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Vehicle Safety Research Notes
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Development of a Simulation Model to Assess Effectiveness and Safety Benefits of Enhanced Rear Brake Light Countermeasures

Rear-end crashes account for more than 29 percent of all crashes; these types of crashes often result from a failure to respond (or delays in responding) to stopped or decelerating lead vehicles (NHTSA, 2007). The work described here is part of a larger program of research intended to develop and evaluate rear signaling applications designed to reduce the frequency and severity of rear-end crashes by redirecting drivers' visual attention to the forward roadway (for cases involving distracted drivers), and/or increasing the saliency or meaningfulness of the brake signal (for attentive drivers).

A computer-based model was developed under this effort to derive estimates of safety benefits associated with various rear signal approaches for avoiding rear-end crashes. The model was implemented in Matlab and relied on empirical data to model lead-vehicle-braking conflicts and estimate the impact of various system designs, including signal type and triggering criteria.

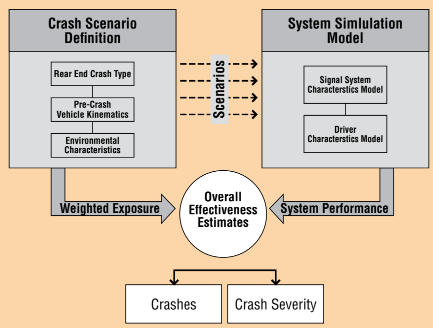
Data Parameters

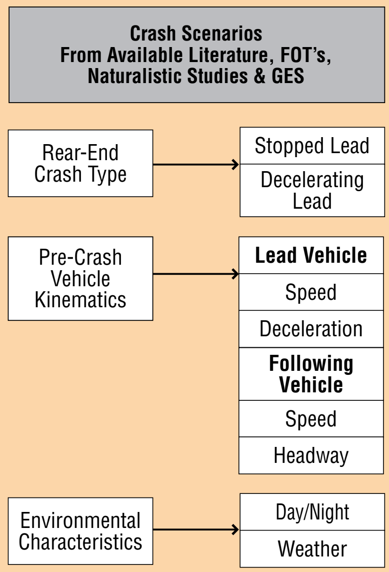
The model itself is comprised of defined constants and distributions across a number of measures. For example, distributions related to driver reaction time, acceleration, headway, initial vehicle speeds, and initial time-to-collision are built into the model, with parameter variations by event type (i.e., Crash, Near-Crash, or Crash Conflict). Model parameters were populated using available data including distributions based on observations and analysis from the 100-car dataset.

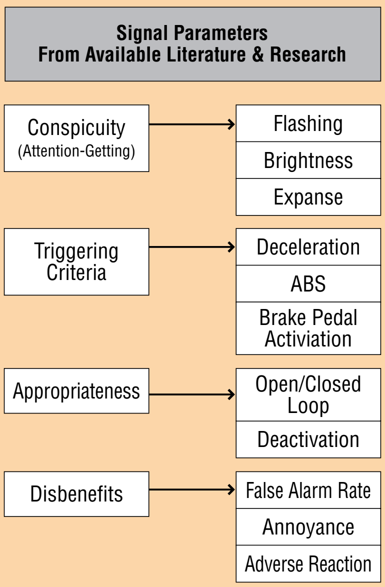
Driver Response to Signals

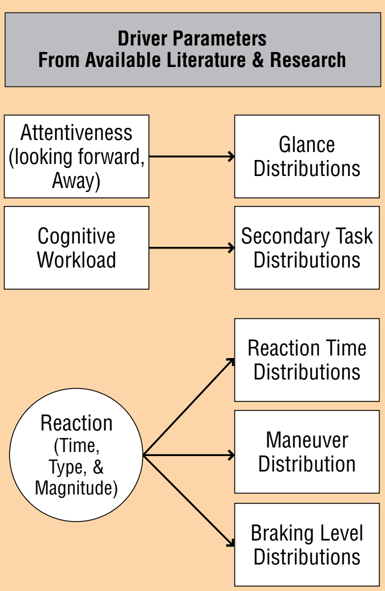
Parameters that determine how drivers respond to different countermeasures were derived from the empirical tests conducted with naïve participants within Task 1 and Task 2 of this effort. One relates to Eye Drawing, specifying the probability that the following vehicle driver's attention will be drawn to the forward scene relative to the countermeasure presented. The second variable addresses a Reaction Time Reduction, which indicates the percentage reduction in reaction time resulting from the presentation of an enhanced signal. Both measures are calculated relative to a standard signal (baseline).

Conceptual Model









Signal Activation

A number of parameters were defined to control signal activation, and are as follows:

- Signal activation if set deceleration parameter is exceeded; default of 0.35 g,
- Signal activation if ABS is activated,
- Signal activation when a minimum TTC threshold is exceeded (closed-loop activation),
- Signal activation timeout, which maintains the signal on for a set amount of time after the initial activation,
- Time of day is used to simulate instances where different system properties are available during daytime compared to nighttime, and
- Minimum speed at which the signal can activate.

Finally, a set of environmental parameters were defined to account for braking limits on wet pavement (default value of 0.65 g) and dry pavement braking (0.90 g).

Simulation Control and Scenario-Variant Parameters

Parameters were also defined to control the simulation, including number of runs (default value of 25), number of iterations (default value of 1000), and an index that indicates whether standard brake lamps or a proposed countermeasure is being evaluated. Once these are defined, the characteristics of the enhanced signal that is being evaluated are defined, specifically luminaire (steady burn, TCL, flashing), brightness (130 cd, 420 cd, 840 cd, or 1420 cd), and location (outboards or CHMSL).

As the simulation is underway, distributions are accessed to assign values to the scenario characteristics discussed previously (e.g., deceleration, reaction time).

Results

The computer-based model was used to estimate safety benefits for several different potential enhanced signal approaches, including the following:

- Dual lighting levels (Day versus Nighttime lighting brake lamp levels; day brightness increased to levels of 420 cd and 840 cd separately, while nighttime levels maintained at 130 cd; steady burn);
- Recommended enhanced system proposed in Wierwille, Llaneras, and Neurauter (2008), but with updated findings using the current allowable brightness level (Simultaneous 5Hz flashing at 420 cd);
- Simultaneous 5Hz flashing at 130cd with deceleration-based activation threshold at 7 m/s2, anti-lock braking system (ABS), and a 31 mph minimum speed;
- Simultaneous 5Hz flashing at 130 cd at 0.35 g activation threshold;
- Increased brightness (Steady burn at 420cd) at 0.7 g activation threshold and/or ABS
- Closed-loop signaling system using activation triggers dependent on time-to-collision values of 1.5, 2.0, and 2.5 seconds;

- Different time-based signal timeouts at 2, 5, and 10 seconds;
- Different deceleration triggering criteria with activations at 0.35 g, 0.5 g, and 0.7 g; and
- ABS activation.

The results for each of these conditions are shown in the table below. Note that the figures shown are based on the empirical data collected, and that a number of assumptions were used in attempting to make these data conform to inputs that would be useful for the model. Therefore, caution should be used in interpreting these estimates. The descriptions of the conditions on the table are abbreviated; please refer to the list above for detailed descriptions of the different enhanced signaling treatments that were examined.

Simulation Condition	System Effectiveness (SE)	Potential Crash Reduction in Annual Crashes	System Harm Reduction (SR)	Potential Harm Reduction*
Dual lighting levels @ 420 cd	ns	ns	ns	ns
Dual lighting levels @ 840 cd	ns	ns	ns	ns
Simultaneous flashing at 420 cd (equivalent to 840 cd and 1420 cd based on empirical tests), with an activation threshold of 0.35 g.	**4.3% (1.0%)**	**18,592 (4,182)**	**8.6% (1.2%)**	**8,603 (1,179)**
Simultaneous flashing at 130 cd, with an activation threshold of 7 m/s2.	ns	ns	ns	ns
Simultaneous flashing at 130 cd, with an activation threshold of 0.35 g.	**1.4% (0.7%)**	**6,003 (2,960)**	**3.3% (1.5%)**	**3,275 (1,471)**
Steady burn at 420 cd, with an activation threshold of 0.70 g.	ns	ns	ns	ns
Closed loop TTC-based activation simultaneous flashing @ 420 cd (equivalent to 840 cd and 1420 cd based on empirical tests) with activation at 0.35 g.				
- 1.5 sec TTC	ns	ns	**2.9% (1.3%)**	**2,935 (1,346)**
- 2.0 sec TTC	**1.9% (0.8%)**	**8,192 (3,379)**	**5.6% (1.4%)**	**5,584 (1,414)**
- 2.5 sec TTC	**2.4% (0.7%)**	**10,430 (3,177)**	**5.9% (1.2%)**	**5,880 (1,232)**
Timeout effects simultaneous flashing @ 420 cd (equivalent to 840 cd and 1420 cd based on empirical tests), with activation at 0.35g				
- 2 sec timeout	**5.1% (0.8%)**	**21,723 (3,269)**	**10.1% (1.2%)**	**10,132 (1,196)**
- 5 sec timeout	**4.6% (0.8%)**	**19,774 (3,241)**	**8.9% (1.1%)**	**8,930 (1,141)**
- 10 sec timeout	**4.1% (0.8%)**	**17,345 (3,267)**	**7.8% (1.1%)**	**7,833 (1,076)**
Activation threshold effects simultaneous flashing @ 420 cd (equivalent to 840 cd and 1420 cd based on empirical tests)				
- 0.35 g	Same as "Simultaneous Flashing at 420 cd"			
- 0.50 g	**3.7% (0.7%)**	**15,635 (2,937)**	**5.4% (1.2%)**	**5,408 (1,243)**
- 0.70 g	ns	ns	**4.6% (1.1%)**	**4,571 (1,142)**
ABS activation	ns	ns	ns	ns

The results suggest estimated potential benefits for conditions involving enhanced signals that flash simultaneously at 420 cd, and to a lesser degree at 130 cd, which is consistent with the results of the empirical tests. Post-hoc pair-wise comparisons between the different closed-loop TTC-based activation, timeout, and activation threshold conditions and the "baseline" (i.e., the "Flashing at 420 cd" condition) showed no statistically significant differences at the α=0.05 significance level. In general, it appears that at a practical level, the model does not predict any detrimental effect because of imposition of a timeout to the enhanced signal. However, it is likely that this factor would have a larger effect in cases where lead vehicles have been stopped for a substantial amount of time (e.g., > 2 sec). Those cases were not considered in the simulation. The closed-loop activation tended to nominally reduce observed effectiveness in the range of threshold values tested, although no significant differences were detected. Similarly, increases in the activation threshold, especially once the threshold is shifted upwards of 0.50 g, nominally reduced the benefits of the enhanced signal.

Conclusions

Estimates generated by the model suggest brake signal effectiveness can be significantly increased by modifying the signal to include flashing at 5Hz under certain brightness and triggering conditions. The most effective signal tested employed simultaneous flashing of all lamps at 5Hz at a brightness level of 420 cd, a deceleration-based trigger threshold set to 0.35 g, and a 2 second timeout following vehicle stop. This signal was found to reduce rear-end crashes by 5.1% (equivalent to 21,723 crashes) and harm by 10.1% (equivalent to 10,132 fatal unit equivalents).

Estimates should be carefully interpreted since the model has not been validated, and is based on a set of underlying simplifying assumptions which restrict the scope, based on the available data.

Additional data are needed in order to refine and/or expand model outputs, including:

- Unintended consequences and disbenefits associated with signal approaches;
- Driver acceptance and annoyance;
- Exposure rates that better quantify the incidence with which a driver is not looking forward at the onset of a lead vehicle braking event; and
- Performance data associated with other signal approaches including activation of the hazards.

References

NHTSA. (2007). Traffic safety facts 2005: A compilation of motor vehicle crash data from the Fatality Analysis Reporting System and the General Estimates System. DOT HS 810 631. Washington, DC: National Highway Traffic Safety Administration.

U.S. Department of Transportation
National Highway Traffic Safety Administration

This Vehicle Safety Research Note is a summary of the technical research report: *Evaluation of Enhanced Brake Lights Using Surrogate Safety Metrics. Task 2 & 3 Report: Development of a Rear Signaling Model and Work Plan for Large-Scale Field Evaluation*. DOT HS 811 329. This report can be downloaded free of cost on the Vehicle Safety Research section of NHTSA's Web site (www.nhtsa.gov).