



**INSURANCE INSTITUTE
FOR HIGHWAY SAFETY**

Volvo Drivers' Experiences with Advanced Crash Avoidance and Related Technologies

December 2012

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ABSTRACT

Objective: Crash avoidance technologies potentially can prevent or mitigate many crashes, but their success depends in part on driver acceptance. Owners of 2010-12 model Volvo vehicles with several technologies were interviewed about their experiences.

Methods: Interviews were conducted in summer 2012 with 155 owners of vehicles with City Safety as a standard feature; 145 owners with an optional technology package that included Adaptive Cruise Control, Distance Alert, Collision Warning with Full Auto Brake (and Pedestrian Detection on certain newer models), Driver Alert Control, and Lane Departure Warning; and 172 owners with both City Safety and the technology package.

Results: Despite some annoyance, most owners always leave the systems on, although fewer do so for Lane Departure Warning (59 percent). For each of the systems, at least 80 percent of owners with the system would want it on their next vehicle. Among owners with City Safety, those with the optional technology package were more likely to want City Safety again compared with those who did not have the optional technology package (92 vs. 80 percent). Many owners reported safer driving habits with the systems (e.g., following less closely with Adaptive Cruise Control, using turn signals more often with Lane Departure Warning). Fewer owners reported potentially unsafe behavior, such as allowing the vehicle to brake for them at least some of the time. About one-third of owners experienced autonomous braking when they believed they were at risk of crashing, and about one-fifth of owners thought it had prevented a crash. About one-fifth of owners with the technology package reported that they were confused or misunderstood which safety system had activated in their vehicle.

Conclusions: Consistent with the results for early adopters in the previous survey of Volvo and Infiniti owners, the present survey found that driver acceptance of the technologies remains high, although less so for Lane Departure Warning. This study is the first to report drivers' experiences with City Safety, a collision avoidance system provided as standard equipment on certain Volvo 2010-12 models, and driver acceptance of this system was high, although not to the same extent as the optional forward collision avoidance system. Future research should continue to monitor drivers' experiences with these technologies as they become available in more vehicles.

Keywords: Crash avoidance technology; Driver behavior

INTRODUCTION

New vehicles increasingly have advanced technologies that monitor driver input and the environment around the vehicle to assist drivers with warnings or automatic braking when the potential for a crash is detected. These technologies have great potential to avoid or mitigate the severity of crashes. Jermakian (2011) estimated that about 1 in 3 fatal crashes and 1 in 5 nonfatal injury crashes potentially could be prevented or mitigated each year in the United States if all passenger vehicles were equipped with four crash avoidance technologies: forward collision avoidance, lane departure warning, side view assist (i.e., blind spot detection), and adaptive headlights. These estimates assume the systems prevent all relevant crashes and they reflect known limitations of the technology available at the time of the study. There are numerous factors, however, that could prevent this potential from being achieved. For example, drivers might switch off systems they find annoying or not respond appropriately to system warnings. Two of these technologies — forward collision avoidance and lane departure warning — are the primary focus of this paper, which examines drivers' experiences with these systems in 2010-12 model year Volvo vehicles. To date, only a few studies have examined the actual effectiveness of the technologies or how drivers respond to them.

Forward collision avoidance systems typically are designed to provide the driver with a visual and/or audible warning when the vehicle is too close to a vehicle ahead, and some systems autonomously brake the vehicle if the driver does not react to a potential collision. These systems often use radar or light detection and ranging (LIDAR) sensors to detect vehicles in front. Some systems that combine cameras with other sensors use complex algorithms to detect pedestrians in front of the vehicle. Among the four advanced technologies studied by Jermakian (2011), forward collision avoidance systems were estimated to have the greatest potential to prevent or mitigate crashes of all severity; the technology is potentially applicable to 1.2 million crashes per year in the United States. Adaptive cruise control is a related feature that automatically slows down or speeds up the vehicle to maintain a set gap with a vehicle ahead, but is not intended to perform emergency braking.

Another technology that is relevant to many serious crashes is lane departure warning and prevention. Although these systems are relevant to a small proportion of overall crashes (179,000 per year), they have potential to prevent or mitigate a large proportion of fatal crashes (7,500 per year;

Jermakian, 2011). Lane departure warning systems use cameras to track the vehicle's position within the lane, alerting the driver if the vehicle unintentionally crosses a lane marking. Lane departure warnings may include haptic (e.g., steering wheel vibration), audible, and/or visual elements. Lane departure prevention systems actively resist moving out of the lane or help move the vehicle back into the lane with minor steering adjustments or light braking.

Analyses of insurance collision claims are giving early indications of how crash avoidance technologies are working. Two studies of Volvo's City Safety, a low-speed forward collision avoidance system, have found reductions in collision claims for vehicles with the systems compared with those without (HLDI, 2011a; Isaksson-Hellman and Lindman, 2012). A study of U.S. insurance loss data compared claim rates per insured vehicle year for the 2010 Volvo XC60, a midsize luxury SUV with City Safety as standard equipment, with rates for two control groups of vehicles: other midsize luxury SUVs and other Volvo vehicles. The rate of property damage liability claims, which pays for damage to vehicles that an at-fault driver hits, was 27 percent lower for the Volvo XC60 than for other midsize luxury SUVs and 19 percent lower than for other Volvo models (HLDI, 2011a). In a Swedish study, the frequency of rear-end frontal collision claims for the Volvo XC60 was reduced by 23 percent compared with other Volvo models without City Safety (Isaksson-Hellman and Lindman, 2012).

Insurance claim rates also have been reduced for some vehicles with forward collision avoidance systems that operate at higher speeds (HLDI, 2011b, 2012a). Property damage liability claim rates were 14 percent lower for Acura and Mercedes-Benz models equipped with forward collision warning with autonomous braking than for the same vehicle models without the technology. In the analysis for Volvo models, the higher-speed forward collision avoidance system was bundled with lane departure warning and other features. Volvo models with this optional package had property damage liability claim rates that were 10 percent lower than for Volvo models without the package, but the difference was not statistically significant (HLDI, 2012b). Mercedes-Benz and Volvo models with forward collision avoidance systems that only provide warnings also appeared to prevent crash claims, but to a lesser extent than systems with automatic braking.

Similar analyses of Buick and Mercedes-Benz models with lane-departure warnings showed higher claim rates for vehicles with the systems compared with their counterparts without the systems

(HLDI, 2011c, 2012a). Another study using OnStar data examined crash rates for General Motors vehicles with and without lane departure warning and/or side blind zone alert (Geisler and Michelini, 2011). Crash events were measured via the OnStar Automated Crash Response system, in which an in-vehicle module monitors airbag deployment and other vehicle data and automatically alerts a call center when the vehicle is involved in a crash. Rate ratios were computed using actual and expected crash rates per 100 million miles. The vehicles equipped with one or both of the crash avoidance features had 3.5 percent fewer crashes than expected, but the results were not statistically significant.

Previously, Volvo and Infiniti drivers' were surveyed about their experiences with selected collision avoidance technologies (forward collision warning, side view assist, adaptive headlights, and lane departure warning; Braitman et al., 2010). The survey found that most owners kept the systems turned on most of the time, reported driving more safely, and would want the system again on their next vehicle. The findings were especially positive for the forward collision warning system: 88 percent of owners with the system reported always having it turned on, and 94 percent would want the system again. Among owners with lane departure warning systems, 69 percent reported always having the system turned on, and about 80 percent would want the system again.

A new survey of owners of Volvo vehicles with forward collision avoidance and lane departure warning systems extends our knowledge about drivers' experiences with these systems. The current survey gathered in-depth information about specific components of the systems. It also gathered information about City Safety and about Pedestrian Detection, which were introduced since the previous survey. In addition, the survey gathered information on related systems that were available but not included in the previous survey: Adaptive Cruise Control, Distance Alert, and Driver Alert Control. The survey sought to understand how drivers use the systems, how the technologies may have affected their driving, how often they experienced the various warnings or automatic braking, and whether drivers find the systems acceptable.

METHODS

System Descriptions

The study focused on 2010-12 model year Volvo vehicles with crash avoidance technologies. Volvo's optional technology package included Adaptive Cruise Control, Distance Alert, Collision Warning

with Full Auto Brake (and Pedestrian Detection on certain newer models), Driver Alert Control, and Lane Departure Warning. City Safety was standard equipment on certain Volvo models. The systems are described briefly below.

Adaptive Cruise Control and Distance Alert help the driver keep a safe distance from a vehicle in front. Adaptive Cruise Control allows a driver to set a speed, as well as a gap behind another vehicle. A radar sensor detects slower moving vehicles ahead and automatically applies the brakes or speeds up in order to maintain the gap. If there are no vehicles in front, the Volvo travels at the set speed. When Adaptive Cruise Control is not being used, Distance Alert monitors the distance to the vehicle ahead, and if the gap becomes shorter than the selected value, a red warning light in the windshield glows steadily. Distance Alert does not affect the speed of the vehicle and can be turned off by the driver.

Collision Warning with Full Auto Brake warns the driver that an impact with another vehicle is imminent, and if the driver does not brake or steer, applies full braking to mitigate or avoid the crash. After the initial determination that an impact might occur, the system pre-charges the brakes. The collision warning consists of a flashing light in the windshield accompanied by a tone. When the system has activated, it will display a message on the dashboard. The collision warning signals can be deactivated, but the autonomous braking cannot be turned off. The system is active at speeds of 4 mph and above.

Collision Warning with Full Auto Brake also includes Pedestrian Detection on certain newer models. Pedestrian Detection uses radar and digital camera technology to identify and track pedestrian paths. If a pedestrian walks into the car's path and an impact is imminent, a flashing windshield light and tone warn the driver. If the driver fails to react to the warning and a collision is imminent, full braking power is automatically applied. The technology can avoid a collision with a pedestrian at speeds up to approximately 21 mph. At higher speeds, the focus is on reducing the car's speed as much as possible prior to impact.

City Safety uses a LIDAR sensor to detect a stopped or slower moving vehicle in front, and if a crash is imminent, applies the brakes if the driver does not. It operates at speeds between 2 and 18 mph. When City Safety has activated, it will display a message on the dashboard. City Safety is standard on certain vehicles that also may be equipped with Collision Warning with Full Auto Brake. City Safety can be deactivated, but it will turn back on at the next ignition cycle.

Driver Alert Control is intended for drivers who may become fatigued or drowsy or who inadvertently leave the lane for any reason. A camera monitors the lane markings on the road, and the system tracks the driver's steering within the lane (i.e., steering inputs). The driver is alerted of possibly dangerous behavior by a coffee cup symbol and message to take a break accompanied by a tone.

Lane Departure Warning also monitors lane markings, and the system provides a warning chime if a lane is crossed without the driver activating a turn signal. Both Driver Alert Control and Lane Departure Warning are activated when the vehicle's speed reaches 40 mph and deactivated at speeds less than 37 mph. The functions can be turned off separately by the driver.

Survey Participants

Volvo Car Corporation provided the names, addresses, and phone numbers of customers who had purchased model year 2010 or newer vehicles in the United States with either City Safety and/or the optional technology package. Participation was restricted to owners for whom phone numbers were known. Vehicles owned by businesses were excluded. The Volvo models in the sample included S60, S80, V70, XC60, and XC70.

An initial letter from the Insurance Institute for Highway Safety and the Volvo Car Corporation was sent to 750 owners of Volvos with City Safety, 487 owners of Volvos with the technology package, and 630 owners of Volvos with both City Safety and the technology package. The letter explained the research effort and explained that owners could opt out of the survey by returning a prestamped postcard or by entering a code on a website created for the study. The number of owners who opted out of the survey is shown in Table 1 for each group. Experienced telephone interviewers conducted the interviews during June and July 2012 with either primary or frequent drivers of the vehicles. The interviews were conducted by Westat, a research organization.

Questionnaires

The survey instruments included questions about general driving habits, how long the vehicle had been owned, use of the technologies, experiences with warnings and autonomous braking, behavioral responses to the technology, potential crashes prevented by the systems, opinions about the technologies, and general demographic questions.

RESULTS

Interviews were conducted with 155 owners with City Safety but without the optional technology package, 145 owners with the optional technology package but without City Safety, and 172 owners with both City Safety and the technology package. The sample characteristics are shown in Table 2.

Adaptive Cruise Control

Among 315 owners who responded to questions about Adaptive Cruise Control, 80 percent reported that they had used it at some point. Fifty-one percent always used it on freeways, expressways, or other high-speed roads, whereas 5 percent reported they always used it on lower speed roads with traffic signals or stops signs (Table 3). Eighteen percent said they had never used it. When using Adaptive Cruise Control, the gap between the vehicles can be adjusted. Different settings are shown in the dashboard display as 1 to 5 bars. Among those who used Adaptive Cruise Control, 62 percent had adjusted these settings at some point. Table 3 lists the settings that drivers typically used.

When asked whether they followed vehicles more or less closely when using Adaptive Cruise Control, 3 percent reported that they followed vehicles more closely, 46 percent followed less closely, and 49 percent reported no change. When asked about looking away from the road when using Adaptive Cruise Control, 4 percent of drivers said they tended to look away from the road more often, 5 percent tended to look away less often, and 90 percent reported no change.

Distance Alert

Among 314 owners who responded to questions about Distance Alert, 89 percent always kept the system on. The time interval setting for distance alert can be changed and is shown as 1 to 5 bars. Table 4 lists the settings typically used by drivers.

Among the 298 owners who ever drove with Distance Alert turned on, 6 percent reported that they always waited for the red warning lights to appear before slowing as they approached another vehicle, 21 percent sometimes did so, 22 percent rarely did so, and 47 percent never waited for the red light to alert them. In response to an open-ended question about situations in which they find Distance Alert useful, the most frequent responses were during heavy traffic or city driving (22 percent), when a car cuts them off or stops in front (18 percent), during highway driving (12 percent), and when they were

distracted (10 percent). Sixteen percent of owners thought Distance Alert was useful in all situations or as a general reminder.

Forward Collision Avoidance Systems

Owners were asked several questions about their experiences with the audible and visual warnings of Collision Warning with Full Auto Brake and a separate set of questions regarding their experiences with autonomous braking by either of the forward collision avoidance systems. All owners surveyed had vehicles equipped with one or both collision avoidance systems.

In vehicles equipped with Collision Warning with Full Auto Brake, the collision warnings can be turned on or off, while the autonomous braking feature of the system cannot be turned off. Autonomous braking by the City Safety system can be turned on or off. Table 5 summarizes drivers' use of these systems among all owners who had the respective systems.

Experiences with collision warnings. Seventy-six percent of owners who sometimes or always drove with collision warnings turned on reported that they had received a collision warning on at least one occasion, and 45 percent of those who ever drove with the system on thought the warning helped prevent a crash. Only one owner said the system failed to activate when there was a risk of a crash. This owner indicated that it occurred while driving less than 5 miles per hour. Among 57 owners whose vehicles were equipped with Pedestrian Detection, 28 percent reported that the vehicle had warned them of a potential crash with a pedestrian.

Thirty-seven percent of owners who ever drove with the system on said they experienced forward collision warnings when they were not at risk of having a collision. These drivers were asked about these situations, and they could provide more than one response to the question. Drivers said this situation occurred when a vehicle in front was turning (42 percent), at a turn or curve in the road (20 percent), and/or when there was a barricade or object along the side of the road (14 percent).

Drivers who experienced the collision warnings were asked whether they agreed or disagreed with several statements about them. Among 233 drivers who experienced the collision warning and heard the warning sound, 97 percent agreed that the warning was useful, 24 percent agreed it was annoying, 6 percent agreed it was too loud, and 1 percent agreed that it was too quiet. Among 235 drivers who had

seen the flashing windshield light that accompanies the warning sound, 98 percent agreed the light was useful, 10 percent agreed it was annoying, and 98 percent agreed it was easy to see.

Fifty-six percent of owners could recall the first time they experienced the collision warning, and 78 percent of these owners understood that it was alerting them to a potential collision. When asked an open-ended question about how they responded to the warning, 63 percent of drivers said they applied the brakes or slowed down, 11 percent were startled or surprised, 11 percent ignored the warning, and 5 percent paid more attention to their driving after the warning.

Drivers also were asked about the most recent warning they had experienced. Among all those who experienced warnings, 27 percent said that they were not paying full attention to their driving at the time they experienced the most recent warning. Nineteen percent of these drivers could not recall what they were doing. Those who could recall the situation indicated that they had been looking around at other vehicles, at mirrors, or something else (35 percent); talking or listening to a passenger (18 percent); mentally distracted or daydreaming (11 percent); adjusting the radio (10 percent); talking on or looking at a phone (5 percent); or falling asleep (2 percent). Most of the collision warnings occurred during the day (90 percent) and in clear weather (91 percent). Seventy-seven percent reported that the most recent warning came at the right time, 13 percent thought it was too early, and 4 percent thought it was too late.

Owners who ever drove with collision warnings turned on were asked whether they waited for the warning light or sound before slowing as they approached another vehicle. Four percent reported that they did.

Experiences with autonomous braking. Of 459 owners who drove vehicles with City Safety and/or Collision Warning with Full Auto Brake, 37 percent reported that they had experienced autonomous braking on at least one occasion when they thought they were at risk of crashing, and 22 percent thought automatic braking helped prevent a crash. Owners who experienced automatic braking included 34 percent of those with City Safety, 36 percent of those with Collision Warning with Full Auto Brake, and 41 percent of those with both systems. Among the 68 owners who experienced automatic braking in a vehicle equipped with both forward crash avoidance systems, 35 percent could not identify which system they had experienced. Thirty-two percent thought they had experienced City Safety, 28 percent thought they had experienced Collision Warning with Full Auto Brake, and 4 percent said they

had experienced both systems. Among owners whose vehicles were equipped with Pedestrian Detection, three drivers (5 percent) reported that the vehicle had braked for a pedestrian.

Among owners who thought they had experienced autonomous braking by City Safety, their recollections about the most recent activation most often indicated that they had been parking or entering a garage (25 percent), driving in heavy or slow traffic (15 percent), at an intersection (12 percent), or driving behind a car that braked or cut them off (10 percent). Among owners who said they experienced autonomous braking by Collision Warning with Full Auto Brake, owners most often indicated that they had been driving “normally” at the time of the most recent activation (18 percent), distracted by passengers or something else within the vehicle (16 percent), driving behind a car that braked or cut them off (14 percent), or driving in heavy or slow traffic (14 percent). Most automatic braking with either system occurred during sunny and/or clear weather (81 percent).

Three owners (1 percent) reported that they had crashed into a vehicle in front of them, and these owners indicated that the vehicle did not brake automatically for them. Two of the crashes involved vehicles with only City Safety, and one crash involved a vehicle with both forward collision avoidance systems.

Fourteen percent of owners reported they experienced autonomous braking when they were not at risk of having a collision. Among 19 drivers who said they experienced these activations with City Safety, the most frequent situations in which this occurred were in a driveway or parking lot (42 percent), when a vehicle ahead was turning (11 percent), with debris or bumps in the roadway (11 percent), or when the driver was deliberately testing the system (11 percent). Among 23 drivers who said they experienced activations with Collision Warning with Full Auto Brake when not at risk of having a collision, the most frequent situations in which this occurred were when a vehicle in front stopped or slowed (17 percent), when they were driving “normally” on the highway (13 percent), or when another vehicle cut them off (13 percent).

Behavioral responses to forward collision avoidance systems. Owners who ever drove with City Safety or Collision Warning with Auto Brake were asked how often they allowed the vehicle to do the braking for them. Eight percent of drivers with City Safety, 34 percent of drivers with Collision Warning

with Full Auto Brake, and 34 percent of drivers who had both systems reported that they allowed the vehicle to brake for them at least some of the time.

Drivers who ever drove with either of the forward collision avoidance systems turned on were asked about their driving behavior with the technologies compared with their behavior before they had their Volvo. When asked whether they follow vehicles more or less closely, 82 percent reported no change, 12 percent reported following vehicles less closely, and 5 percent reported following vehicles more closely. When asked whether they look away more or less often, 92 percent reported no change, 4 percent reported looking away less, and 3 percent reported looking away more.

Driver Alert Control

Drivers were asked if they had ever experienced Driver Alert Control, which consists of an audible alert accompanied by a coffee cup symbol and a message on the dashboard telling them to take a break. Of 299 owners, 70 percent had received the message, and 40 percent had received it on multiple occasions. Eighty percent of drivers who received the message at least once thought they were fully alert the last time they received it. Most of these drivers (56 percent) said they ignored the alert, 13 percent paid closer attention to their driving, 9 percent took a break, and 8 percent said they deactivated the system.

Lane Departure Warning

Among owners with Lane Departure Warning, 59 percent always kept the system on. Lane Departure Warning has two settings, a less sensitive setting that warns the driver when a tire crosses a lane marking and a more sensitive setting that warns the driver before the tire crosses the lane marking. The less sensitive setting is the default setting. Table 6 lists the settings typically used by drivers.

Among owners who ever drove with Lane Departure Warning turned on, 55 percent reported no change in their use of the turn signal when the system was turned on, and 44 percent of drivers said they used their turn signal more often with it. Sixty-one percent reported no change in how often they drifted from their lane, and 35 percent said they drifted from their lane less often.

Eleven percent of drivers who ever drove with Lane Departure Warning turned on reported that they heard warning alerts very often, 49 percent heard the warnings sometimes, 35 percent heard them

rarely, and 5 percent never heard them. Twelve percent thought the system had prevented them from crashing into a vehicle in another lane, and 22 percent thought it prevented them from running off the road.

Seventy-seven percent of owners reported that the departure system had never failed to warn them when they believed they were at risk of drifting out of their lane, and 17 percent reported that it had. The most frequently reported situations in which this happened included missing or unclear lane markings (60 percent), inclement weather (17 percent), driving at slow speeds (7 percent), and driving in the dark (7 percent).

Forty percent of owners thought the system mistakenly warned them on at least one occasion when they had not drifted out of their lane. Among drivers who experienced alerts perceived as false or unnecessary, the situations included pavement markings (other than lane markings) or crosswalks (21 percent); exits, splits, and merges (20 percent), old markings or stains on the road (18 percent); construction (12 percent); and driving on curves (6 percent).

Owners who ever heard the lane departure warning sound were asked whether they agreed or disagreed with various statements. Among these drivers, 96 percent agreed the warning sound was useful, 33 percent agreed it was annoying, 7 percent agreed it was too loud, and 1 percent agreed the sound was too quiet.

General Opinions of Systems

Drivers were asked whether they would want each of the systems again if they bought another vehicle, as well as some open-ended questions regarding which systems, if any, relieved them of stress while driving, annoyed them, or distracted them. For each of the open-ended questions, drivers could specify multiple responses. The results for these questions are summarized in Table 7.

The large majority of owners said they would want each technology in their next vehicle. Owners were least likely to say they would want Lane Departure Warning (83 percent) or City Safety (86 percent) again. The percentage who mentioned that a technology relieved stress while driving ranged from 23 percent for Pedestrian Detection and Driver Alert Control to 49 percent for Adaptive Cruise Control. One-quarter of owners with Lane Departure Warning mentioned that it was annoying, and 9 percent mentioned

it was distracting. For all the other technologies, fewer than 5 percent mentioned the technology was annoying or distracting.

Owners with the technology package were more likely to want City Safety again (92 percent) than were owners without the technology package (80 percent). There was little or no difference between those with and without the technology package in terms of whether City Safety relieved stress (28 vs. 31 percent), was annoying (1 vs. 2 percent), or was distracting (1 vs. 1 percent).

Owners who were annoyed by any of the technologies were more likely to report that they had turned off one or more of the systems at some point. Sixty-six percent of owners who were annoyed said they had turned off a system compared with 19 percent of those who were not annoyed or did not know whether they were annoyed.

Owners were asked whether there was anything they disliked about any of the technologies, and if so, they were asked to describe what they disliked. Among all owners, 20 percent said that there was something they disliked. The most common complaint was warnings or activations that were perceived as false or unnecessary (43 percent). Of the 39 drivers who reported this problem, some mentioned that it occurred with a specific technology: Lane Departure Warning (15 owners), Driver Alert Control (7 owners), Collision Warning with Full Auto Brake (7 owners), City Safety (2 owners), and Pedestrian Detection (2 owners).

Nineteen percent of drivers with the technology package reported that they had been confused about which system was activated, and 7 percent of owners with only City Safety were confused about whether the system was activated.

Owners were asked how they learned about the safety systems in their Volvos and could provide multiple responses. Owners learned about their vehicle's safety systems from the owner's manual (75 percent), dealership demonstrations (60 percent), trying it out on the roadway (56 percent), Volvo's website (16 percent), a family member or friend (11 percent), and DVDs, CDs, or videos (9 percent).

DISCUSSION

Crash avoidance technologies and related driver support systems like Adaptive Cruise Control have great potential to prevent and mitigate crashes, but their safety impact will be limited if drivers are unwilling to use them or if drivers alter their behaviors in unintended ways that jeopardize their safety. A

previous survey found that most drivers of Volvo and Infiniti vehicles with several crash avoidance technologies drove with the systems on most of the time, and many reported driving more safely as a result of the systems (Braitman et al., 2010). The previous survey included owners of certain Volvo 2007-08 models, the first model years for which the technologies were available. As advanced crash avoidance technologies become available on more vehicles, it is important to continue studying the impact of these technologies on driver acceptance and behavior.

This paper reports on a new survey that updates the information on Volvo owners of vehicles with Collision Warning with Full Auto Brake and Lane Departure Warning and gathers information on additional systems. This study is the first to report drivers' experiences with City Safety, a collision avoidance system provided as standard equipment on certain Volvo 2010-12 models.

For each of the systems, at least 80 percent of owners would want it again if they bought another vehicle; the results were similar to findings for Volvo owners in the previous survey. The systems that drivers were most likely to want again included those that warned the driver of a collision with another vehicle or pedestrian in front of them (i.e., Collision Warning with Full Auto Brake, Pedestrian Detection) and those that provided assistance with maintaining an appropriate gap to a vehicle ahead (i.e., Adaptive Cruise Control, Distance Alert). Drivers were least likely to want Lane Departure Warning again, yet most still wanted it again (83 percent).

Owners with the optional technology package were more likely to want City Safety again compared with those who did not have the optional technology (92 vs. 80 percent). This difference suggests that owners who have the optional technology may be more favorable toward such technology in general. However, there was little or no difference between the groups in terms of whether City Safety relieved stress, was annoying, or was distracting. There also were some demographic differences between the two groups: owners without the technology package included a larger percentage of drivers younger than 40 and more women compared with those who had the technology package. The group of owners with only City Safety may be slightly more representative of the general driving population.

More than 80 percent of owners reported that they used the systems frequently or kept them on all the time, with the exception of City Safety (78 percent always used) and Lane Departure Warning (59 percent always used). It is important to note that 18 percent of owners with City Safety were not aware

they had the system; these owners probably were driving with the system on, as well. City Safety can be turned off, but it will automatically switch on at the next ignition cycle. The tendency to turn off Lane Departure Warning has grown from the previous survey: 69 percent of Volvo owners always used it in the previous survey compared with 59 percent in the current survey. Use of Collision Warning with Full Auto Brake was very similar to the previous survey (89 vs. 88 percent).

Although it is not possible to know how many crashes actually may have been prevented by the systems, owners self-reported experiences with the systems are promising. Forty-five percent of owners believed the forward collision warnings had prevented a crash, and 22 percent believed autonomous braking had prevented a crash. Some drivers thought Lane Departure Warning had prevented them from crashing into a vehicle in another lane (12 percent) or running off the road (22 percent).

Reports of systems failing to activate were infrequent. Some owners reported that Lane Departure Warning did not warn when they drifted out of their lane, but this often happened in situations in which the system would not be expected to work (e.g., missing or unclear lane markings, inclement weather). Three owners in the sample reported that they had crashed into a vehicle in front of them, and these owners indicated that the vehicle did not brake automatically for them. Based on the drivers' descriptions, the situations were possible circumstances in which the forward collision avoidance systems might not operate (e.g., higher speeds for City Safety, inclement weather).

Some drivers were annoyed by the technologies. The system most often mentioned was Lane Departure Warning, with 25 percent volunteering that it was annoying, which is the same percentage in the previous survey of Volvo owners. A substantial number of drivers received lane departure warnings that they perceived as false or unnecessary. However, the vast majority of owners still agreed that the lane departure warnings were useful.

There have been concerns about long-term adaptation to crash avoidance technologies, such that drivers may become over-reliant on the technologies and adopt less safe driving practices or become less attentive the driving task. In the current survey, many owners reported safer driving habits with the systems. The safer driving habits included following vehicles less closely when using Adaptive Cruise Control and using turn signals more often and drifting from their lanes less often when using Lane Departure Warning. There were far fewer reports of less safe driving habits, but one troubling finding was

that some owners reported that they allowed the vehicle to brake for them at least some of the time. This behavior was reported more often among owners with the technology package, and it is possible that drivers were referring to braking with Adaptive Cruise Control rather than the autonomous braking associated with an impending collision.

The study has some important limitations. Drivers with several different technologies may have been unable to distinguish warnings and alerts from different systems. Almost one-fifth of drivers with the technology package reported that they had been confused about which safety system was activated. Although the interviewers described the specific technologies for drivers, it is still possible that drivers may have confused the different technologies in answering questions about them. For example, the red light for Distance Alert is identical to the warning light for Collision Warning with Full Auto Brake. To the extent that the systems being confused are designed to elicit the same driver response, this confusion does not necessarily pose a safety problem. However, it could not be determined from the present survey which technologies were being confused or why they were confusing.

Another limitation of the study is that the sample may not be representative of the general population of U.S. drivers. The drivers interviewed for this survey owned luxury vehicles. They also tended to be older than the general population of drivers; only 15 percent of the Volvo drivers were younger than 40, whereas an estimated 42 percent of the general driving population is younger than 40 (Insurance Institute for Highway Safety, 2012). Their experiences with and attitudes toward the technologies may not be the same as the general driving population.

Driver acceptance of the technologies remains high among owners in the present survey compared with the early adopters in the previous survey of Volvo and Infiniti owners. One exception is that the early adopters were more likely to use Lane Departure Warning all the time compared with the owners in the present survey. The present study also included a group of owners who did not choose the optional technology package but still had a forward collision avoidance system provided as a standard feature. Driver acceptance of this system was high, although not to the same extent as the optional forward collision avoidance system. Future research should continue to monitor drivers' experiences with these technologies as they become available in more vehicles.

ACKNOWLEDGEMENTS

The authors thank Volvo Car Corporation for their cooperation with this study and assistance with contacting vehicle owners. The authors wish to thank Adam Kopstein, Bruno DiGennaro, Magdalena Lindman, Thomas Broberg, Bengt Schultz, and Joseph Saunier from Volvo Car Corporation for providing information about the systems, addressing technical questions, and providing helpful feedback. The authors thank colleagues who provided information or helpful comments, including David Zuby, David Kidd, David Aylor, Jessica Jermakian, Matt Moore, Lisa Henke, and Drew Knoblauch from the Insurance Institute for Highway Safety and Jeremiah Singer and James Jenness from Westat. The authors thank Nate Oesch for his assistance with coding drivers' responses to open-ended questions. This work was supported by the Insurance Institute for Highway Safety.

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Table 1 Disposition of sample

	City Safety	Technology package	City Safety and technology package
Letters mailed	750	487	630
Owners who opted out before they were called	90	41	53
Owners who opted out when called	127	84	125
Nonworking numbers	19	7	14
Owners with numbers who could not be reached before quota was met	359	210	266
Answered some or all of the survey questions	155	145	172

Table 2 Sample characteristics for each group of survey respondents (percentage)

	City Safety (N=155)	Technology package (N=145)	City Safety and technology package (N=172)
Age distribution			
30 or younger	3	0	2
31-40	16	7	15
41-50	25	10	21
51-60	32	22	24
61-70	17	27	20
71-80	7	21	8
81 and older	0	5	3
Unknown	1	8	8
Gender			
Male	44	63	48
Female	55	28	45
Unknown	1	8	7
Miles driven in typical week in vehicle			
100 or less	30	28	27
101-200	30	24	33
201-300	18	26	19
301 or more	14	14	13
Unknown	7	9	7
Number of months vehicle was owned			
Less than 6	3	1	1
6-11	15	11	8
12-17	31	30	24
18-23	21	16	21
24-29	17	26	23
30 or more	12	14	21
Unknown	2	3	3

Note: Percentage do not always sum to 100 percent due to rounding.

Table 3 Drivers' use of Adaptive Cruise Control

	Percent
Use of Adaptive Cruise Control	(N=315)
On freeways, expressways, or other high-speed roads	
Always used	51
Sometimes used	23
Rarely used	5
On lower-speed roads with traffic signals or stop signs	
Always used	5
Sometimes used	18
Rarely used	25
Never used	18
Don't know	1
Not aware they had the system	1
Settings typically used among those who ever turned on Adaptive Cruise Control	(N=252)
Smaller gap: 1 or 2 bars	33
Default setting: 3 bars (or never changed)	36
Larger gap: 4 or 5 bars	22
Don't know	10

Note: Percentage do not always sum to 100 percent due to rounding.

Table 4 Drivers' use of Distance Alert

	Percent
Use of Distance Alert	(N=314)
Always kept the system turned on	89
Sometimes used (sometimes or rarely turn off)	6
Never used (always turn off)	3
Don't know	1
Not aware they had the system	1
Settings typically used among those who ever used Distance Alert	(N=298)
Smaller gap: 1 or 2 bars	22
Default setting: 3 bars (or never changed)	36
Larger gap: 4 or 5 bars	21
Don't know	20

Note: Percentage do not always sum to 100 percent due to rounding.

Table 5 Drivers' use of forward collision avoidance systems

	Percent
Use of collision warnings (Collision Warning with Full Auto Brake)	(N=313)
Always kept the warnings turned on	89
Sometimes used (sometimes or rarely turn off)	3
Never used (always turn off)	2
Don't know	5
Not aware they had the system	1
Settings typically used among those who ever drove with collision warnings on (Collision Warning with Full Auto Brake)	(N=305)
Earlier warning	4
Normal warning (or never changed)	91
Later warning	2
Don't know	2
Use of City Safety	(N=320)
Always kept the system turned on	78
Sometimes used (sometimes or rarely turn off)	3
Never used (always turn off)	1
Not aware they had the system	18

Note: Percentage do not always sum to 100 percent due to rounding.

Table 6 Drivers' use of Lane Departure Warning

	Percent
Use of Lane Departure Warning	(N=299)
Always kept the warnings turned on	59
Sometimes used (sometimes or rarely turn off)	26
Never used (always turn off)	14
Don't know	<1
Not aware they had the system	<1
Settings typically used among those who ever drove with Lane Departure Warning turned on	(N=255)
Less sensitive setting (or never changed)	99
More sensitive setting	<1
Don't know	1

Note: Percentages do not always sum to 100 percent due to rounding.

Table 7 Drivers' opinions of systems (percentage of owners who had each technology)

	Adaptive Cruise Control (N=297)	Distance Alert (N=297)	Collision Warning with Auto Brake (N=297)	Pedestrian Detection (N=56)	City Safety (N=315)	Lane Departure Warning (N=297)	Driver Alert Control (N=297)
Would want the technology again	93	95	97	93	86	83	88
Technology relieved stress while driving	49	27	33	23	30	30	23
Technology was annoying	1	3	3	2	2	25	4
Technology was distracting	1	2	2	0	1	9	1