Safety Impact of an Integrated Crash Warning System Based on Field Test Data

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ABSTRACT

This paper provides the results of an analysis conducted to assess the safety impact of an integrated vehicle-based crash warning system based on naturalistic driving data collected from a field operational test. The system incorporates four functions that warn the driver of an imminent rear-end crash, excessive speed to an upcoming curve, lane-change crash, or unintentional lane departure. The safety impact is assessed in terms of observed changes in driving behavior, exposure to driving conflicts, near-crash experience, and projected potential reductions in the number of annual target crashes. Unintended consequences are examined by analyzing driver engagement in secondary tasks and eyes-off-the-forward-scene behavior. A total of 108 subjects, split by gender and three age groups, participated in the field test by driving in an unrestricted manner for a period of six weeks each. In the first two weeks, designated as the baseline period, the subjects performed their naturalistic driving with the system turned off while the data acquisition system collected their performance data. In the last four weeks, designated as the treatment period, the system was turned on and provided the subjects with visual, auditory, and haptic crash warning signals. This paper discusses the safety impact of the system for individual subject groups based on gender and age. The integrated system has the potential to reduce the number of rear-end, opposite-direction, lane-change, and road-departure crashes involving at least one passenger car. Moreover, the system did not influence drivers to engage in more secondary tasks.

INTRODUCTION

An integrated vehicle-based crash warning system was developed and tested under the Integrated Vehicle-Based Safety System (IVBSS) initiative of the United States Department of Transportation's (U.S. DOT) Intelligent Transportation System program [1]. The system was designed to address rear-end, curve-speed, lane-change, and roadway departure crashes for light vehicles that encompass passenger cars, vans and minivans, sport utility vehicles, and light pickup trucks with gross vehicle weight ratings less than or equal to 4,536 kg. The IVBSS initiative was launched in November 2005 as a two-phase, multi-year cooperative research effort between the U.S. DOT and an industry team led by the University of Michigan Transportation Research Institute and supported by Visteon, Takata, and Honda. In the first phase, the team designed, built, and verified through a series of track and public road tests that the integrated safety system prototype met the performance requirements and was safe for use by unescorted volunteer drivers during a planned field operational test. In the second phase, the team devised the field test concept, built a vehicle fleet of 16 passenger cars, and conducted the field test using 108 participants who drove the IVBSS-equipped cars as their own personal vehicle for 6 weeks each.

The Volpe National Transportation Systems Center of the U.S. DOT's Research and Innovative Technology Administration performed an independent evaluation to assess the safety impact, gauge driver acceptance, and characterize the capability of the integrated crash warning system. This paper focuses on the safety impact assessment of this independent evaluation.

System Description

The integrated safety system assists drivers in avoiding or reducing the severity of crashes by providing the following four crash warning functions [2]:

- Forward crash warning (FCW)
- Curve-speed warning (CSW)
- Lane-change/merge (LCM) warning
- Lane-departure warning (LDW)
  - LDW cautionary (LDW-C): refers to alerts issued when the vehicle drifts out

of its lane into a clear area (unoccupied lane or clear shoulder).
- LDW imminent (LDW-I): refers to alerts issued when the vehicle drifts into an occupied lane or towards a roadside object, causing potential for a collision.

Using radar and vision-based sensors, the integrated system addresses crashes in which an equipped vehicle strikes the rear end of another vehicle (FCW), approaches a curve at excessive speed (CSW), changes lanes or merges into traffic and collides with another same-direction vehicle (LCM), and unintentionally drifts off the road edge or crosses a lane boundary (LDW). Figure 1 illustrates the field of view for the various sensors of the integrated system.

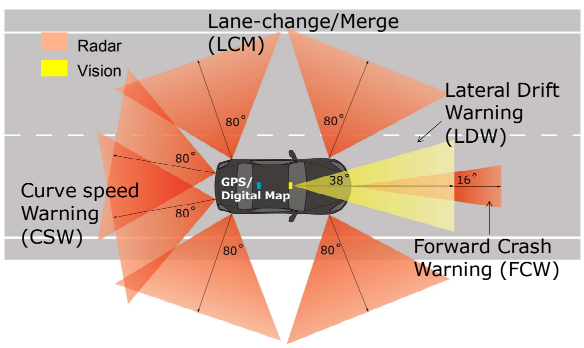

Figure 1. Integrated system sensor coverage

System alerts are communicated to the driver through a combination of auditory, haptic, and visual warnings. Figure 2 shows the visual elements of the driver interface and system controls. The visual elements include a center display and blind spot monitoring lights in the side rear-view mirrors. System controls consist of a three-position volume switch and a mute button that temporarily silences the alerts for a two-minute period. Auditory alerts are issued through speakers in the dashboard (FCW and CSW) and each side of the driver's headrest (LCM and LDW-I). Haptic alerts are transmitted through vibrations on each side of the driver's seat (LDW-C) and a brake pedal pulse (FCW).

Description of Field Operational Test

The field operational test employed 108 subjects from southeast Michigan who drove 16 IVBSS-equipped 2006 and 2007 Honda Accords. While an Accord was used as the prototype test vehicle, the research conducted in this field test applies to all light vehicles. Subjects were balanced for gender and age, including younger (20-30 years old), middle-aged (40-50 years old), and older (60-70 years old) groups.

Figure 2. Driver-vehicle interface of the integrated system

Throughout their participation in the field test, the subjects drove the instrumented vehicle in an unrestricted manner.

The field test started in April 2009 and ended in early May 2010. A within-subject experimental design was implemented where each subject experienced two test conditions over a period of 40 days. During the first condition, called the baseline period, subjects drove the instrumented vehicle for about 12 days with the integrated safety system turned off. In the second condition, treatment period, subjects drove the vehicle for about 28 days with the integrated safety system enabled. Even though the system alerts were disabled during the baseline period, the on-board data acquisition system recorded all data and alerts. All analyses were conducted within subjects.

Throughout the course of the field test, drivers accumulated over 213,000 miles (343,000 km) of driving – 32% during the baseline period and 68% during the treatment period. The number of alerts issued per 100 miles (161 km) in the baseline period ranged from 1.5 to 53.6, with an average of 14.0 alerts per 100 miles. Alert rates decreased during the treatment period. The driver with the lowest alert rate during the treatment period received 1.7 alerts per 100 miles and the driver with the highest alert rate received 28.8 alerts per 100 miles. The average alert rate across drivers during the treatment period was 8.3 per 100 miles. About 84% of all alerts issued during the field test were cautionary drift alerts.

TARGET CRASHES

The integrated safety system was designed to address the pre-crash scenarios listed in Table 1. Pre-crash scenarios identify vehicle movements and the critical event immediately prior to a crash [3]. Based on crash statistics from the 2004-2008 National Automotive Sampling System General Estimates System (GES) crash databases, light vehicles were involved in crashes preceded by these 9 pre-crash scenarios at an average annual frequency of about 2,674,000 police-reported crashes in the United States.

Table 1. Annual frequency of target crashes by pre-crash scenario

Pre-Crash Scenario	Crashes	% Crashes
Rear-end/lead vehicle stopped	907,000	33.9%
Rear-end/lead vehicle decelerating	378,000	14.1%
Road edge departure/no maneuver	371,000	13.9%
Changing lanes/same direction	311,000	11.6%
Turning/same direction	195,000	7.3%
Negotiating a curve/lost control	181,000	6.8%
Rear-end/lead vehicle moving	177,000	6.6%
Opposite direction/no maneuver	103,000	3.9%
Drifting/same direction	51,000	1.9%
Total	2,674,000	100.0%

Each pre-crash scenario listed in Table 1 is described below:

- Rear-end/lead vehicle stopped: driver is going straight and then closes in on a stopped lead vehicle. In some of these crashes, the lead vehicle first decelerates to a stop and is then struck by the following vehicle, which typically happens in the presence of a traffic-control device or when the lead vehicle is slowing down to turn.
- Rear-end/lead vehicle decelerating: driver is going straight while following another lead vehicle and then the lead vehicle suddenly decelerates.
- Road-edge departure/no maneuver: vehicle is going straight or negotiating a curve and then departs the edge of the road at a non-junction area. Vehicle was not making any maneuver such as passing, parking, turning, changing lanes, merging, or a prior corrective action in response to a previous critical event.
- Changing lanes/same direction: driver is changing lanes, passing, or merging and then encroaches into another vehicle traveling in the same direction.
- Turning/same direction: driver is turning left or right at a junction and then cuts across the path of another vehicle initially going straight in the same direction.
- Negotiating a curve/lost control: driver is negotiating a curve and loses control of the vehicle.
- Rear-end/lead vehicle moving: driver is going straight or decelerating and then closes in on a lead vehicle moving at a slower constant speed.
- Opposite direction/no maneuver: vehicle is going straight or negotiating a curve and then drifts and encroaches into the lane of another vehicle traveling in the opposite direction.
- Drifting/same direction: driver is going straight or negotiating a curve and then drifts into an adjacent vehicle traveling in the same direction.

SAFETY IMPACT ASSESSMENT METHODOLOGY

Safety impact is assessed in terms of changes in drivers' behavior when the system was enabled, and the potential of the system to reduce the number of target crashes. Figure 3 illustrates the analysis framework used to assess the safety impact. This framework divides the driving experience of test subjects into three areas: overall experience, driving conflicts, and near crashes. Overall driving data include all field test exposure. Driving conflict data are comprised of high-risk driving scenarios in which a crash would occur if the driver did not intervene. Near crashes constitute a small subset of longitudinal and lateral driving conflicts in which an intense driver response was observed.

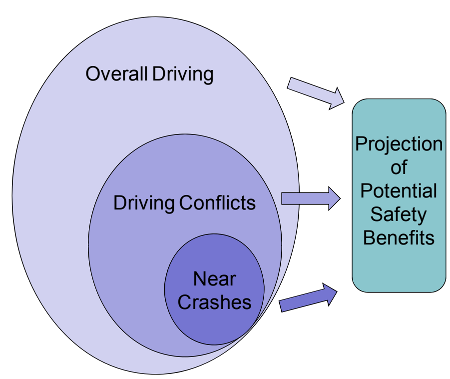

Figure 3. Safety benefits framework

Overall Driving

To determine changes in overall driving, both driver performance and driver attention were analyzed. Driver performance was assessed by comparing overall driving data from the baseline and treatment periods. The following measures were used to define driver performance:

- Travel speed
- Time headway
- Number of lane changes per 100 miles driven
- Proportion of signaled lane changes
- Number of lane excursions per 100 miles driven
- Duration of lane excursions
- Speed at curve entry

Driver attention to the driving task was analyzed through video analysis of driver behavior during the 10 seconds leading up to about 17,000 system alerts. Driver behavior leading up to alerts that occurred during the baseline period (muted to the driver but recorded by the system) was compared to behavior leading up to alerts during the treatment period. The following measures were used to define driver attention:

- Frequency of secondary tasks
- Frequency of eyes off forward scene

Driving Conflicts

The analysis of driving conflicts focused on driver encounter and response to various dynamically distinct driving situations that correspond to the pre-crash scenarios listed in Table 1. These driving scenarios were extracted from the field test data through the application of data mining algorithms that took into account the location and vehicle dynamics of the IVBSS-equipped vehicle, the relative location and dynamics of surrounding vehicles and objects, and the geometry of the roadway. The algorithms differentiated between four different types of conflicts:

- Rear-end: host vehicle approaches a lead vehicle that is stopped, decelerating, or moving a slower, constant speed.
- Lane-change: host vehicle makes a lane change or drifts into an adjacent lane and encounters another vehicle.
- Road-departure: host vehicle departs the roadway.
- Curve-speed: host vehicle approaches a curve with excessive speed.

The data mining algorithms extracted 20,839 driving conflicts or 10.2 conflicts per 100 miles from the field test data.

Near Crashes

The analysis of near crashes addressed driving conflicts of each type that resulted in a driver response above a certain intensity level. Thus, near crashes constitute a subset of longitudinal and lateral driving conflicts in which an intense driver response was observed during the field test data based on various kinematic measures. Near-crash thresholds were determined using distributions of intensity measures recorded in the field test [4]. By applying the near-crash criteria shown in Appendix A, the query of the processed numerical database extracted 1,946 potential near crashes from the field test data. A video analysis was conducted for each near crash to determine whether a valid threat was actually present in the driving scenario. As a result, a total of 1,810 near crashes or about 93% contained a valid threat. The analysis compared the experience with valid near crashes between the baseline and treatment periods.

Two-tail paired *t*-tests were performed for all safety impact analyses that compared data between the baseline and treatment periods. A paired t-test is used to determine if there is a statistically significant difference between the means of the same subjects under different circumstances. A two-tailed test is used when the mean under the treatment condition could be either greater than or less than the mean during baseline. For all these *t*-tests, a p value of 0.05 or 95% confidence level was used to claim statistical significance in observed differences.

Projection of Potential Safety Benefits

The system's potential to reduce the number of target crashes is ideally measured from actual crash data. However, only three crashes occurred during the field test. Thus, this analysis estimates potential safety benefits of the integrated system using driver experience with near crashes observed during the field operational test. The exposure to near crashes in the baseline and treatment periods provides a suitable, surrogate measure to estimate the potential safety benefits because it captures the frequency and severity of driving conflicts encountered during the field test. Equation (1) estimates the effectiveness of each system function for each driver based on driver exposure to near crashes with and without the assistance of the integrated system [5]:

$$E(S_i) = 1 - PNC_w(S_i)/PNC_{wo}(S_i) \qquad \textbf{(1)}$$

$PNC_w(S_i) \equiv$ Near crash rate of type S_i in treatment
$PNC_{wo}(S_i) \equiv$ Near crash rate of type S_i in baseline

To project the annual reduction in the number of target crashes, effectiveness estimates of system functions were applied to the corresponding number of annual crashes for each pre-crash scenario listed in Table 1 [6].

RESULTS

This section presents results related to overall driving, driving conflicts, near crashes, and the projection of potential safety benefits.

Overall Driving

When driving with the integrated system, drivers showed changes in time headway, turn signal usage, frequency of lane departures, and duration of lane departures. Drivers did not show significant differences in travel speed, frequency of lane changes, speed at curve entry, or attention to the driving task.

Drivers showed a small decrease in time headway when driving over 25 mph (40 km/h) on non-freeway roads with the system enabled. Drivers did not show a significant change when driving on freeways. Table 2 shows the results of the paired *t*-test, where *n* represents the number of drivers in the test and a bold *p* value indicates significant results.

Table 2. Paired *t*-test results of mean headway in second

	Road Type	
	Freeway	Non-Freeway
Baseline	1.41	2.05
Treatment	1.37	1.98
p	0.16	**0.00**
n	108	108

Drivers showed a significant increase in the proportion of lane changes in which they used their turn signal overall, and for each age and gender group. Overall, drivers used their turn signal during 62% of lane changes in the baseline and 75% of lane changes during the treatment, indicating that driving with the integrated system encourages drivers to use their turn signal. These results are shown in Table 3. Drivers increased turn signal use on both freeway and non-freeway roads.

Table 3. Paired *t*-test results of percent of signaled lane changes

	Overall	Gender		Age (years)		
		Male	Female	20-30	40-50	60-70
Baseline	62%	56%	69%	67%	60%	61%
Treatment	75%	72%	78%	78%	76%	72%
p	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
n	108	54	54	36	36	36

Drivers showed an overall 21% decrease in the rate of lane excursions when driving with the integrated system. As shown in Table 4, results were significant for each age and gender group, indicating that drivers maintained better lane positioning when driving with the integrated system. While the rate of lane excursions was much higher during freeway driving than non-freeway driving (55.9 per 100 miles compared to 20.6 per 100 miles), drivers showed a larger reduction in the rate of lane excursions on non-freeway roads (25% compared to 20%).

Table 4. Paired *t*-test results of lane excursions per 100 miles

	Overall	Gender		Age (years)		
		Male	Female	20-30	40-50	60-70
Baseline	38.7	37.1	40.3	41.1	40.4	34.5
Treatment	30.6	29.2	32.0	33.2	29.6	29.0
p	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.01**
n	108	54	54	36	36	36

In addition to experiencing fewer lane excursions with the system enabled, the duration of the lane excursions that occurred were an average of 3% shorter with the system enabled, suggesting that drivers were returning to their travel lane more quickly. Results were significant overall, and for males and middle-aged drivers, as shown in Table 5.

Table 5. Paired *t*-test results of lane excursion duration in seconds

	Overall	Gender		Age (years)		
		Male	Female	20-30	40-50	60-70
Baseline	2.72	2.70	2.74	2.72	2.72	2.72
Treatment	2.64	2.59	2.69	2.70	2.56	2.65
p	**0.03**	**0.02**	0.38	0.61	**0.01**	0.44
n	108	54	54	36	36	36

In the video analysis of alert scenarios, two measures pertaining to driver attention were recorded: presence of secondary tasks within 10 seconds before a system alert was issued, and whether or not drivers had their eyes off the forward scene for over 1.5 continuous seconds within the 5 seconds before an alert. Secondary tasks include behaviors exhibited by the driver that do not support the driving task and could be potentially distracting. These measures describe how attentive drivers are to the driving task with and without the integrated system.

The most frequent secondary tasks engaged in by the drivers in alert scenarios included talking to or looking at passengers (19% of all alerts), grooming (8% of alerts), talking on cellular phones (7% of alerts), and looking outside the car (6% of alerts). Secondary task engagement ranged from 17% of alerts for a middle-aged female driver to 87% of alerts for a younger female driver.

Table 6 shows the percent of alerts in which drivers were engaged in secondary tasks overall, and by age group and gender. Overall, drivers were engaged in secondary tasks during 52% of the alerts issued during the baseline period and 54% of the alerts issued during the treatment period. Younger drivers were engaged in secondary tasks more frequently than older and middle-aged drivers. The change in secondary task engagement was not significant overall, or for any of the age or gender groups.

Table 6. Paired *t*-test results of percent of analyzed alerts with secondary tasks

	Overall	Gender		Age (years)		
		Male	Female	20-30	40-50	60-70
Baseline	52%	54%	51%	60%	50%	46%
Treatment	54%	54%	53%	60%	52%	49%
p	0.28	0.83	0.20	0.89	0.41	0.27
n	107	54	53	36	35	36

Similar to the results of secondary task engagement, there were no significant differences in driver's eyes-off-forward-scene behavior leading up to an alert between the baseline and treatment periods. Drivers had their eyes off the forward scene during 7% of the alerts during the baseline period, and during 6% of alerts in the treatment period. Table 7 shows the results broken down by age group and gender.

Table 7. Paired *t*-test results of percent of analyzed alerts with eyes off forward scene

	Overall	Gender		Age (years)		
		Male	Female	20-30	40-50	60-70
Baseline	7%	8%	6%	8%	7%	6%
Treatment	6%	7%	5%	8%	6%	5%
p	0.34	0.51	0.48	1.00	0.36	0.28
n	107	54	53	36	35	36

The results for driver attention indicate that drivers are no more likely to engage in secondary tasks or take their eyes off the road leading up to scenarios that trigger system alerts when the system is enabled. These findings suggest that the system does not impose unintended negative consequences on driver attention.

Driving Conflicts

While there were no significant differences between the baseline and treatment periods in the overall rate of conflicts, results showed an overall decrease in the rate of conflicts at speeds over 55 mph (88.5 km/h). When broken down by conflict type, the data revealed a decrease in the rate of lane-change and road-departure conflicts on curved roads. Additionally, results showed a reduction in the duration of road-departure conflicts on straight roads. These results indicate that drivers got into fewer lateral potential crash situations when driving with the integrated system.

Near Crashes

Driver involvement in valid near crashes was analyzed using the exposure measure of the number of near-crash encounters per 1,000 miles traveled. This analysis included only the drivers who were exposed to near crashes in both the baseline and treatment periods. Data were broken down by near-crash type, gender, age group, and road type.

Table 8 shows the results of the paired *t*-tests comparing the rate of all near crashes between the baseline and treatment periods. For all near-crash types combined, only younger drivers showed a significant change in the rate of near crashes (a 19% reduction).

Table 8. Paired *t*-test results of average number of near crashes per 1,000 miles

	Overall	Gender		Age (years)		
		Male	Female	20-30	40-50	60-70
Baseline	9.64	10.64	8.31	12.20	9.24	7.06
Treatment	9.19	10.00	8.10	9.84	9.82	7.74
p	0.45	0.42	0.82	**0.05**	0.57	0.44
n	91	52	39	33	30	28

When broken down by near-crash type, results showed an overall decrease in the rate of lane-change and road-departure near crashes. No significant changes were observed in the rate of rear-end or curve-speed near crashes.

Tables 9 and 10 show the results for lane-change and road-departure near crashes, respectively. Drivers experienced an overall 33% reduction in the rate of lane-change near crashes and an overall 19% reduction in road-departure near crashes. Males experienced a significant reduction in lane-change near crashes, females experienced a significant reduction in road-departure near crashes, and younger drivers experienced a significant reduction in both types of near crashes.

Table 9. Paired *t*-test results of average number of lane-change near crashes per 1,000 miles

	Overall	Gender		Age (years)		
		Male	Female	20-30	40-50	60-70
Baseline	2.12	1.72	2.73	2.63	1.92	1.55
Treatment	1.43	1.08	1.93	1.48	0.95	1.79
p	**0.02**	**0.03**	0.20	**0.02**	0.06	0.58
n	37	22	15	16	10	11

Table 10. Paired *t*-test results of average number of road-departure near crashes per 1,000 miles

	Overall	Gender		Age (years)		
		Male	Female	20-30	40-50	60-70
Baseline	5.40	5.45	5.34	6.19	5.12	4.77
Treatment	4.38	4.62	4.05	3.99	5.02	4.19
p	**0.00**	0.08	**0.03**	**0.00**	0.87	0.33
n	74	43	31	27	24	23

Table 11 shows the results of the road-departure near crashes broken down by departure direction. While there is a trend towards a reduction in road-departure near crashes to the left ($p = 0.06$), most of the improvement was in the reduction in near crashes to the right.

Table 11. Paired *t*-test results of road-departure near crash rates by departure direction

	Left	Right
Baseline	4.58	2.75
Treatment	3.69	1.68
p	0.06	**0.00**
n	62	35

Projection of Potential Safety Benefits

Figure 4 illustrates the mean effectiveness, E(Si), of the system for each near-crash type (error bars represent 95% confidence interval and values shown in each bar represent the number of drivers included in each analysis) calculated using Equation (1). Based on the mean and 95% confidence interval, the system showed a reduction in rear-end, lane-change/merge, all road-departure, left road-departure, and right road-departure near crashes.

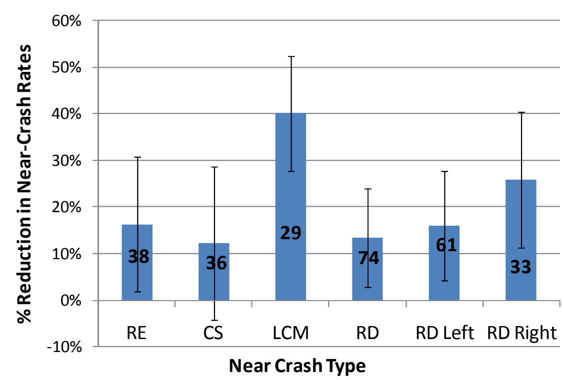

Figure 4. Average system effectiveness values by near crash type

Potential safety benefits from 100% deployment of the integrated safety system were projected using the effectiveness values shown in Figure 4 and annual crash frequencies listed in Table 1. These projections are supported by the analysis of driver exposure to driving conflicts and near crashes discussed in the previous section. Figure 5 shows the annual target crashes, the mean estimated crash reduction, and the 95% confidence bounds for each system function.

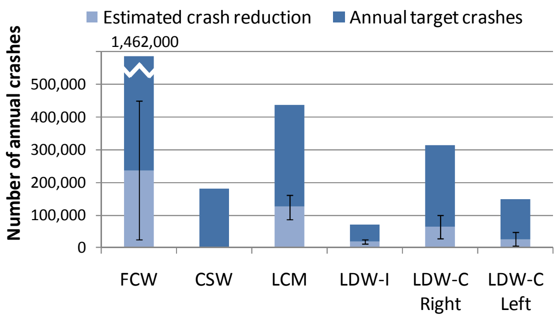

Figure 5. Annual target crashes and estimated crash reductions with full deployment of the integrated system, by system function

With an overall system effectiveness range between 6 and 29%, approximately 162,000 to 788,000 police-reported crashes could be prevented annually if all light vehicles in the United States were equipped with the integrated safety system. The following list ranks the system functions in terms of their maximum annual crash reduction potential:

1. FCW: 450,000 police-reported rear-end crashes
2. LCM: 163,000 police-reported lane-change crashes
3. LDW-C right: 101,000 police-reported road-departure crashes
4. LDW-C left: 47,000 police-reported road-departure and opposite-direction crashes
5. LDW-I: 27,000 police-reported lane-change crashes

Safety benefits could not be estimated for the CSW function due to the lack of statistically-significant differences between baseline and treatment periods in the analysis of near-crash exposure and the analysis of system effectiveness. Moreover, safety benefits could not be estimated for the LCM function in turning scenarios due to insufficient exposure to these scenarios during the field test.

CONCLUSIONS

Drivers experienced positive changes in their driving behavior when driving with the integrated system, including an increase in turn signal usage and a decrease in the rate of lane excursions. These results indicate that the integrated safety system reinforces good driving habits and helps drivers maintain better lane positioning. Additionally, drivers did not experience an increase in either the frequency of secondary tasks or instances of having their eyes off the forward scene when driving with the system enabled, indicating that the integrated system does not promote a degradation in driver attention.

One result that suggests a potential unintended consequence of the integrated system is the decrease in headway when drivers follow a lead vehicle on non-freeway roads. Although the 3% reduction is statistically significant, it is unlikely to have a negative impact on safety as the average treatment time headway of 1.98 s is still considered to be safe [5]. In addition, this shorter time headway in the treatment period did not lead to more rear-end driving conflicts or near crashes in the field test.

During the field test, drivers experienced significant reductions in both lane-change and road-departure near crashes when the system was enabled. Additionally, drivers showed significant positive effectiveness for three of the four crash warning functions. Based on the reduction of near crashes that drivers experienced, the integrated system could help prevent approximately 161,000 to 787,000 police reported crashes annually (between 7 and 29% of target crashes).

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APPENDIX A: NEAR-CRASH THRESHOLDS

Conflict Type		Variable	Value
Rear-end		POV is moving	
		Min TTC	< 3 s
		Max deceleration	> 4.0 m/s
		Brake duration	> 0.5 s
Curve speed		Max lateral acceleration	> 3.5 m/s^2
		Speed reduction at tightest point of curve	≥ 3 m/s
		OR	
		Max lateral acceleration	> 4.5 m/s^2
		Speed reduction at tightest point of curve	< 3 m/s
Lane change	Straight road	No lane excursion	
		Max lateral acceleration	≥ 1.0 m/s^2
		OR	
		Maximum lane excursion	0.1 m - 0.3 m
		Max lateral acceleration	≥ 0.75 m/s^2
		OR	
		Maximum lane excursion	0.3 m - 0.9 m
		Max lateral acceleration	≥ 0.0 m/s^2
	Depart to outside of curve	No lane excursion	
		Max lateral acceleration	≥ 0.5 m/s^2
		Normalized relative acceleration	> 0.25
		OR	
		Maximum lane excursion	0.1 m - 0.9 m
		Max lateral acceleration	≥ 0.0 m/s^2
		Normalized relative acceleration	> 0.25
	Depart to inside of curve	Maximum lane excursion	0.1 m - 0.9 m
		Max lateral acceleration	≥ 0.0 m/s^2
		Normalized relative acceleration	> 0.75
		OR	
		No lane excursion	
		Max lateral acceleration	≥ 0.0 m/s^2
		Normalized relative acceleration	> 0.75
Road Departure	Straight road	Maximum lane excursion	0.1 m - 0.3 m
		Max lateral acceleration	≥ 1.5 m/s^2
		OR	
		Maximum lane excursion	0.3 m - 0.9 m
		Max lateral acceleration	≥ 1.0 m/s^2
	Depart to outside of curve	Maximum lane excursion	0.1 m - 0.9 m
		Max lateral acceleration	≥ 1.0 m/s^2
		Normalized relative acceleration	> 0.25
	Depart to inside of curve	Maximum lane excursion	0.1 m - 0.9 m
		Max lateral acceleration	≥ 2.5 m/s^2
		Normalized relative acceleration	> 2.25