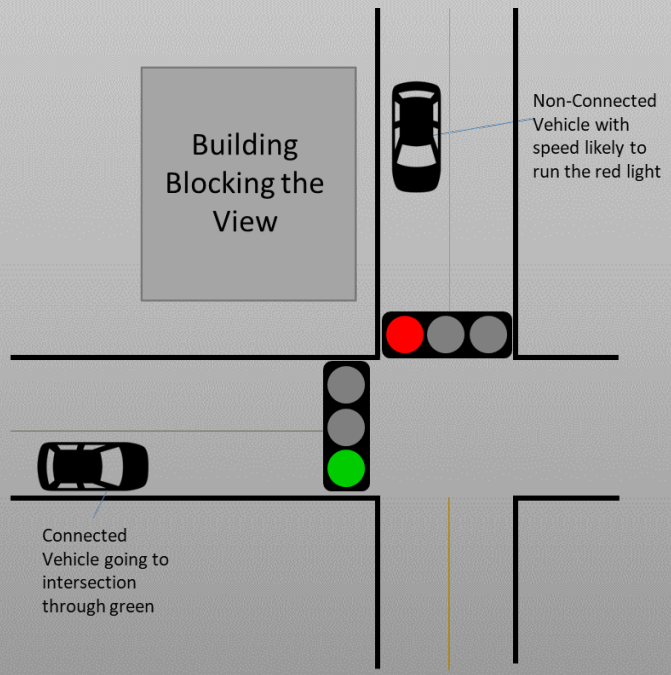
Introduction

- Red-light violation has high rates at busy urban intersections
- Connected vehicles (CVs) can increase highway safety
- In-vehicle sensors should be able to detect a potential red-light runner
- In-vehicle sensors can be the victims of blocked lines of sight



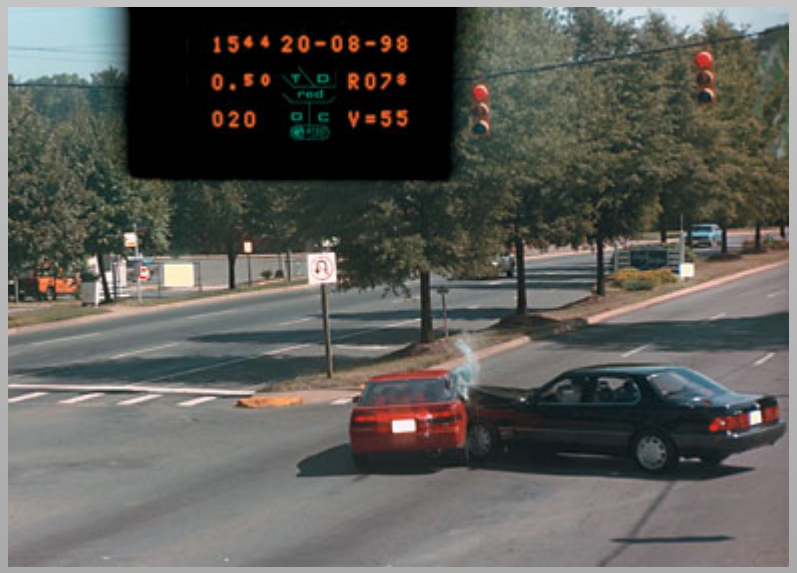
Objective

- Evaluate the effectiveness of an advanced warning message
  - Audio-visual
  - Communicate the presence of a potential non-connected red-light-running vehicle crossing from a blind spot



Literature Review

- Driving Behavior
  - Driving - ubiquitous
  - Crashes:
    - 75-95% Human error
    - 40% of crashes at intersections
- Red-light running causes
  - 165,000 injuries/year
  - 800 fatalities/year
  - Pedestrians and people in other vehicles



Literature Review

- Warning Systems
  - Advanced driver-assistance systems
    - Collision warning system
    - Blind spot information system

Literature Review

- Warning Systems
  - Displays
    - Head-up displays (HUD)
    - Head-down displays (HDD)
    - Augmented reality (AR) displays

Literature Review

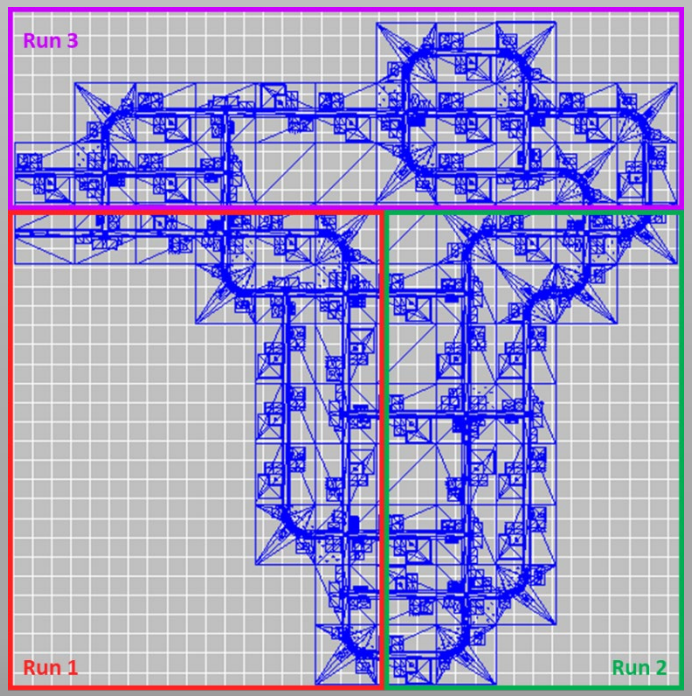
- Driving Simulator
  - Safer and more economical method than the on-road testing
- Testing in-vehicle technologies
  - Supplemental speed information from in-vehicle systems
  - Advisory-information conditions
  - AR windshield-based in-vehicle navigation system

Experimental Design

- Experimental procedures were conducted on a full-scale driving simulator located at UW-Madison

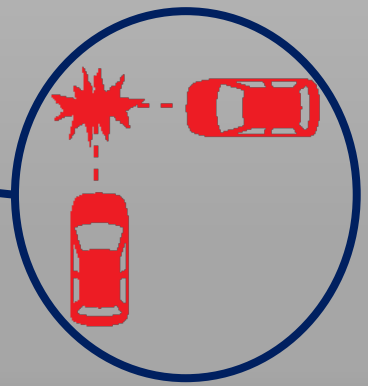
Experimental Design

- Subjects drove through an urban environment
  - Speed limit = 35 mph
  - 3 driving scenarios (144 to 209 sec)
  - normal weather conditions

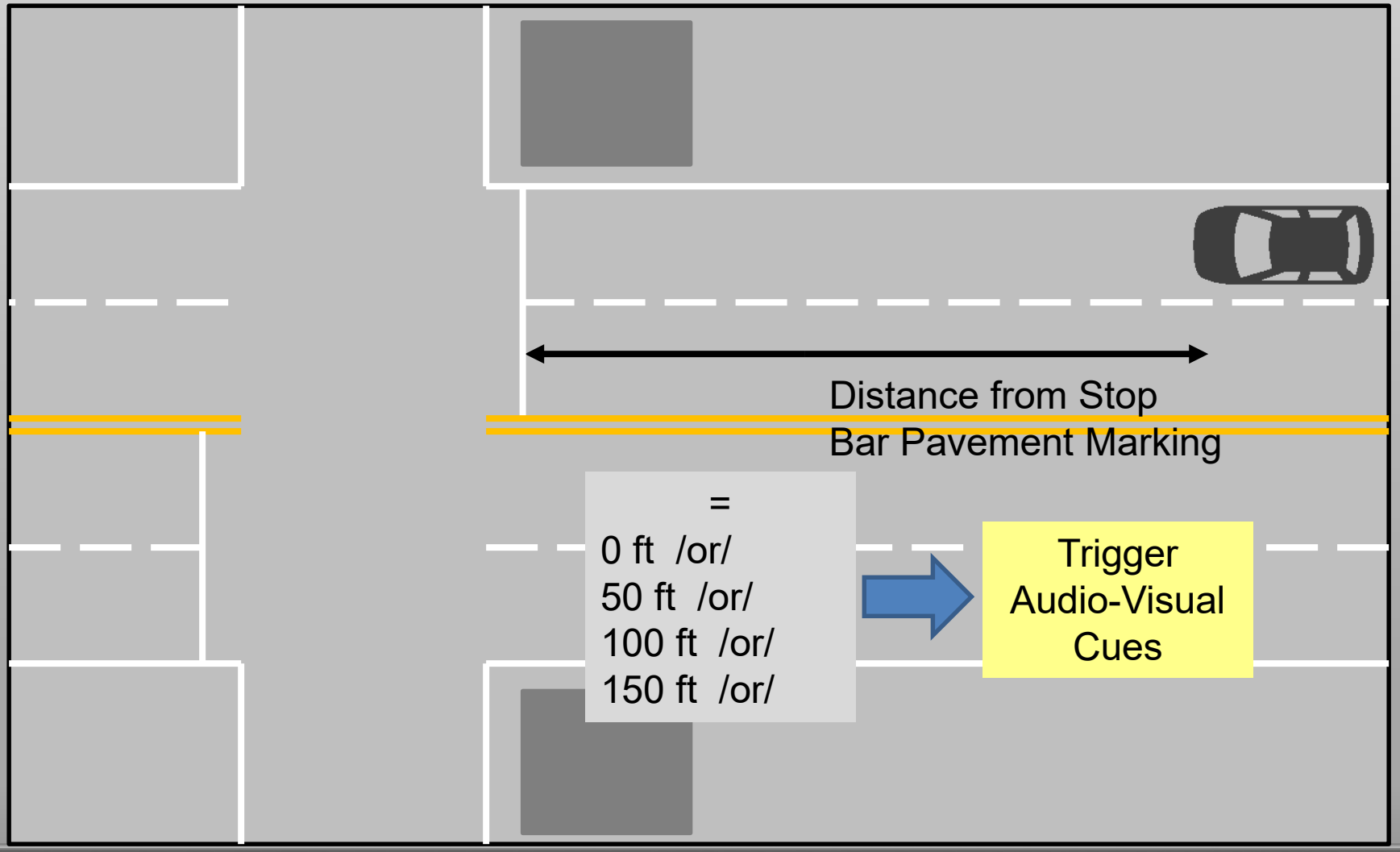


Experimental Design

- Each warning message (visual cue) was accompanied by an auditory cue in the form of a beep.
- The cues were triggered based on a randomized experimental matrix.

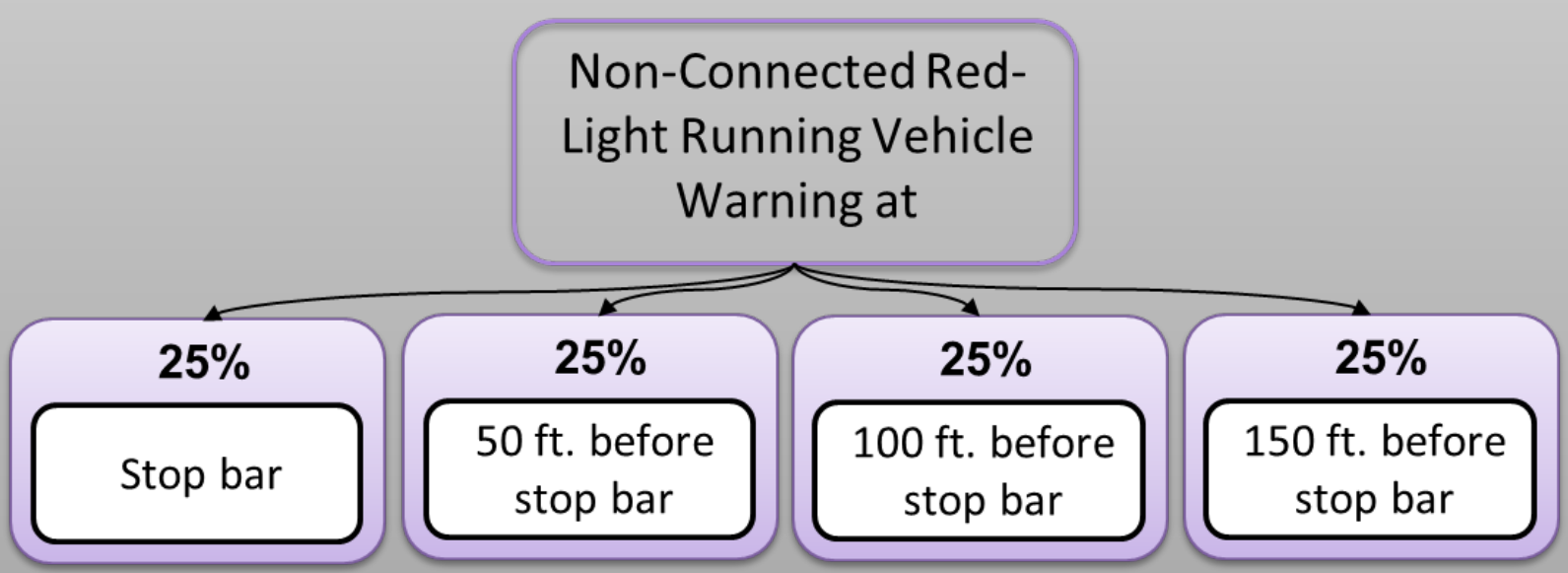


Experimental Design



Experimental Design

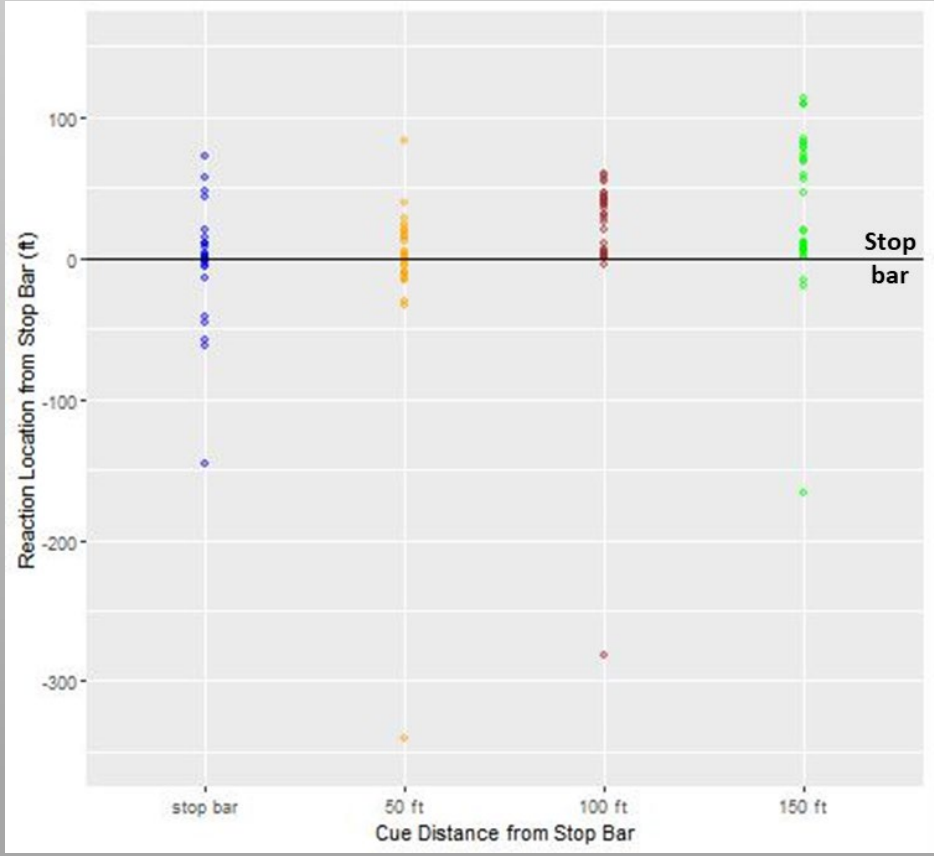
Experimental Design



Experimental Design

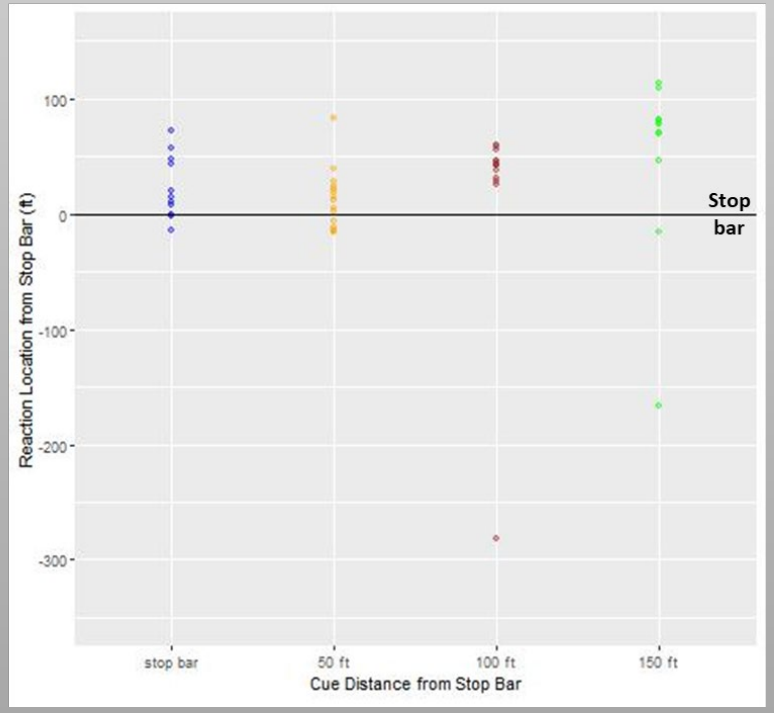
- Sample size = 20 (10 M, 10 F)
- Age range: 19 to 75 years old (Mean = 32)
- Driving experience: 1 to 52 years
- Each subject encountered 9 red-light-runners events
- Simulation sickness dropouts
  - 3 including oldest and youngest driver – after 1st run
  - 2 – after 2nd run

Results

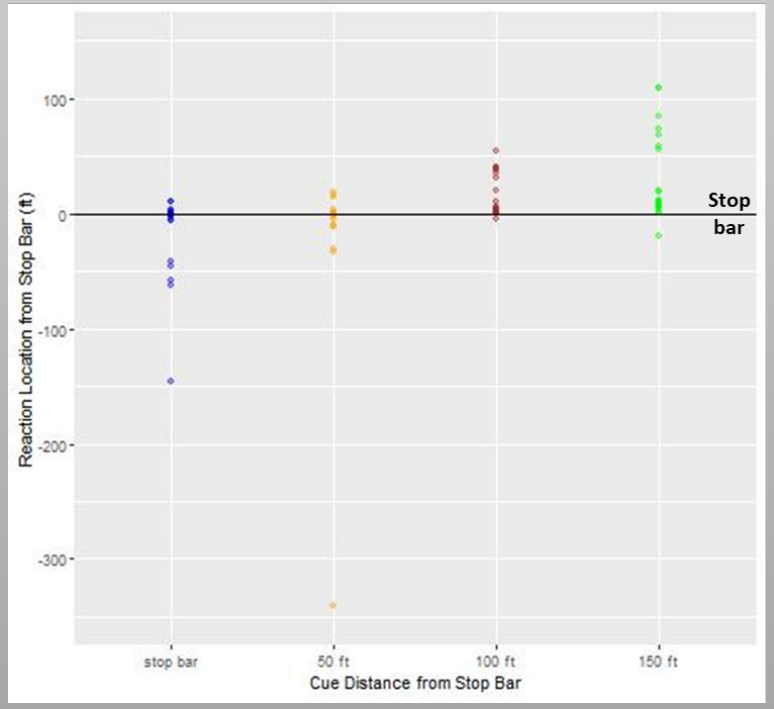

100
0
-100
-200
-300
Reaction Location from Stop Bar (ft)
Stop bar
stop bar
50 ft
100 ft
150 ft
Cue Distance from Stop Bar

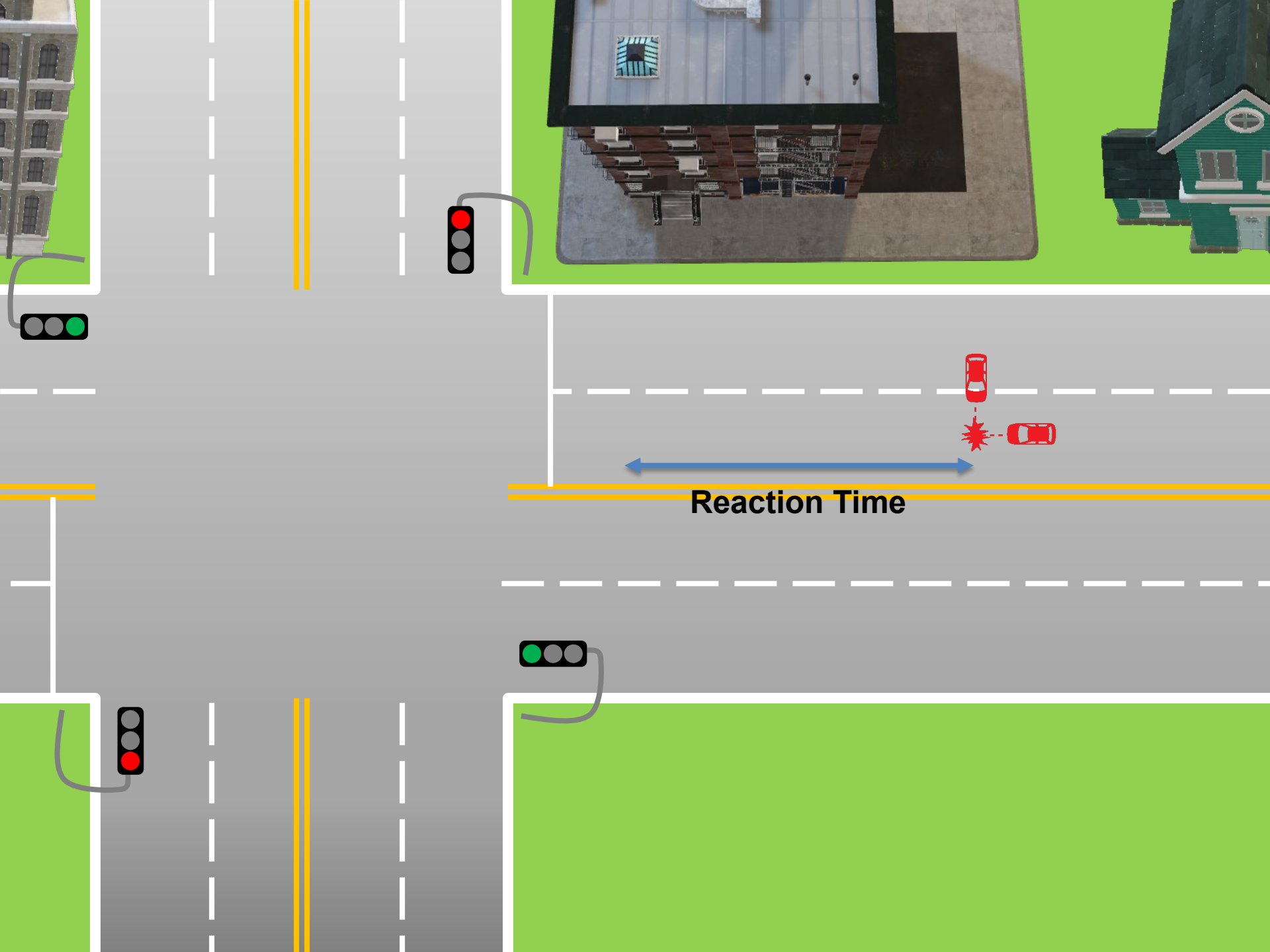
Results

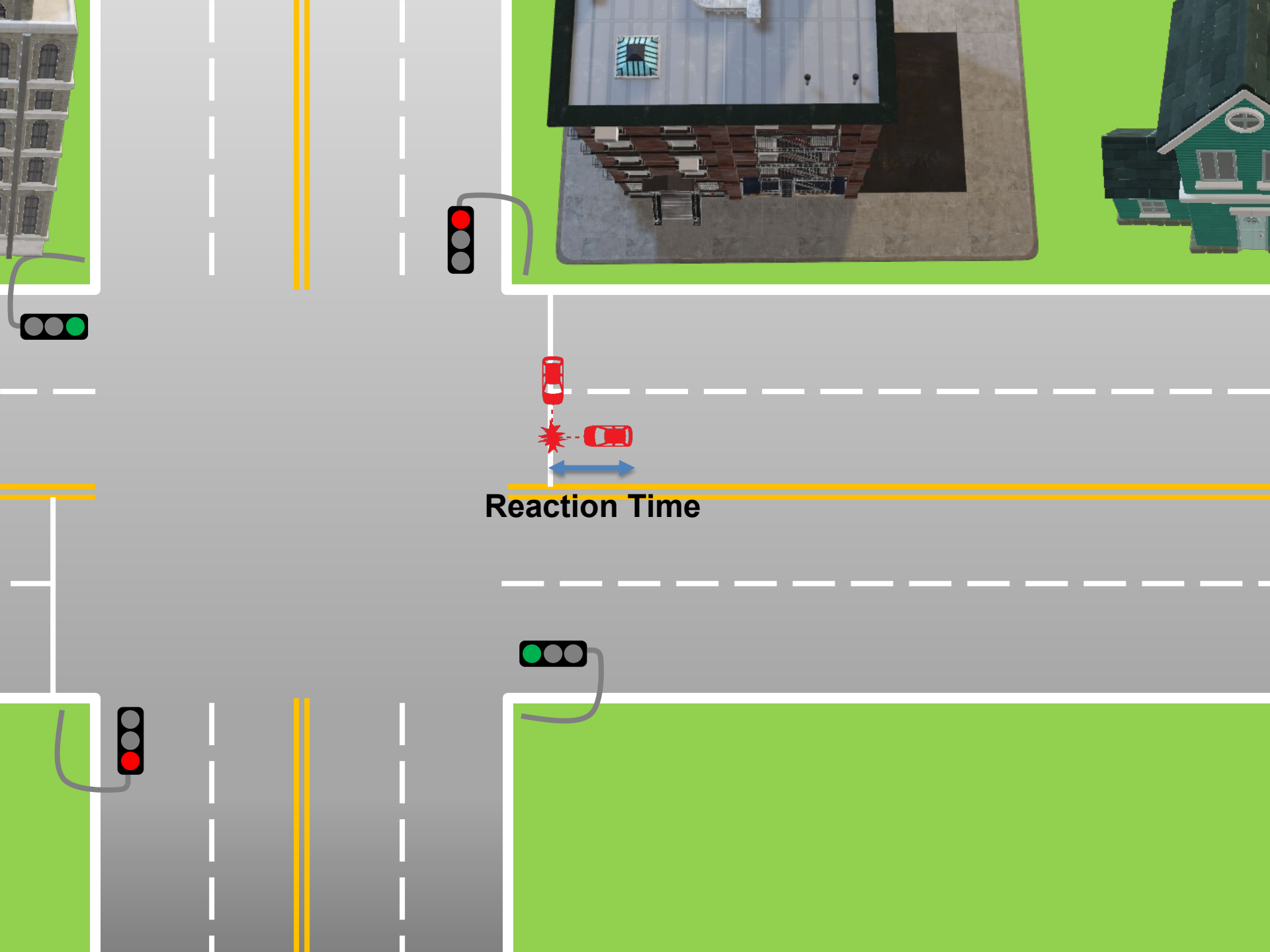
Non-Connected red light running vehicle



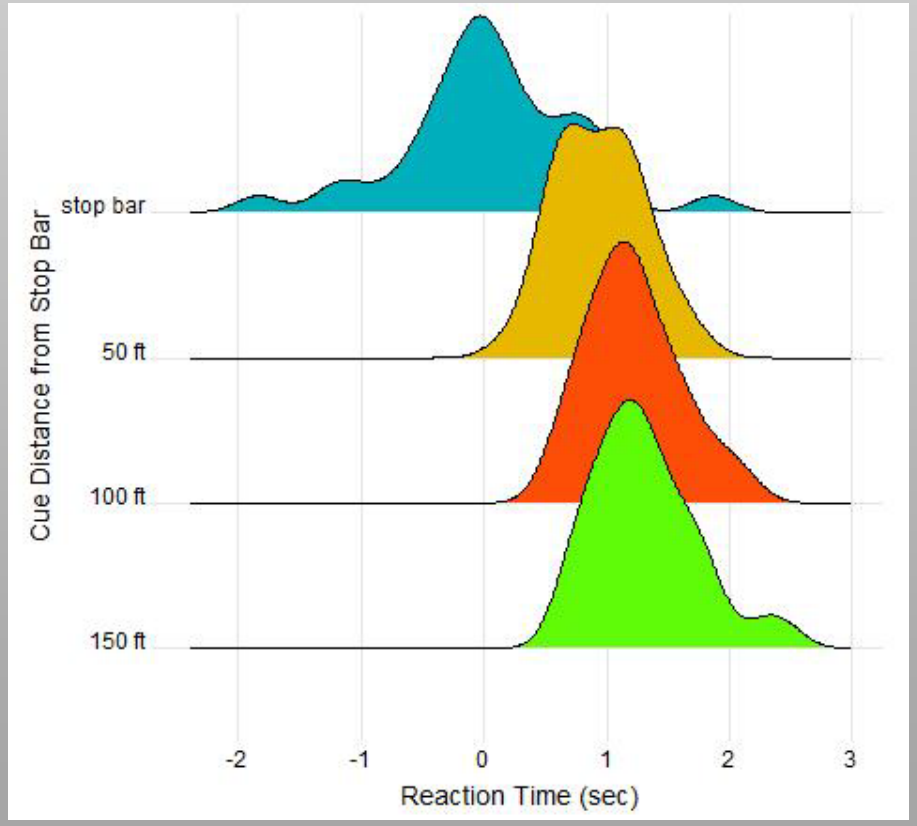
Non-Connected red light running vehicle

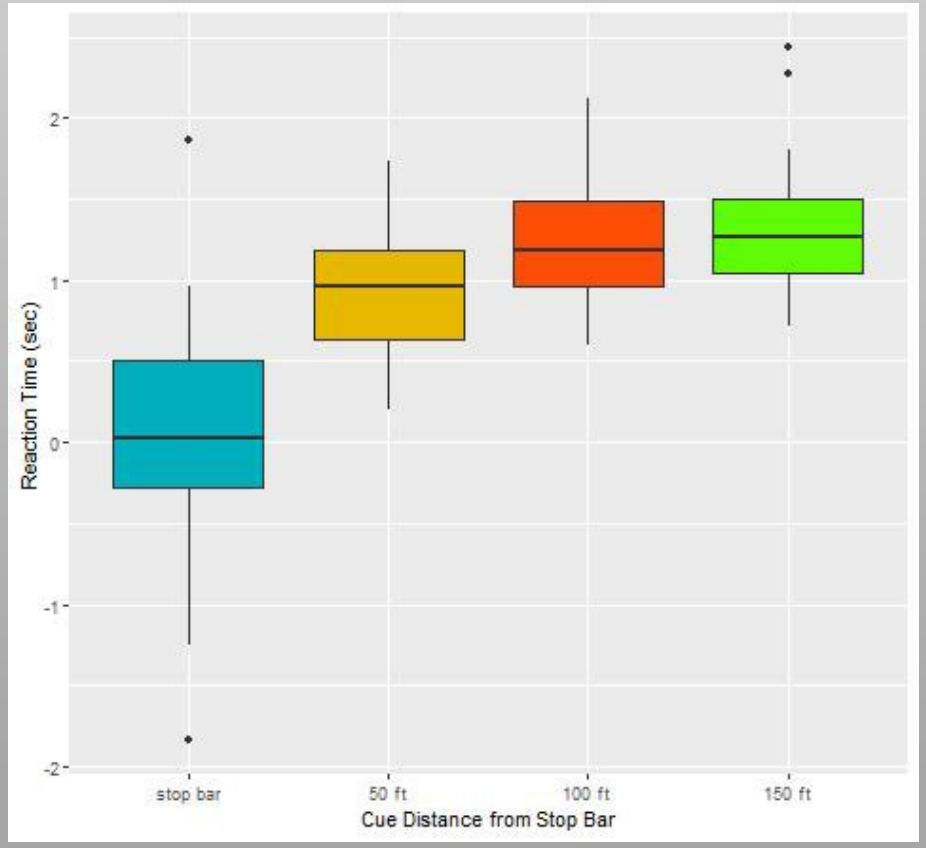



Reaction Time


Reaction Time

Results


Cue Distance from Stop Bar
stop bar
50 ft
100 ft
150 ft
-2
-1
0
1
2
3
Reaction Time (sec)


Reaction Time (sec)
2
1
0
-1
-2
stop bar
50 ft
100 ft
150 ft
Cue Distance from Stop Bar

Results

- Kruskal-Wallis test – compare the reaction time means → statistically significant difference

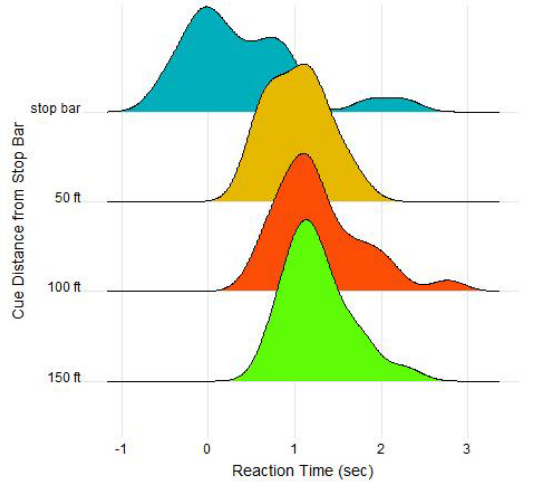
(all data) Reaction time to warning at:				
	Stop Bar	50 ft before the stop bar	100 ft before the stop bar	150 ft before the stop bar
Sample Size	34	37	39	31
Mean	0.0515	0.942	1.22	1.31
Standard Deviation	0.709	0.353	0.376	0.422
Median	0.025	0.967	1.18	1.27
IQR	0.775	0.550	0.525	0.458
p-value – Kruskal-Wallis test	3.809e-14			

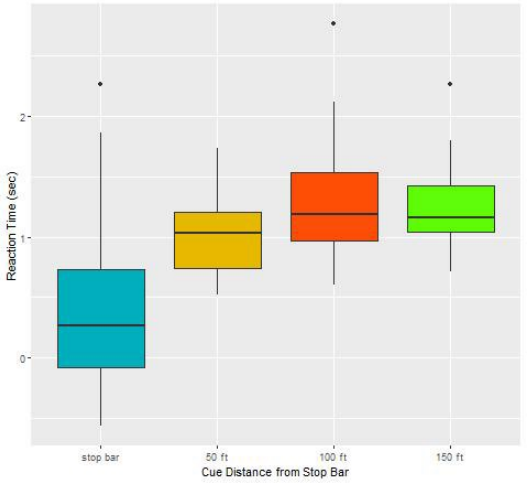
Results

- Pairwise Mann-Whitney Wilcoxon test – calculate pairwise comparisons between group levels

	Stop Bar	50 ft before stop bar	100 ft before stop bar
50 ft before stop bar	1.6e-07	-	-
100 ft before stop bar	4.9e-10	0.0149	-
150 ft before stop bar	2.8e-09	0.0033	1.0000

Results

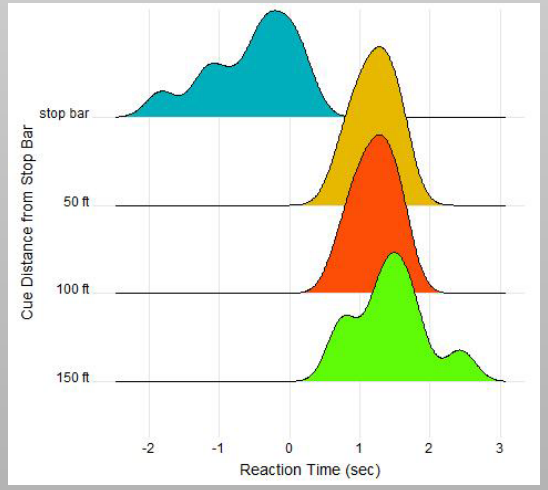


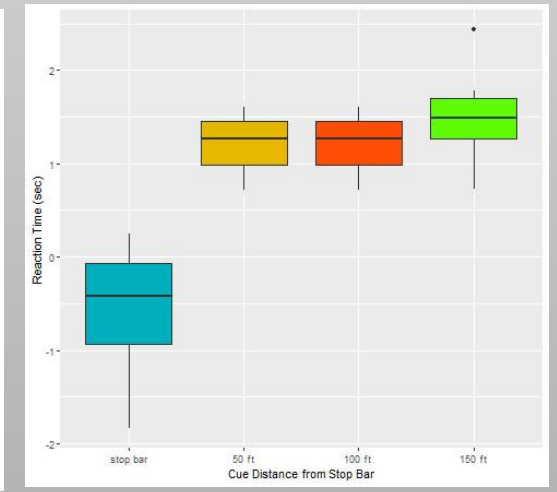


	Stop Bar	50 ft before the stop bar	100 ft before the stop bar	150 ft before the stop bar
Sample Size	25	23	27	22
Mean	0.382	1.03	1.28	1.26
Standard Deviation	0.679	0.342	0.508	0.375
Median	0.267	1.03	1.18	1.16
IQR	0.817	0.467	0.567	0.392
p-value – Kruskal-Wallis test	2.564e-07			

	Stop Bar	50 ft before the stop bar	100 ft before the stop bar
50 ft before the stop bar	0.00043	-	-
100 ft before the stop bar	1.3e-05	0.49850	-
150 ft before the stop bar	2.1e-05	0.48189	1.00000

Results



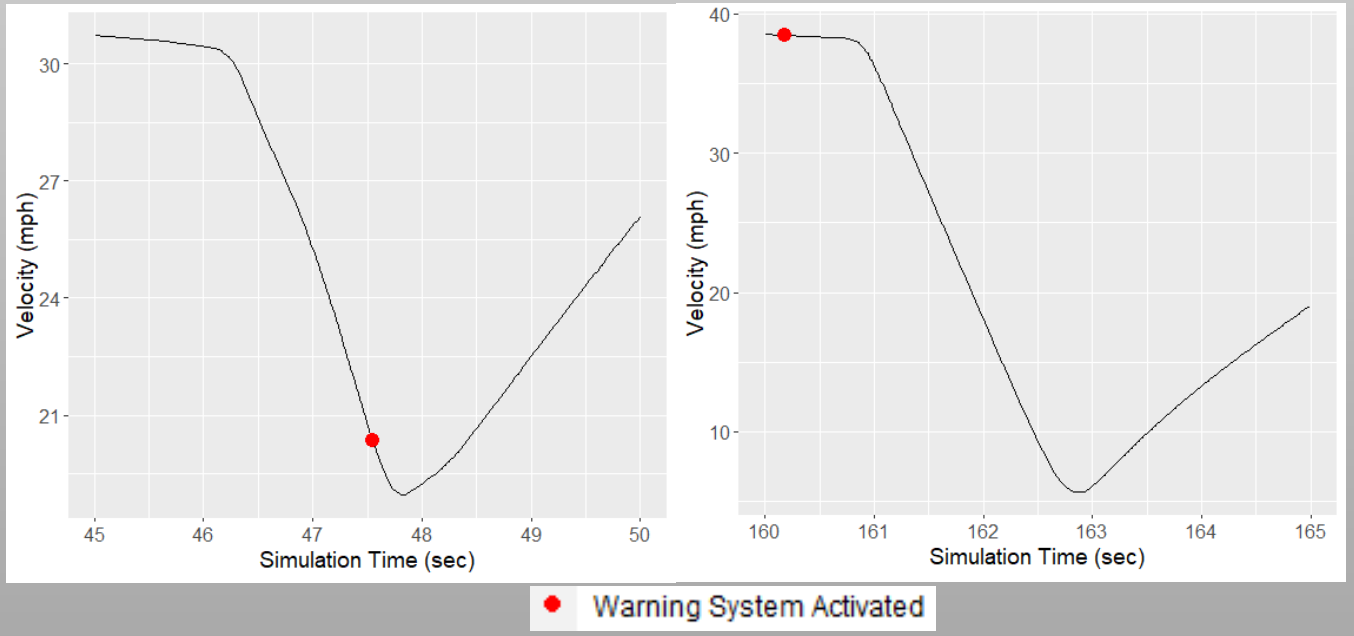


	Stop Bar	50 ft before the stop bar	100 ft before the stop bar	150 ft before the stop bar
Sample Size	11	14	13	9
Mean	-0.541	1.21	1.21	1.44
Standard Deviation	0.636	0.285	0.285	0.521
Median	-0.417	1.27	1.27	1.48
IQR	0.867	0.467	0.467	0.433
p-value – Kruskal-Wallis test	1.184e-05			

	Stop Bar	50 ft before the stop bar	100 ft before the stop bar
50 ft before the stop bar	0.00023	-	-
100 ft before the stop bar	0.00023	1.00000	-
150 ft before the stop bar	0.00118	1.00000	1.00000

Results

Speed Behavior



warning system activation at a stop bar

warning system activation at 30 ft before the stop bar

Results

Speed Behavior

	Speed reduction (mph)				Duration of speed reduction (sec)			
	Stop Bar	50 ft before the stop bar	100 ft before the stop bar	150 ft before the stop bar	Stop Bar	50 ft before the stop bar	100 ft before the stop bar	150 ft before the stop bar
Minimum	0.85	0.43	1.02	0.67	0.48	0.42	0.98	1.63
Maximum	36.07	37.19	36.7	34.27	12.25	14.68	16.16	17.82
Average	16.17	15.47	16.86	21.62	2.15	2.24	2.59	3.15
Standard Deviation	10.67	8.99	11.28	8.62	1.86	2.30	2.28	2.87

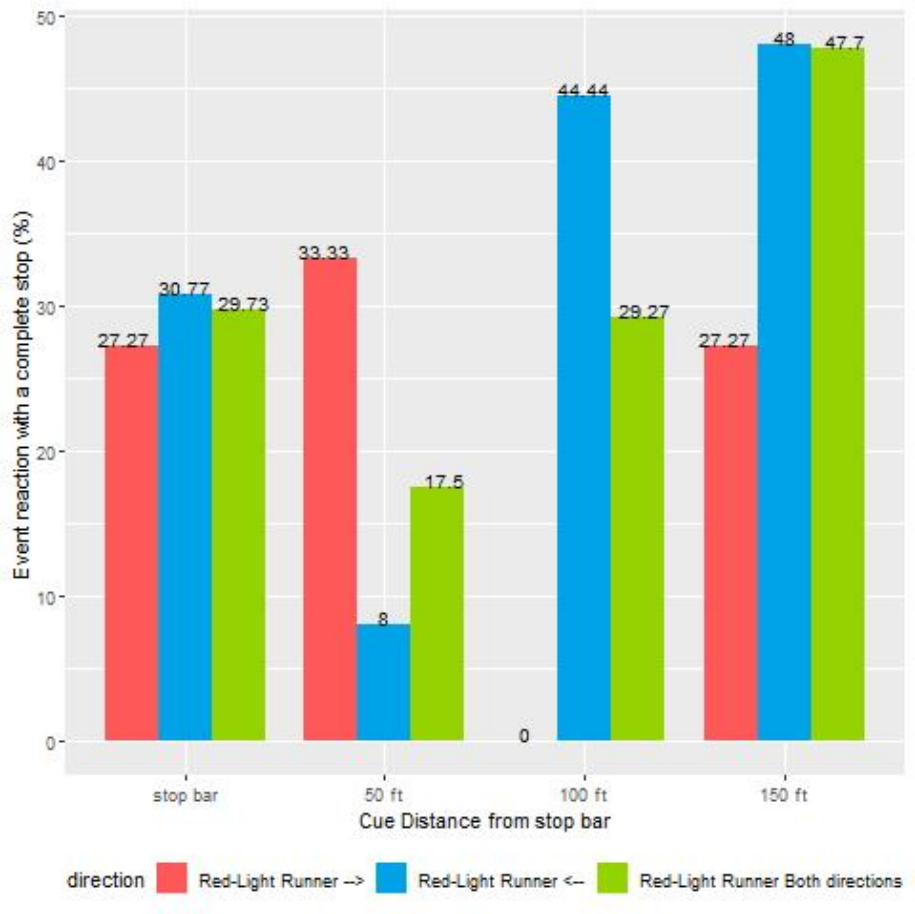
Results

Speed Behavior

		Speed reduction (mph)				Duration of speed reduction (sec)			
		Stop Bar	50 ft before the stop bar	100 ft before the stop bar	150 ft before the stop bar	Stop Bar	50 ft before the stop bar	100 ft before the stop bar	150 ft before the stop bar
Red-Light Runner ← 	Minimum	0.85	0.43	1.40	2.12	0.48	0.97	1.32	1.63
	Maximum	36.07	30.71	36.71	34.27	12.25	14.68	16.17	9.78
	Average	16.06	15.05	21.33	22.89	2.14	2.52	2.71	2.88
	Standard Deviation	11.18	8.06	10.83	8.20	2.15	2.86	2.74	1.57
Red-Light Runner → 	Minimum	1.57	0.43	1.03	0.67	0.82	0.42	0.98	1.64
	Maximum	29.36	37.19	18.48	34.10	3.97	3.08	4.25	17.82
	Average	16.43	16.18	8.24	18.73	2.17	1.79	2.38	3.78
	Standard Deviation	9.85	10.63	5.92	9.24	0.97	0.64	0.96	4.71

Results

Speed Behavior



Conclusion

- Communicating information from roadway infrastructure to CVs
  - Line of sight of in-vehicle sensors obstructed by other vehicles, pedestrians, buildings, and other objects
- In-vehicle warning system at signalized intersections when a conflicting non-CV ran a red light from a blind spot
- Speed reduction after the activation of the warning system
- Warning system activation at 50 ft or 100 ft before the stop bar pavement marking

Questions?