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Toyota Drivers' Experiences with Dynamic Radar Cruise Control, the Pre-Collision System, and Lane-Keeping Assist

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Abstract

Background: Previous surveys about drivers' experiences with crash avoidance technologies have focused on luxury vehicles. It is important to continue studying acceptance and use of systems as they spread throughout the vehicle fleet. **Methods:** Interviews were conducted with 183 owners of 2010-13 Toyota Sienna and Prius models equipped with adaptive cruise control and forward collision avoidance. Prius models were also equipped with lane departure warning/prevention. **Results:** About 9 in 10 respondents wanted adaptive cruise control and forward collision avoidance on their next vehicle, and 71 percent wanted lane departure warning/prevention again. Many respondents reported potentially safer driving habits with the systems (e.g., using turn signals more often with lane departure warning/prevention); reports of safer driving were more common among drivers age 40 and younger relative to older drivers. Some respondents reported potentially less safe behavior, such as following more closely when driving with forward collision avoidance. There were some gender differences (e.g., males reported more frequent lane departure warning/prevention warnings). **Discussion:** Consistent with previous surveys of owners of luxury vehicles, Toyota driver acceptance of crash avoidance technologies was high. However, experiences differed by driver age and gender to a greater degree than in previous surveys, suggesting that drivers' experiences may differ as this technology becomes available on a wider variety of vehicles. **Practical application:** Crash avoidance technologies potentially can prevent or mitigate many crashes, but their success depends in part on driver acceptance.

1. Introduction

Advanced crash avoidance technologies, which initially were offered only as options on certain luxury models, are being offered on increasing numbers of new mainstream vehicles. Advanced technologies monitor driver input and the environment around the vehicle to assist drivers when the potential for a crash is detected. These technologies have great potential to avoid or reduce the severity of crashes. Jermakian (2011) estimated that as many as 1 in 3 fatal crashes and 1 in 5 nonfatal injury crashes potentially could be prevented or mitigated annually in the United States if all passenger vehicles were equipped with four crash avoidance technologies: forward collision avoidance, lane departure warning, blind spot detection, and adaptive headlights. These estimates assume the systems prevent all relevant crashes and that drivers use the systems.

Forward collision avoidance systems are designed to assist 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. Among the four advanced technologies studied by Jermakian (2011), forward collision avoidance systems potentially were applicable to 20 percent of passenger vehicle 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. Adaptive cruise control may contribute to safe driving by helping the driver maintain a safe following distance behind another vehicle.

Another technology that is relevant to many serious crashes is lane departure warning and prevention. Although this technology is relevant to a small proportion of overall crashes, it has the potential to prevent or mitigate about 1 in 5 fatal crashes (Jermakian, 2011). Lane departure warning systems track the vehicle's position within the lane, alerting the driver prior to or as 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 the vehicle 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 suggest that some crash avoidance technologies are working. 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). Insurance claim rates also have been reduced for some vehicles with forward collision avoidance systems that operate at higher speeds (HLDI, 2011b, 2012a, 2012b). Property damage liability claim rates were lower for Acura, Mercedes-Benz, and Volvo models equipped with forward collision warning with autonomous braking than for the same vehicle models without the technology. Mercedes-Benz and Volvo models with forward collision avoidance systems that provide only warnings also appeared to prevent crash claims, but to a lesser extent than systems with automatic braking. Similar studies with lane departure warning systems have found less promising results. 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, but these findings were not statistically significant (HLDI, 2011c, 2012a).

As advanced technologies with the potential to reduce crashes become available on more vehicles, it is important to monitor the experiences of drivers with the systems. The systems will only improve safety to the extent that drivers accept and use them. Previous surveys of luxury Volvo and Infiniti drivers' experiences with crash avoidance technologies found that most drivers kept the systems turned on most of the time, reported driving more safely, and would want the systems again on their next vehicle (Braitman et al., 2010; Eichelberger & McCart, 2012). Among drivers of Volvo models, about half of drivers reported that they always used adaptive cruise control on freeways, expressways, or other high-speed roads, and 93 percent would want the technology again. With regard to the forward collision warning systems equipped on some Volvo models, 78-89 percent of survey respondents with the system reported always having it turned on, and 86-97 percent would want the system again. Among drivers of Volvo or Infiniti models with lane departure warning or prevention systems, 59-69 percent reported always having the system turned on, and about 76-83 percent would want the system again.

Surveys of drivers of luxury models may not be representative of all drivers. Crash avoidance technologies also vary in many important respects. As the technologies spread throughout the vehicle fleet, it is important to continue monitoring drivers' experiences with them. The current survey of owners of Toyota vehicles equipped with Dynamic Radar Cruise Control, the Pre-Collision System, and Lane-Keeping Assist extends the knowledge about drivers' experiences with these crash avoidance

technologies. The survey sought to understand how drivers use the systems, how the technologies may have affected their driving, how often they experienced warnings or automatic braking, and whether drivers find the systems acceptable.

2. Methods

2.1. System Descriptions

The study focused on 2010-13 Toyota Sienna and Prius models that were equipped with crash avoidance technologies. The vehicles selected for study had Toyota's optional advanced technology package, which included Dynamic Radar Cruise Control, the Pre-Collision System, and Lane-Keeping Assist (on Prius models only). The systems are described briefly below.

Dynamic Radar Cruise Control allows a driver to set a speed, as well as a gap behind another vehicle, and it functions at speeds of approximately 30 mph and above. A radar sensor detects slower moving vehicles ahead and automatically applies the brakes or speeds up in order to maintain the gap. If the system cannot decelerate sufficiently, a warning chime alerts the driver. If there are no vehicles in front, the vehicle travels at the set speed.

The Pre-Collision System uses the radar sensor to detect the possibility of a frontal collision and warns the driver with a buzzer and warning lights that say PCS and Brake. If the system determines that a crash is unavoidable, the system applies the brakes automatically to reduce the collision speed, and the seat belt is retracted. Seat belt retraction (linked to the radar sensor) is operational when the vehicle speed is above 4 mph and the relative speed difference is greater than 19 mph. Automatic braking, which can be turned off by the driver, is operational when the vehicle speed is above 10 mph and the relative speed difference between the vehicle and another vehicle or obstacle is greater than 10 mph. If the driver depresses the brake pedal when the system has detected that there is a high possibility of a frontal collision, the system amplifies the braking force in relation to the driver's brake operation. This brake assist function is operational when the driver depresses the brake, the vehicle speed is above 19 mph, and the speed difference between the vehicle and another vehicle or obstacle is greater than 19 mph.

Lane-Keeping Assist uses a camera to monitor lane markings. When the system is turned on, the warning function is active at speeds above 30 mph. When the system detects that the vehicle is drifting from the lane, it alerts the driver with a rapid beeping sound, blinking lane lines on the visual display, and

a slight nudge to the steering wheel. When Lane-Keeping Assist is used with Dynamic Radar Cruise Control at speeds above 45 mph (model year 2013) or 50 mph (model years 2010-12), the system will continuously apply a small amount of force to the steering wheel to help maintain the vehicle inside the lane.

2.2. Survey Participants

Toyota Motor Sales, U.S.A., Inc. provided the names, addresses, and phone numbers of customers who had purchased model year 2010 or newer Prius or Sienna models in the United States equipped with the optional advanced technology package. Participation was restricted to owners for whom complete contact information was known. Before contacting survey respondents, the survey instrument and study procedures were reviewed and approved by an Institutional Review Board.

A letter of invitation from the Insurance Institute for Highway Safety was sent to a random sample of 643 Prius owners and 547 Sienna owners. The letter explained the research effort and 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. Eight percent of owners opted out of the survey before being called, and 22 percent declined to participate when called. Of the 1,190 owners randomly selected for participation, 183 (15 percent) completed some or all of the survey questions. Experienced telephone interviewers from Westat, a research organization, conducted the interviews during July and August 2013 with either primary or frequent drivers of the vehicles.

2.3. Questionnaires

The interviewers briefly described the features of the different systems. Respondents were then asked about their use of the technologies, experiences with warnings and autonomous braking, behavioral responses to the technology, opinions about the technologies, general driving habits, and demographic questions.

2.4. Analyses

Chi-square analysis was used to examine the relationships between experiences with the system and characteristics such as driver age and gender and the duration of vehicle ownership. The Mantel-Haenszel chi-square statistic was used to test the statistical significance of linear trends involving driver

age and duration of ownership, and the Pearson chi-square statistic was used in analyses of gender differences.

3. Results

Interviews were conducted with 183 vehicle owners. The sample characteristics are shown in Table 1. More than half (64 percent) were male. Thirteen percent were 40 and younger, 9 percent were 41-50, 24 percent were 51-60, 29 percent were 61-70, and 17 percent were 71 and older.

3.1. Dynamic Radar Cruise Control

3.1.1. Use of system: Eighty-six percent of owners reported they had used Dynamic Radar Cruise Control at some point. Sixty percent always used it on freeways, expressways, or other high-speed roads, whereas 10 percent reported they always used it on lower speed roads with traffic signals or stop signs (Table 2). When using Dynamic Radar Cruise Control, the gap between the vehicles can be adjusted. The setting is shown as 1, 2, or 3 bars. One bar represents a shorter gap to the vehicle ahead, and 3 bars represent a longer gap. Among survey respondents who used Dynamic Radar Cruise Control, 76 percent had adjusted these settings at some point. Table 2 lists the settings that drivers typically used. Drivers most often used the longer gap setting (42 percent).

3.1.2. Experiences with system warnings: If Dynamic Radar Cruise Control detects a vehicle ahead and cannot decelerate sufficiently, a warning tone alerts the driver. Among those who used the system, 62 percent reported they received the warning alert, and 82 percent of these drivers reported they applied the brakes the last time they had received the warning. When using Dynamic Radar Cruise Control, 11 percent of drivers who used the system reported they usually waited for the warning before braking as they approached another vehicle.

3.1.3. Behavioral responses to system: When asked whether they followed vehicles more or less closely when using Dynamic Radar Cruise Control, 3 percent of survey respondents reported they followed vehicles more closely, 41 percent followed less closely, and 55 percent reported no change. When asked about looking away from the road when using the system, 4 percent of survey respondents said they tended to look away from the road more often, 4 percent tended to look away less often, and 92 percent reported no change.

3.1.4. Understanding of system: Four percent of drivers who used the system reported they had misunderstood or been confused by it. Most of these drivers (67 percent) found the system less confusing or easier to use the next time they used it.

3.2. Pre-Collision System

3.2.1. Use of system: Among 181 owners who responded to questions about the Pre-Collision System, 70 percent were aware of the system in their vehicles. Few drivers (3 percent) reported they ever turned off the system (Table 3).

3.2.2. Experiences with system activations: Owners were asked several questions about their experiences with the audible and visual warnings of Pre-Collision System and a separate set of questions regarding their experiences with autonomous braking. Forty percent of survey respondents who drove with the system turned on reported they had received a collision warning on at least one occasion, and 27 percent of those who drove with the system on thought a warning helped prevent a crash. Thirty-five percent of people who drove with the system reported they had experienced autonomous braking on at least one occasion when they thought they were at risk of crashing, and 20 percent of those who drove with the system on thought automatic braking helped prevent a crash.

Respondents who experienced system activations were asked whether the warning came too early, too late, or at the right time. Most respondents (81 percent) thought the warning came at the right time, 10 percent thought it was too late, and 4 percent thought it was too early. Three percent of survey respondents said the system failed to warn them when there was a risk of a crash. Two percent of survey respondents reported they had crashed into a vehicle in front of them, and these respondents indicated the system did not warn them before they crashed. These drivers said they were driving at speeds of 10 mph or less, which is below the speed at which the Pre-Collision System will brake automatically.

Among survey respondents who drove with the system turned on, 16 percent said they experienced collision warnings and 13 percent said they experienced autonomous braking when they were not at risk of having a collision. The most frequent situations or circumstances were when there was a dip, bump, or object in the road (31 percent), when a vehicle cut in front (14 percent), at a turn or curve in the road (14 percent), or passing a vehicle or changing lanes (10 percent).

3.2.3. Behavioral responses to system: Of survey respondents who drove with the system turned on, 6 percent reported they generally waited for the warning light or sound before slowing as they approached another vehicle. When asked how often they allowed the vehicle to do the braking for them, 8 percent of respondents reported they always or most of the time allowed the vehicle to brake for them, 9 percent reported they sometimes allowed the vehicle to brake for them, and 13 percent reported they rarely allowed the vehicle to brake for them. When asked whether they follow vehicles more or less closely, 71 percent reported no change, 11 percent reported following vehicles less closely, and 16 percent reported following vehicles more closely. When asked whether they look away from the road more or less often, 94 percent reported no change, 4 percent reported looking away less often, and 2 percent reported looking away more often.

3.2.4. Opinions of warnings: Survey respondents who experienced the collision warnings were asked whether they agreed or disagreed with several statements about them. Among 79 drivers who experienced the collision warning and heard the warning sound, 74 percent agreed the warning was useful, 5 percent agreed it was annoying, 4 percent agreed it was too loud, and 8 percent agreed it was too quiet. Among 54 drivers who had seen the warning lights on the dashboard that say PCS and Brake and accompany the warning sound, 83 percent agreed the light was useful, 2 percent agreed it was annoying, and 70 percent agreed it was easy to see.

3.2.5. Understanding of system: Thirteen percent of drivers who drove with the system turned on reported they had misunderstood or been confused by an activation of the system. Most of these drivers (59 percent) thought the system would be easier to understand or less confusing the next time they experienced an activation.

3.3. Lane-Keeping Assist

3.3.1. Use of system: Among survey respondents with Lane-Keeping Assist, 88 percent reported they ever turned the system on. Thirteen percent said they always used the system, 46 percent said they sometimes used it, and 29 percent rarely used it (Table 4).

3.3.2. Experiences with system activations: Eight percent of respondents who drove with Lane-Keeping Assist turned on reported they heard warning alerts very often, 41 percent heard the warnings sometimes, 45 percent heard them rarely, and 6 percent never heard them. Four percent thought the

system had prevented them from crashing into a vehicle in another lane, and 34 percent thought it prevented them from running off the road.

Seventy-five percent of survey respondents reported the system had never failed to warn them when they believed they were at risk of drifting out of their lane, and 25 percent reported it had. The most frequently reported situations in which this happened included missing or unclear lane markings (64 percent), inclement weather (24 percent), and driving at slow speeds (4 percent).

Twenty-seven percent of survey respondents 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 old markings or stains on the road (43 percent); pavement markings (other than lane markings) or crosswalks (32 percent); exits, splits, and merges (29 percent); missing or unclear lane markings (14 percent); heavy rain or snow (11 percent); driving on curves (11 percent); shadows or brightness contrast (7 percent); and construction (4 percent).

3.3.3. Behavioral responses to system: Among survey respondents who drove with Lane-Keeping Assist turned on, 85 percent reported no change in their use of turn signals when the system was turned on, and 14 percent of drivers said they used their turn signals more often with it. Fifty-nine percent reported no change in how often they drifted from their lane, and 35 percent said they drifted from their lane less often.

3.3.4. Opinions of warnings: Survey respondents who ever experienced activations of Lane-Keeping Assist were asked whether they agreed or disagreed with various statements. Among 92 drivers who heard the warning sound, 95 percent agreed the warning sound was useful, 29 percent agreed it was annoying, 5 percent agreed it was too loud, and 7 percent agreed the sound was too quiet. Among 82 drivers who had seen the visual display accompanied by the warning sound, 82 percent agreed the display was useful, 9 percent agreed the display was annoying, and 91 percent agreed it was easy to see. Among 76 drivers who had experienced a physical warning (i.e., a nudge to the steering wheel), 93 percent agreed the physical warning was useful, 9 percent agreed it was annoying, and 89 percent agreed it was easy to notice.

3.3.5. Understanding of system: Six percent of drivers who drove with the system turned on reported they had misunderstood or been confused by an activation of the system. Most of these drivers

(63 percent) thought the system would be easier to understand or less confusing the next time they experienced an activation.

3.4. 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, made driving less stressful, annoyed them, or distracted them. For each of the open-ended questions, respondents could give multiple responses. The results for these questions are summarized in Table 5.

For each technology, the large majority of survey respondents said they would want it in their next vehicle. Respondents were least likely to say they would want Lane-Keeping Assist (71 percent) again. The percentage who mentioned that a technology made driving less stressful ranged from 47 percent for the Pre-Collision System to 76 percent for Dynamic Radar Cruise Control. Fourteen percent of respondents with Lane-Keeping Assist mentioned it was annoying, and 9 percent mentioned it was distracting. Few respondents (1-2 percent) mentioned that Dynamic Radar Cruise Control and the Pre-Collision System were annoying or distracting.

Survey respondents were asked whether there was anything they disliked about each of the technologies and, if so, were asked to explain. A majority of respondents (57 percent) who used Dynamic Radar Cruise Control reported there was nothing they disliked about it. The most common complaints about Dynamic Radar Cruise Control were that the system slows the vehicle when not needed (e.g., for vehicles in other lanes) (10 percent), slows down too soon (8 percent), and has other limitations (e.g., does not operate at slower speeds, may not work in inclement weather) (7 percent). Most respondents (81 percent) reported there was nothing they disliked about the Pre-Collision System. A few drivers did not understand or were confused by the Pre-Collision System (2 percent), thought the system was overly sensitive (2 percent), or did not trust it (2 percent). The majority of respondents (60 percent) reported there was nothing they disliked about Lane-Keeping Assist. The most frequent complaints were that Lane-Keeping Assist does not work consistently (21 percent) and is too sensitive (7 percent). Eleven percent of drivers did not like certain aspects of the warning: visual display (4 percent), the feel of the physical warning (4 percent), or the beeping sound (3 percent).

Survey respondents were asked how they learned about the safety systems in their Toyotas and could provide multiple responses. Owners learned about the systems from the owner's manual (81 percent), trying it out on the roadway (70 percent), dealership demonstrations (44 percent), Toyota's website (28 percent), other website (11 percent), a family member or friend (11 percent), and DVDs, CDs, or videos (10 percent).

3.5. Differences by Driver Age, Gender, and Duration of Ownership

3.5.1. Differences by driver age: There were some differences in experiences with the systems by driver age (40 and younger, 41-60, 61 and older), which are summarized in Table 6. Drivers younger than 40 were more likely to have seen or heard a warning from the Pre-Collision System than were older drivers. Relative to the older age groups, drivers younger than 40 were more likely to report a warning perceived as unnecessary from the Pre-Collision System (36 vs. 12-18 percent) or Lane-Keeping Assist (62 vs. 13-37 percent). The proportion of drivers who believed the Pre-Collision System prevented a collision ranged from 15 percent of drivers 61 and older to 32 percent of drivers 40 and younger. Drivers younger than 40 more often reported positive behavior changes when using the systems; for example, the proportion of drivers who reported following a vehicle ahead less closely when using Dynamic Radar Cruise Control decreased with age. There were no other significant differences by driver age in the use of systems, general opinions about them, or experiences with activations.

3.5.2. Differences by driver gender: There were few significant differences in response by driver gender (Table 7). Males were more likely than females to have received a warning while using Dynamic Radar Cruise Control, and more likely to have received a warning from the Pre-Collision System perceived as unnecessary. Males also were more likely to have turned on Lane-Keeping Assist, and more likely to have received frequent warnings from the system.

3.5.3. Differences by duration of ownership: It was expected that drivers' opinions or use of the systems might change as they became more familiar with them. Drivers' responses were compared among drivers who owned their vehicles less than 12 months, 12-23 months, 24-35 months, and 36 months or more. Drivers' use of Dynamic Radar Cruise Control on roads with lower speed limits and traffic signals or stop signs increased with duration of ownership, ranging from 24 percent of drivers who owned the vehicle from less than 12 months to 49 percent of drivers who owned the vehicle for 36

months or more ($\chi^2[1]=4.0, p=0.046$). The proportion of drivers who reported they allowed the Pre-Collision System to brake for them at least sometimes increased with duration of ownership, ranging from 5 percent of drivers who owned the vehicle for less than 12 months to 25 percent of drivers who owned the vehicle for 36 months or more ($\chi^2[1]=44.43, p=0.035$). There were no other significant differences by duration of ownership in the use of systems or general opinions about them.

4. Discussion

Previous surveys with owners of luxury Volvo and Infiniti vehicles with crash avoidance technologies found that owners drove with the systems turned on most of the time, and many reported driving more safely as a result of the systems (Braitman et al., 2010; Eichelberger & McCartt, 2012); however, these studies are not necessarily representative of all drivers and all crash avoidance systems. 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 with Toyota owners who had 2010-13 Prius or Sienna models equipped with Dynamic Radar Cruise Control, the Pre-Collision System, and Lane-Keeping Assist.

For each of the systems, a large majority of survey respondents would want it again if they bought another vehicle. Consistent with previous surveys (Braitman et al., 2010; Eichelberger & McCartt, 2012), the systems that drivers were most likely to want again were Dynamic Radar Cruise Control (92 percent) and the Pre-Collision System (90 percent). Also consistent with previous surveys, drivers were least likely to want Lane-Keeping Assist again (71 percent). Many drivers reported the systems made driving less stressful, and this was particularly so for Dynamic Radar Cruise Control.

Most respondents drove with the systems turned on at least some of the time, and use was consistent with previous surveys (Braitman et al., 2010; Eichelberger & McCartt, 2012; Cicchino & McCartt, 2013). Eighty-eight percent of survey respondents always kept the Pre-Collision System turned on. In comparison, previous surveys found that 78-89 percent of Volvo owners and 84 percent of Dodge and Jeep owners always kept their forward collision systems turned on. Toyota's Lane-Keeping Assist system is turned off by default, and only 13 percent of Toyota owners always used the system. This finding is similar to a previous survey in which 15 percent of drivers with Infiniti's lane departure prevention system said they always used the system. In previous surveys with Volvo and Infiniti owners

who had lane departure warning systems that are on by default, a majority of drivers (59-69 percent) reported they always used the system. Differences in drivers' use of lane departure prevention versus warning-only systems could be due to the default settings, but differences also could reflect drivers' opinions of the two types of lane departure systems.

It is not possible to know how many crashes may have been prevented by the systems. Twenty-seven percent of survey respondents believed the forward collision warnings had prevented a crash, and 20 percent believed autonomous braking had prevented a crash. Drivers 40 and younger were twice as likely as drivers 61 and older to report the system had prevented a crash. In addition, some drivers thought Lane-Keeping Assist had prevented them from crashing into a vehicle in another lane (4 percent) or running off the road (34 percent).

There were some reports of situations in which drivers thought the system should have provided a warning, but did not. Three percent of drivers who used the Pre-Collision System and 25 percent of drivers who used Lane-Keeping Assist reported this problem. Some survey respondents reported that Lane-Keeping Assist 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). Two percent reported they had crashed into a vehicle in front of them, and these respondents indicated they were driving at speeds of 10 mph or less before they crashed. The autonomous braking feature of the Pre-Collision System does not operate at speeds of 10 mph or lower.

Some drivers were annoyed by the technologies. The system most often mentioned was Lane-Keeping Assist, with 14 percent volunteering it was annoying, which is a smaller percentage than in previous surveys of other lane departure warning and/or prevention systems. About a quarter of drivers received lane departure warnings they perceived as unnecessary, and these warnings were more common among younger drivers. However, the large majority of survey respondents still agreed the warnings were useful.

There have been concerns that crash avoidance technologies may have unintended effects on driver behavior or make drivers less attentive. In the current survey, many owners reported safer driving habits with the systems, and reports of safer driving were more common among the younger driver age groups. The safer driving habits included following vehicles less closely when using Dynamic Radar

Cruise Control and using turn signals more often and drifting from their lanes less often when using Lane-Keeping Assist. With regard to potentially less safe driving habits, 17 percent of owners reported they allowed the Pre-Collision System to brake for them at least sometimes, and the proportion of drivers who reported this increased with age and with duration of ownership. It is not clear why some drivers reported they allowed the vehicle to brake for them. It is possible that drivers may have been referring to braking by Dynamic Radar Cruise Control, rather than emergency braking by the Pre-Collision System. Sixteen percent reported following vehicles more closely with the Pre-Collision System, which is a greater proportion than in previous surveys with other forward collision avoidance systems (Braitman et al., 2010; Eichelberger & McCartt, 2012).

The study has some important limitations. Drivers with several different technologies may have been unable to distinguish warnings and alerts from different systems. 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. Another limitation of the study is that the sample may not be representative of the general population of U.S. drivers. Although this study focused on owners of non-luxury vehicles, the technologies were optional equipment that drivers chose to purchase. The suggested retail prices for models with crash avoidance technologies, which ranged from \$33,320-\$35,085 for Prius models and from \$41,910-\$42,785 for Sienna models, were substantially greater than the base prices for these models. Only 1 percent of the drivers interviewed for this survey were 30 and younger. Although the findings with regard to age generally were linear, it cannot be determined from the present study how drivers in their teens and twenties may use the technologies. Only 13 percent of the Toyota 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 what those of drivers will be when the technologies penetrate the vehicle fleet. In addition, the drivers in the current study are not necessarily representative of all Toyota owners. Respondents who chose to participate in the survey or who chose the technology package may have different opinions than those who declined to participate.

Driver acceptance of the technologies was high among Toyota owners in the present survey and was similar to previous surveys of owners of Volvo and Infiniti luxury vehicles. Based on self-reports, it

appears the systems may be encouraging some drivers to drive more safely, and this finding was especially true for drivers younger than 40. Reports of having experienced warnings generally were more common among the youngest drivers and males. Altogether, these findings suggest the systems may have the most positive impact on drivers who are at highest risk of being involved in a serious crash. However, there also were some troubling reports of potentially unsafe behavior. Some drivers reported following the vehicle ahead more closely with the Pre-Collision System. Future research should continue to monitor drivers' experiences with these technologies.

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Table 1 Characteristics of survey respondents (percentage)

	Percent (N=183)
Age	
30 or younger	1
31-40	12
41-50	9
51-60	24
61-70	29
71 and older	17
Unknown	8
Gender	
Male	64
Female	29
Unknown	7
Miles driven in typical week in vehicle	
100 or less	34
101-200	16
201-300	21
301 or more	24
Unknown	5
Number of months vehicle was owned	
Less than 12	11
12-23	27
24-35	31
36 or more	30
Unknown	1

Table 2 Drivers' use of Dynamic Radar Cruise Control

	Percent (N=183)
Use of system	
On freeways, expressways, or other high-speed roads	
Always used	60
Sometimes used	21
Rarely used	5
On lower-speed roads with traffic signals or stop signs	
Always used	10
Sometimes used	30
Rarely used	24
Never used	13
Unknown	2
Settings typically used among those who ever turned on system (N=157)	
Smaller gap: 1 bar	32
Medium setting: 2 bars	19
Larger gap: 3 bars (default setting)	42
Never changed	3
Unknown	4

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

Table 3 Drivers' use of Pre-Collision System

	Percent
Use of system	(N=181)
Never turn off	88
Sometimes or rarely turn off	3
Unknown	9

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

Table 4 Drivers' use of Lane-Keeping Assist

	Percent
Use of system	(N=116)
Always use	13
Sometimes use	46
Rarely use	29
Never use	12

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

Table 5 Drivers' opinions of systems (percentage of owners who had each technology)

	Dynamic Radar Cruise Control (N=172)	Pre-Collision System (N=171)	Lane-Keeping Assist (N=116)
Would want the technology again	92	90	71
Technology makes driving less stressful	76	47	48
Technology is annoying	2	1	14
Technology is distracting	2	1	9

Table 6 Differences in experiences with systems by driver age (percentage)

	40 and younger (N=23)	41-60 (N=54)	61 and older (N=74)	p-value
Among drivers who ever used Dynamic Radar Cruise Control				
Follow the vehicle ahead less closely when using Dynamic Radar Cruise Control	57	46	34	0.036
Among drivers who ever drove with Pre-Collision System on				
Have ever heard the warning sound	82	50	37	<0.001
Have ever seen the warning display	70	34	22	<0.001
Have received more than one collision warning	64	25	24	0.003
Received a warning perceived as unnecessary	36	18	12	0.010
Believed system has prevented a collision	32	26	15	0.049
At least sometimes let the system do the braking for them	44	88	2727	0.001001
Among drivers who ever used Lane-Keeping Assist				
Drift from lane less often when using system	50	49	25	0.028
Warning sound is too loud	17	10	0	0.010
Received a warning perceived as unnecessary	62	37	13	<0.001

Table 7 Differences in experiences with systems by driver gender (percentage)

	Males	Females	p-value
Among drivers who ever used Dynamic Radar Cruise Control	(N=106)	(N=47)	
Received a warning while using the system	73	40	<0.001
Among drivers who ever drove with Pre-Collision System on	(N=117)	(N=52)	
Received a warning perceived as unnecessary	21	8	0.030
Had ever been confused about whether the system was activated	6	30	<0.001
Among drivers with Lane-Keeping Assist	(N=79)	(N=36)	
Have ever turned on the system	92	78	0.026
Among drivers who ever used Lane-Keeping Assist	(N=73)	(N=28)	
Received warnings sometimes or often (vs. rarely or never)	58	25	0.003