DRIVER ACCEPTANCE AND BEHAVIORAL CHANGES WITH AN INTEGRATED WARNING SYTEM: KEY FINDINGS FROM THE IVBSS FOT

David J. LeBlanc, James R. Sayer, Shan Bao, Scott Bogard,
Mary Lynn Buonarosa, Adam Blankespoor and Dillon Funkhouser
University of Michigan Transportation Research Institute
USA
Paper Number 11-0260

ABSTRACT

The Integrated Vehicle-Based Safety System Field Operational Test (IVBSS FOT) was conducted to develop and evaluate an integrated system of crash warning technologies. A field operational test was conducted with prototype integrated crash warning systems onboard both passenger vehicles and heavy trucks. The evaluation reported here focused on driver acceptance of the integrated system, as well as identifying changes in driver behavior associated with the system. The integrated system was designed to address rear-end, lateral drift, and lane-change/merge crashes. The light vehicle system also addressed curve speed crashes.

One hundred and eight light vehicle drivers and 18 professional heavy truck drivers were recruited for the field operational test. The passenger car drivers used a prototype vehicle as their own personal vehicle. The commercial drivers used the heavy truck as part of their daily work. A data acquisition system captured onboard data, and analyses were conducted on driver performance and secondary task behaviors. Subjective feedback from questionnaires, debrief interviews, and focus groups were also analyzed.

Drivers on both vehicle platforms were largely accepting of these systems. Several behaviors were observed to be influenced by the presence of these systems; other behaviors were unaffected.

INTRODUCTION

Analyses by the US Department of Transportation (US DOT) indicate that 61.6 percent (3,541,000) of police-reported, light-vehicle crashes and 58.7 percent (424,000) of police-reported, heavy-truck crashes could potentially be addressed through the widespread deployment of integrated crash warning systems that address rear-end, roadway departure, and lane-change/merge collisions [1].

Furthermore, integration can be expected to significantly improve overall warning system performance relative to the non-integrated subsystems. This would result from each warning functionality being able to leverage additional sensors, i.e. sensors required for the other warning functionalities, creating a better awareness of the driving context. This may improve the reliability of threat detection, allowing more timely warnings, and also reduce invalid or nuisance warnings which may help driver acceptance.

The IVBSS project was launched to develop and evaluate a state-of-the-art integration of multiple crash warning technologies, and field operational test the systems with drivers recruited from the general public and from a commercial trucking fleet. Three crash-warning subsystems were integrated into both light vehicles and heavy trucks in the IVBSS program. The systems were:

- Forward crash warning (FCW), intended to warn drivers of the potential for a rear-end crash with another vehicle,

- Lateral drift warning (LDW), intended to alert drivers that they are drifting outside their travel lane,
- Lane-change/merge warning (LCM), designed to warn drivers who are initiating lane changes that adjacent same-direction vehicles are present (accompanied by full-time side-object-presence indicators), and
- Curve speed warning (CSW) (light vehicles only), which warns drivers if they may be traveling too fast to travel comfortably through an upcoming curve.

The IVBSS FOT was conducted under a cooperative agreement between the US DOT and the University of Michigan Transportation Research Institute (UMTRI). UMTRI team partners included Visteon Corporation, Eaton Corporation, Honda R&D America, TK Holdings, and Con-way Freight. A separate analysis of the data in the FOT was conducted by the US DOT Volpe National Transportation Systems Center, including estimation of the integrated system's potential safety benefits.

This paper is arranged in sections, including: a description of the integrated systems; a methodology section; a report on the travel made during the tests as well as the frequency of warning events; a description of the results addressing driver acceptance; a separate section on driver behavioral changes related to the integrated system; and a conclusions section.

INTEGRATED SYSTEM DESCRIPTIONS

The integrated systems were prototypes that were designed to address specific crash scenarios that were identified by the US DOT [1]. The design process included using these scenarios to establish functional requirements [2], [3], then determining technical specifications for the systems [4], [5]. A program of human factors research was also pursued within the project, providing guidance for both the driver-vehicle interface (DVI) requirements as well as rules for handling situations in which two or more warnings were requested within a few seconds.

Prototypes of the two platforms were then validated using a set of objective test procedures. Throughout this process, the methodology for the two vehicle platforms was similar, but given the differences in vehicle types and use, the system designs and driver interfaces were different in implementation.

Light vehicle platform

The light vehicle platform development was led by Visteon and TK Holdings, with support from UMTRI on systems engineering and human factors, and technical support from Honda R&D America for installing the system on a set of MY 2006 and 2007 Accord SE sedans. (The warning systems are not related to Honda OEM products.) The system included seven radars: one long-distance 77 GHz forward-looking sensor and six 24 GHz radars to cover the adjacent lanes as well as a distance of 10 to 15 m behind the vehicle for overtaking traffic (see Figure 1). A vision system was used to identify lane boundaries and provide lane position and lateral drift warning functions. Automotive-grade, non-differential global positioning system (GPS) was used with an onboard digital map to predict upcoming curvature for the curve-speed warning, as well as providing information about the roadway for other warning functions. A fleet of 16 such vehicles was built.

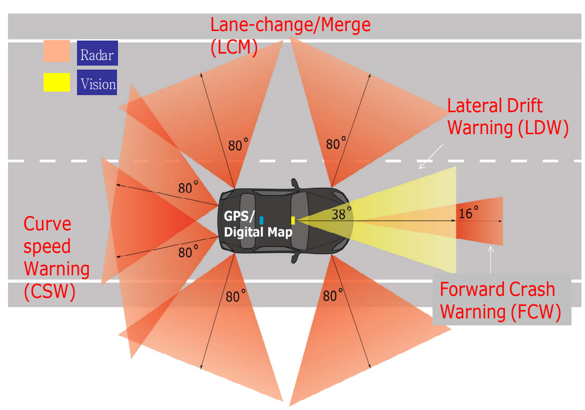

Figure 1. Light vehicle sensors (not to scale).

Figure 2. Light vehicle fleet of 16 vehicles.

The FCW function responded to moving and stationary targets, employing assumptions about an inattentive driver's response time and likely deceleration levels, as well as other considerations. The warning for the FCW was a combination of an auditory cue (a series of short beeps), plus a brief brake pulse. The CSW function warned the driver during approaches to a curve, using thresholds for a comfortable lateral speed. Since the purpose of the warning for CSW is similar to that for FCW – to ensure the driver looks forward to assess the situation – the CSW shared the same auditory cue with the FCW. The CSW did not include a brake pulse, given that the time criticality of driver response is a bit less for CSW.

The set of warnings for lateral motions of the vehicle employed two different driver cues. If the vehicle was moving across a lane boundary (with no turn signal applied), and the adjacent space was unoccupied, then a set of pulsing motors in the seat pan provided the driver with a simulated rumble strip (and no auditory cue). If there was either a potential threat in the adjacent space, such as same-direction traffic or a nearby roadside barrier, then the driver would receive an auditory alert with directionality (left side warning for left-going motion). This was true whether the turn signal was applied or not.

Several seconds after a warning, a message in text was shown to the driver on the center console, including "Hazard ahead", "Sharp Curve", "Left Drift," or "Left Hazard." This was not used as a stimulus, but to allow the driver to better understand the system. Note that the driver could not disable the alerts in either FOT, and could not alter the timing of the alerts. There was a volume adjustment, but the minimum level was chosen to provide enough signal to noise ratio that driver would hear even the quietest setting. The vehicle sound system volume was lowered briefly in situations where an alert was presented while the sound system volume was very high.

Heavy truck platform

The heavy truck integrated system was installed on ten MY2008 International TransStar 8600s (two-axle units) which were purchased by Con-way Freight for use in their commercial line-haul and pickup and delivery operations in the Detroit area. The integrated system was developed and installed by Eaton Corporation, with the lane tracking and lateral drift warning system provided by TK Holdings. Navistar (parent company of the International brand) provided technical assistance in the integration. Pickup & delivery was typically conducted with one trailer (28 to 32 foot, or a 45 to 53 foot trailer). Almost all line-haul driving was done in a double trailer configuration. The sensor set is shown for the heavy truck in Figure 3, and a photo of a FOT tractor is in Figure 4.

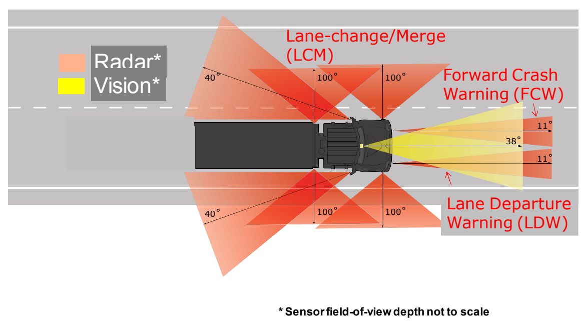

Figure 3. Heavy truck tractor and sensor coverage (not to scale).

Figure 4. An IVBSS tractor.

The driver-vehicle interface (DVI) for the heavy truck FCW included auditory and visual information. A set of short tones was given as time headway decreases to 3 sec, 2 sec, or 1 sec. A crash warning tone is also given when crossing a threshold that is based on the distance and closing kinematics relative to the forward target. A small screen mounted on the dash provided yellow indicators for the headway alerts and a red icon for the crash warning. Moving across a lane boundary triggered a directional auditory tone, with an accompanying graphic on the visual screen. If a lane change was initiated when traffic occupied the adjacent space, a directional auditory signal was provided. Anytime there was adjacent-lane traffic, color light emitting diodes (LEDs) installed on the forward A-pillars was illuminated so a driver consulting the side mirrors would see them.

METHODOLOGY

Light vehicle

The light vehicle field operational test involved the recruitment of 108 drivers, each of whom used a prototype vehicle for their own personal use over six weeks. During the first 12 days, the integrated system did not issue warnings to the driver, but was taking sensor readings and performing all calculations. The system then automatically enabled itself, and the driver is exposed to the warnings for another four weeks. Thus the individual driver's behavior and performance was compared to their own baseline. The light vehicle FOT took 12.5 months to complete.

Drivers were recruited within the southeast portion of Michigan, an area that is approximately 10,000 sq mi (260,000 sq km). This area includes metropolitan Detroit, its suburbs, a few smaller cities, and rural areas. Drivers were contacted randomly using a driver's license database from the state of Michigan. The final sample included 18 drivers in each of six age/gender cells, with age groups 20 to 30 yrs, 40 to 50 yrs, and 60 to 70 yrs. Gender was evenly split.

Each driver received an hour of training with the system, including a short test drive, and then they had full freedom to use the vehicle as they chose. They were only contacted during the six week period if the remote health-monitoring system indicated to researchers that the vehicle may need attention. Upon the completion of their driving, the driver returned the vehicle to UMTRI, completed a questionnaire, and was interviewed about specific alerts they received (using a video review). Twenty eight of the driver also participated in one of three focus groups. Each driver was paid $250 for his or her time spent traveling to UMTRI and for completing the subjective data protocols. The questionnaires covered the individual and the integrated warning functions, usability, comprehension, perceptions of safety benefit, system performance, and acceptance issues.

The prototype vehicle fleet included an UMTRI data acquisition system that collected all data from the radars, GPS, five video streams, and the prototype subsystem data bus traffic, as well as vehicle data bus information. This totaled up to 700 different signals at rates of 10 to 100 Hz, continuously collected. Remote monitoring of the fleet was done using cellular modems, with automatic diagnostics tools in place to maintain progress of the experiment. The bulk of the data was uploaded upon the driver's return, verified, and loaded into a set of relational databases for analysis.

Heavy truck

The Con-way fleet purchased the ten tractors, and agreed to have those retrofitted with the integrated system before the tractors entered normal operations at a terminal in the Detroit area. Twenty drivers were recruited from the existing drivers at that terminal, with the reward of a minimal amount of employee "points," plus the use of a newer tractor during their shift. The tractors were used for two shifts per day, so that each of the drivers essentially drove an equipped tractor all the time during the ten-month FOT period. Half the drivers drove a daytime pickup & delivery operation, operating in the Detroit metro area. The other half drove line-haul routes at night, transferring freight to terminals a few hundred miles away, returning home during the same shift.

This FOT also employed a within-subject design. Each driver had approximately two months in the baseline condition, and eight months with the system providing alerts. There were no structured interactions with the drivers during this period of time. At the end of the test, the drivers did complete a questionnaire addressing usability, comprehension of the functions and interfaces, system performance, perceptions of safety benefit, and acceptance. The tractors were also equipped with a data acquisition system that was similarly integrated to produce a very rich data set. Both the cellular modem-enabled monitoring operation and the direct download of data were similar to that described for the light vehicle platform.

EXPOSURE & SYSTEM EVENTS

Table 1 summarizes the distance traveled, trips (ignition cycles), and driving time associated with the onboard data gathered in the FOTs. Figures 5, 6, and 7 show the travel for the light vehicles and heavy trucks, respectively.

Table 1.
Travel during the FOTs

	Light vehicle	Heavy truck
Distance	213,309 mi 343,214 km	601,944 mi 968,528 km
Trips	22,657	22,724
Hours	6,164	13,678

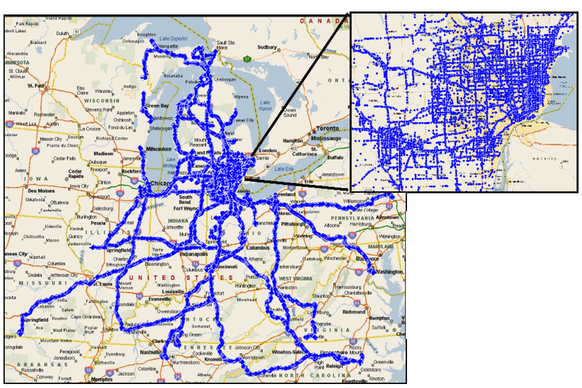

Figure 5. Light vehicle platform travel.

The mean alert rates (across drivers) when the system was enabled was 7.9 and 18.3 per 100 mi (161 km) for the light vehicle and heavy truck, respectively. Individual's alert rates varied substantially. For example, the individual with the highest light vehicle alert rate has more than 15 times the alerts, per unit distance, as the driver with the lowest rate.

Figure 8 shows the relative frequencies of the different warnings in the FOTs (averaging across the different driver experiences, and using data from the period in which the system was enabled to present alerts). Most warnings were lane drift warnings, which often reflected the common occurrence of drivers allowing their vehicle to cross a lane edge in situations where they may have felt little crash risk.

Figure 6. Heavy truck platform line-haul travel.

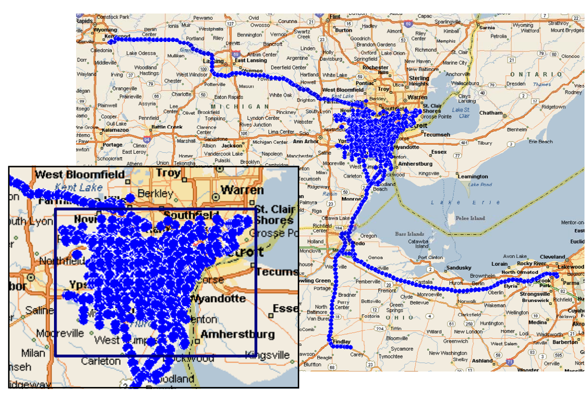

Figure 7. Heavy truck platform pickup & delivery travel in the Detroit area.

Another common cause of these particular warnings is unsignaled lane changes. Notice for the light vehicle population, the occurrence of FCW and CSW alerts is relatively rare, with a combined mean alert rate of 0.8 warnings per 100 mi (161 km). For the heavy truck drivers, lane-change/merge alerts were the second most common, although many of these were invalid alerts associated with false targets from reflections and 'ghosting' effects from radars looking backwards besides the large surface of box trailers. The truck FCW also had a fairly pronounced set of false positives for stationary objects, especially bridges and roadside objects. Given the repetitive nature of some of the routes, a geo-location feature to suppress false positives based on past history could have been an effective feature.

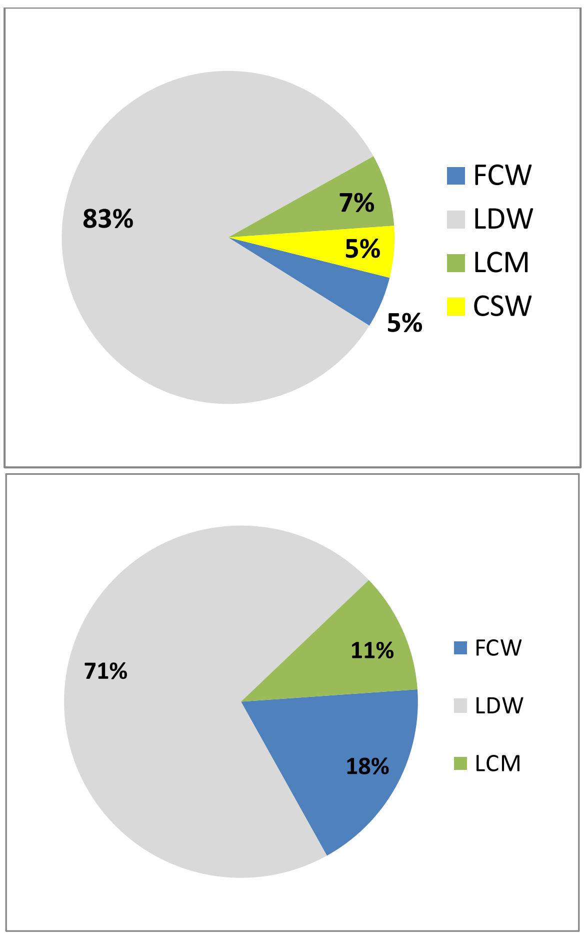

Figure 8. Fraction of warnings by warning type for light vehicle (upper chart) and heavy truck (lower chart).

RESULTS: DRIVER ACCEPTANCE

Light vehicle drivers were accepting of the integrated system and rated it well in terms of both usefulness and satisfaction, with 72 percent of all light vehicle drivers reporting they would like the integrated system in their personal vehicle. The majority of light vehicle drivers reported that they were willing to purchase the integrated system. However, most drivers were not willing to spend more than $750.

Fifteen of 18 heavy truck drivers stated that they would prefer driving with an integrated crash warning system, and they would recommend purchasing trucks with an integrated system.

Most light vehicle drivers self-reported that their driving behavior changed as a result of driving with the integrated system. The most frequently mentioned change in behavior was an increase in turn-signal use, which was the result of receiving LDW warnings provoked by failing to use turn signals when changing lanes (which is confirmed by the objective data). Heavy truck drivers reported that the integrated system made them more aware of the traffic environment, particularly their position in the lane, and eight heavy truck drivers stated that the integrated system potentially helped them avoid a crash. Thus there was evidence that both light vehicle and heavy truck drivers will be accepting of such systems. Furthermore, in responding to the questionnaire, both sets of drivers reported believing such systems will increase their driver safety.

Subjective feedback was used to compute ratings of the individual system features on the Van der Laan scale [6]. The Van der Laan scale shows "usefulness" and "satisfaction," each on a scale from -2 to 2, where positive ratings are for positive responses. The values are computed from a set of questions specifically designed for this purpose. The mean ratings for each subsystem as well as the integrated system are shown in Figure 9. All warning features score in the positive quadrants for both usefulness and satisfaction.

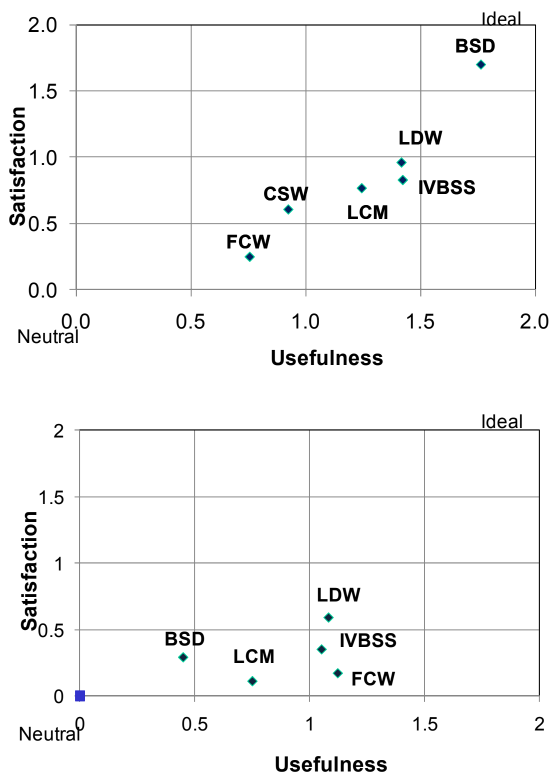

Figure 9. Van der Laan scale: usefulness and satisfaction as reported by light vehicle drivers (upper) and heavy truck drivers (lower).

Light vehicle drivers rated the lateral subsystems (LCM with BSD and LDW) more favorably than the longitudinal subsystems (FCW and CSW), and reported getting the most satisfaction out of the BSD component of the LCM subsystem. Light vehicle drivers found the integrated system to be useful in particular when changing lanes and merging into traffic. Light vehicle drivers reported FCW to be the least usefulness and least satisfying of the subsystems. Numerous light vehicle drivers commented that they did not like the brake pulse that accompanied warnings.

Heavy truck drivers stated that the system was convenient and easy to use, despite a relatively high ratio of invalid warnings to valid warnings when responding to stopped objects ahead or lane change/merge scenarios. Heavy truck drivers clearly preferred the LDW system the most, rating it the most satisfying of the three subsystems, with FCW being rated the most useful. LDW was a particular favorite for the line-haul heavy truck drivers, given the long hours and great distances covered on limited access roadways. However, both P&D and line-haul heavy truck drivers mentioned the headway time element of the FCW subsystem as being particularly helpful.

Light vehicle drivers did report in the questionnaires, debrief interviews, and in focus groups that there were alerts that they did not consider necessary. Older drivers were more forgiving than middle-aged or younger drivers in this regard, even though the rate of invalid alerts was relatively constant across age groups.

RESULTS: BEHAVIORAL CHANGES

Specific research hypotheses were posed a priori, and then addressed with onboard data or subjective data. Several statistical techniques were used, with the two most common techniques being general linear model and linear mixed model techniques. Findings that are based on results of a mixed linear model are derived from a model, not directly from raw data *per se*. However, model-predicted means and probabilities were checked against queries of the raw data set to validate the models. In all uses of linear mixed models, drivers were treated as a random effect. Significant factors in the linear mixed model approach were determined using a backwards step-wise method. Additional information regarding the statistical techniques used in analyzing the heavy truck field test data can be found in the data analysis plans for the project.

The independent variables varied slightly between analyses, but often the variables included whether the integrated system was enabled, the road class, wiper state (surrogate for precipitation), truck route type, and sometimes speed and trailer weight, as well as several others. References for details are cited in the following discussions.

Light vehicles

Analysis of onboard data showed statistically significant support for the following, at $p < 0.05$ (see [7] for detailed discussion of each of these):

- A 41% lower rate of lane departures with the integrated system (see Figure 10)
- A reduction of more than 50% in the fraction of lane changes in which a turn signal was not used, both on limited access and surface roads (see Figure 11)
- A 16% decrease in the time spent outside the lane on lane departures after which the driver returned the vehicle to the original lane (from a mean of 1.98 to 1.66 sec)
- A 13% increase in the number of lane changes per mile (even when accounting for several independent variables).
- Increase from 21% to 24% in the fraction of following time at headways of less than 1 second.

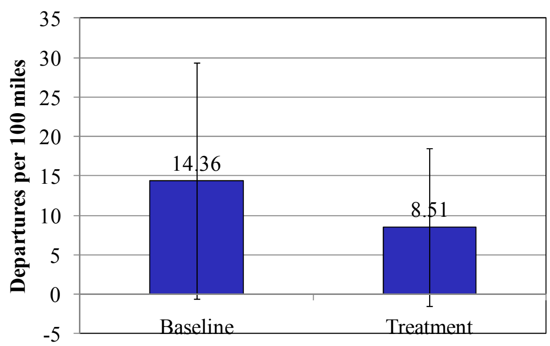

Figure 10. Frequency of light vehicle lane departures with and without the integrated system.

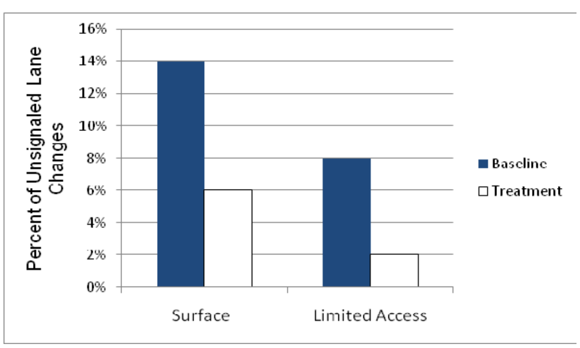

Figure 11. Frequency of unsignaled lane changes in the light vehicle test.

Two of these are unexpected outcomes: the increase in lane change frequency and the decrease of headway time. The cause behind each is not clear, but may be a reflection of increased driver confidence due to the integrated system; if so, it does not extend to other measures of related driving behavior. Specifically, here was no statistically significant effect of the integrated system on the following:

- No increase in secondary tasks while driving with the system.
- Mean position in the lane did not depend on whether the integrated system was enabled.
- No change in the general locations of adjacent vehicles when an LCM warning occurred (i.e., there was no clear trend suggesting drivers were filling gaps differently with the system.
- No change in conflict levels, as measured by the peak deceleration needed in any event to avoid striking the rear end of another vehicle.
- No change in frequency of hard-braking events or brake response time in FCW situations.
- No effect on lateral accelerations in curves, or on braking levels when approaching curves.

Heavy trucks

Analyses were performed that were similar to those done for the light vehicles. Analysis of onboard data showed statistically significant support for the following, at $p < 0.05$ (see [10] for detailed discussion of each of these):

- Drivers move closer to the lane center when the integrated system is active, from 10.8 cm right of center with a disabled system to 9.1 cm right of center with the system.
- Slightly longer time headways, from 2.84 sec to 2.97 sec [9].
- Drivers had shorter brake response times (from 1.56 sec to 1.35 sec) [9].

There was no statistically significant effect of the integrated system on the following:

- No increase in secondary tasks while driving
- No decrease in lane departure frequency, although 13 of 18 drivers had fewer departures.
- No change in how long the vehicle is outside its lane (unlike the effect seen in light vehicles).
- No change in turn signal use during lane changes (unlike light vehicles).

- No change in the general locations of adjacent vehicles when an LCM warning occurred (i.e., there was no clear trend suggesting drivers were filling gaps differently with the system.
- No change in the rate of lane changes (unlike light vehicles).
- No change in forward gap distances during lane changes.
- No change in the frequency of hard-braking events.

As reported earlier, drivers did feel positive about these systems and there was no evidence of negative, unanticipated risks for the heavy truck system.

CONCLUSIONS

The IVBSS FOT studied driver acceptance and behavioral changes of 108 light vehicle drivers and 18 heavy truck drivers while they were operating vehicles equipped with prototype integrated warning systems. The systems addressed forward crashes, lane drift crashes, and lane change/merge crashes. The light vehicle system also addressed curve-overspeed crashes.

Drivers were generally accepting of both systems, with functions addressing lane drifts and blind spot indications being the most popular. A number of analyses were reported in this paper which addressed behavioral changes including driver performance and secondary task behavior. For light vehicle drivers, the most striking changes in behavior were a 41% decrease in the frequency of lane departures, and a large increase in the usage of turn signals during lane changes. The time spent at shorter headways did increase, however. For the heavy truck drivers, there were slightly longer headways with the system and faster brake response times.

The outcome of these tests suggests it is possible to develop and successfully deploy a system with multiple functions without overwhelming or confusing the driver with warnings. In fact, drivers as a whole were positive about the system and 72% of the light vehicle drivers would like to have a similar system on their own vehicle, and 15 of the 18 commercial heavy truck drivers felt the same way.

ACKNOWLEDGMENTS

This work was done as part of US DOT cooperative agreement DTNH22-05-H-01232, with Jack Ference (NHTSA) as technical representative, in conjunction with the ITS Joint Program Office. UMTRI acknowledges the tremendous contributions of Visteon, Eaton, TK Holdings, and Honda, as well as Mike Hagan, Mark Gilbert, Michelle Barnes, Dan Huddleson, John Koch, and Mike Campbell of UMTRI. The Volpe NTSC team provided extensive information and collaboration throughout the program.
.

All reports generated by the UMTRI team for the IVBSS program can be found at: http://www.umtri.umich.edu/ivbss.php

REFERENCES

[1] Najm, W., Smith, J., and Toma, S. (2005): Development of Crash Imminent Test Scenarios for Integrated Vehicle-Based Safety Systems (IVBSS). U.S. Department of Transportation report DOT HS 810 757, April 2007.

[2] LeBlanc, D., Bezzina, D., Tiernan, T., Freeman, K., Gabel, M. and Pomerleau, D. (2008). Functional requirements for an integrated vehicle-based safety system (IVBSS) – light vehicle platform." University of Michigan Transportation Research Institute technical report UMTRI-2008-17.

[3] LeBlanc, D., Nowak, M., Tang, Z., Pomerleau, D., and Sardar, H. (2008): Functional requirements for an integrated vehicle-based safety system (IVBSS) – heavy truck platform." University of Michigan Transportation Research Institute technical report UMTRI-2008-19.

[4] LeBlanc, D., Bezzina, D., Tiernan, T., Freeman, K., Gabel, M. and Pomerleau, D. (2008): System performance guidelines for a prototype integrated vehicle-based safety system (IVBSS) – light vehicle platform." University of Michigan Transportation Research Institute technical report UMTRI-2008-20.

[5] LeBlanc, D., Nowak, M., Tang, Z., Pomerleau, D., and Sardar, H. (2008): System performance

guidelines for a prototype integrated vehicle-based safety system (IVBSS) – heavy vehicle platform." University of Michigan Transportation Research Institute technical report UMTRI-2008-19.

[6] Van Der Laan, J. D., Heino, A., and De Waard, D. (1997). A simple procedure for the assessment of acceptance of advanced transport telematics. Transportation Research, 5(1), 1-10.

[7] Sayer, J., Buonarosa, M. L., Bao, S., Bogard, S., LeBlanc, D., Blankespoor, A., Funkhouser, D., and Winkler, C. (2010). "Integrated Vehicle-Based Safety Systems Light-Vehicle Field Operational Test, Methodology and Results Report. Ann Arbor, MI. : University of Michigan Transportation Research Institute report UMTRI-2010-19.

[8] Sayer, J., Funkhouser, D., Bao, S., Bogard, S., LeBlanc, D., Blankespoor, A., Buonarosa, M. L., and Winkler, C. (2010). "Integrated Vehicle-Based Safety Systems Heavy Truck Field Operational Test, Methodology and Results Report." Ann Arbor, MI: University of Michigan Transportation Research Institute report UMTRI-2010-27.

[9] Bao, S., LeBlanc, D., Sayer, J., and Flannagan, C. (2011). "Field Evaluation of an Integrated, In-vehicle Warning System on Heavy Truck Drivers' Driving Performance. Submitted to Human Factors.