RDCW•FOT

Road Departure Crash Warning System Field Operational Test: Methodology and Results

Volume 1: Technical Report

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16. Abstract

This report summarizes results from the Intelligent Vehicle Initiative (IVI) Road Departure Crash Warning System Field Operational Test (RDCW FOT) project. This project was conducted under a cooperative agreement between the U.S. Dept. of Transportation and the University of Michigan Transportation Research Institute, along with its partners, Visteon Corporation and AssistWare Technologies. Road departure crashes account for 15,000 fatalities annually in the U.S. This project developed, validated, and field-tested a set of technologies intended to warn drivers in real time when the driver was drifting from their lane, and a curve-speed warning system designed to provide alerts to help driver slow down when approaching a curve too fast to safely negotiate the curve This report describes the field operational test of the system and subsequent analysis of the data to address the suitability of similar systems for widespread deployment within the U.S. passenger-vehicle fleet. Two areas were addressed: safety-related changes in driver performance including behavior that may be attributed to the system, and levels of driver acceptance in key areas. Testing used 11 passenger sedans equipped with RDCW and a data acquisition system that compiled a massive set of numerical, video, and audio data. Seventy-eight drivers each drove a test vehicle, unsupervised, for four weeks. The resulting data set captured 83,000 miles of driving, with over 400 signals captured at 10 Hz or faster.

Analysis of the data shows that with the RDCW system active, relative to the baseline condition, drivers improved lane-keeping by remaining closer to the lane center and reducing the number of excursions near or beyond the lane edges. In addition, turn signal use increased dramatically. The data, however, were unable to confirm a change in driver's curve-taking behaviors that could have been attributed to the curve speed warning system. Driver acceptance was generally positive in relation to the lateral drift component of the system, with reactions to the curve speed warning system being rather mixed. Many additional results and insights are documented in the report.

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Executive Summary

The purpose of the Road Departure Crash Warning System Field Operational Test (RDCW FOT) was to gain insight into the suitability of road departure crash warning systems for widespread deployment within the U.S. passenger vehicle fleet. This was done by developing and field-testing a set of automotive crash warning functionalities – the RDCW system – and observing a set of lay drivers as they used an equipped test vehicle as their own personal travel vehicle for four weeks. A rich set of data was collected onboard the vehicles to observe the interaction of drivers with the RDCW system and their driving performance with and without the system. In addition, a set of questionnaires, focus groups, and debriefings were used to collect the drivers' subjective assessments of the system. Together, these data were analyzed with three focuses: to look for safety-related impacts within the driving data, to determine driver acceptance of the system along several dimensions, and to make observations of system performance in order to provide a context for discussing the first two focuses. This report summarizes the execution of the FOT experiment and presents analyses of the onboard data and the subjective data to address the three focuses.

Road departure crashes are among the more dangerous crash types. While single-vehicle road departure crashes comprise approximately 17 percent of all U.S. police-reported crashes (1.10 million per year), they are responsible for approximately 37 percent of the annual highway fatalities (over 15,000 annually). Road departure crashes are particularly dangerous because vehicles often roll over or strike stationary objects, such as trees or other fixed objects.

The RDCW system targeted crashes involving vehicles that drift off the road edge or into occupied adjacent lanes, as well as those involving vehicles traveling too quickly into turns for the driver to maintain control. Included in the RDCW package were two warning functions. The lateral drift warning system (LDW) was intended to help drivers avoid drifting off the road by providing a set of driver-alert cues when the vehicle was observed to be moving over either dashed or solid lane edge boundaries. The driver was expected to assess the situations and consider steering the vehicle back into the original travel lane if the drift was unintentional. The crashes addressed by LDWD are often associated with driver inattention, intoxication, and drowsiness. The LDW system used a camera to observe visual features that dilineate lane and road edges, such as painted lane boundaries. Furthermore, a set of onboard radars was used to modulate the warnings when potentially dangerous objects were sensed alongside the edge of the lane or road.

The curve speed warning system (CSW) was intended to help drivers slow down to a safe speed before entering an upcoming curve. The desired driver response to a CSW alert was for the driver to consider applying the brakes to slow the vehicle and reduce the lateral acceleration in the curve ahead. The CSW system relied on GPS and a digital map to anticipate the curve location and radius. Measurements of recent driver control actions, such as changing lanes or applying turn signals, were considered in CSW's decision to issue an alert. Both the CSW and the LDW used a set of visual, audible, and haptic cues to alert the driver at two levels per system.

The design of the RDCW system was completed during the first phase of the RDCW FOT project. A set of publications reported on the objective test procedures used in closed-course work to validate that the system performance was consistent with the design intent. A fleet of 11 passenger vehicles was then equipped with the RDCW system and a data collection system in order to conduct the field operational test. Approximately 400 data signals were collected at a rate of 10 Hz or higher, with video capturing the forward scene and driver's face at various frame rates throughout testing. Drivers were recruited from the southeast Michigan area, including Detroit and surrounding suburbs and rural areas. Each driver was trained briefly on the RDCW system and then asked to drive the vehicle where – and how – they normally would during their four weeks of vehicle use. In order to account for variations between drivers, the RDCW alerts were not displayed in the first week of use, which provided a baseline data set for each driver. The RDCW system displays were then presented to the driver during the subsequent three-week period.

A complete set of data was collected from 78 drivers distributed evenly by gender and within three age cells. The total distance traveled was 83,000 miles (133,000 km), covering almost 2500 hours and over 11,000 separate trips. This testing occurred within a 10-month window including summer, fall, and winter weather. Over 5700 LDW alerts and 3500 CSW alert events were presented to the drivers. No crashes relevant to the RDCW system occurred, as expected, given the rarity of these crashes (or any crashes) per driver-year.

The LDW presented one of two alert types when it sensed a potentially inadvertent drifting of the vehicle toward or over the lane edge. A cautionary alert (visual and haptic seat vibrations) was given when the vehicle was crossing a dashed lane boundary without any real-time or historical observation of an object near the lane edge. Imminent-level LDW alerts were given in other conditions considered more hazardous, and consisted of visual and audible cues. The data was then studied to identify influences of the RDCW system on driving behavior. Three major behavioral changes were noted and concluded to be attributable to the LDW system. First, the rate of turn signal use during lane changes increased, especially among drivers with lower-than-average rates of usage during their baseline week. This is because the LDW would issue an alert when the vehicle moved from its lane without a turn signal application, and therefore an intentional lane change without a turn signal application would trigger an alert. Among all drivers, the number of lane changes executed without a turn signal decreased by 43 percent on freeways and by 24 percent on surface roads. The overall rate of turn signal use per unit distance traveled also increased by 9 percent across the entire driver set, with the quartile of drivers with the lowest initial rates showing an increase of 23 percent in the number of turn signal applications per unit distance.

A second influence was found when studying data from 183 hours of extended periods of lane-keeping. Within that data set, the standard deviation of lane position decreased significantly. Furthermore, the number of events in which the outside of the vehicle's tire crossed the lane edge or came within four inches (10 cm) of the lane edge was reduced by 50 percent. The time spent within four inches of the lane edge, or outside the lane edge, was reduced by 63 percent. Therefore it is concluded that drivers were influenced by RDCW to improve their lane-keeping performance.

Thirdly, the data suggest that the vehicle returns to the lane more quickly following imminent alerts when RDCW is enabled, compared to the first baseline week. While the first two effects were very strong in a statistical sense, this third effect was more subtle, and detected by comparing median values of lane excursions at different points in time, and is therefore a weaker finding in a statistical sense.

The CSW system provided sets of alerts that could include one or more alerts for a given approach to a curve. A cautionary alert consisting of a visual icon and a vibration of the front of the seat pan was provided early in the approach, with a subsequent imminent alert provided if the perceived threat continued to escalate and the system had sufficient confidence that the vehicle would travel on the branch of the road system on which the curve was located. Imminent alerts consisted of a visual icon and a audible message to the driver. The CSW was observed to be successful in issuing alerts for upcoming curves, and for being relatively successful in anticipating whether a vehicle would take an upcoming branch, such as an exit ramp from a freeway.

The analysis did not identify any clear and broad change in drivers' curve-taking behavior, as measured by lateral acceleration patterns in curves. While there was some evidence that there might be an effect in reducing the lateral accelerations associated with curves on ramps, the result was only statistically significant in one of three statistical tests and may be due to confounding influences. This study did control the comparisons for variables that were shown to be influential in drivers' curve-taking decisions, i.e., road type, daytime/nighttime conditions, and the presence of precipitation or wet roads. Nonetheless, neither the mean of the lateral accelerations nor two measures of the tails of each drivers' lateral acceleration distributions were seen to be systematically affected.

As a concept, the RDCW system was seen by the majority of drivers to be both convenient and easy to use. Most reported that the RDCW system would increase driving safety and that they would be somewhat willing to purchase the RDCW system. The LDW and CSW systems and the combined RDCW system were generally received positively, according to feedback from the drivers. Most drivers made distinctions between the LDW and CSW systems in terms of their perceived utility. Ratings of utility of individual alert events by the drivers found 75 percent of LDW and 54 percent of a sample of the CSW alerts to be useful. Drivers reported a willingness to purchase LDW more often than they reported the same willingness in regard to CSW. LDW was considered by a number of drivers to be a generally desirable feature. CSW was also seen as a useful concept and was frequently described as being useful in unfamiliar surroundings or poor weather. Drivers subjectively reported that they were better drivers when LDW was enabled, using cell phones less often and turn signals more often, and drivers infrequently reported concerns regarding false alerts from LDW. For CSW, reducing the number of CSW false alerts was the most frequently cited change required in order for those participants not interested in purchasing CSW to consider buying the feature.

Overall, the Road Departure Crash Warning System Field Operational Test succeeded in field-testing an advanced set of crash warning systems to help drivers keep from departing the road. The lateral drift warning system was seen to influence drivers to use turn signals more frequently when changing lanes, and to improve their lane-keeping performance. Both effects are indicative of possible improvements in safety. This system was received positively by most drivers with some mixed opinions regarding current cost and current performance levels. The curve speed warning system succeeded in warning drivers about upcoming curves. While the analysis was not able to identify specific changes in driving habits, the CSW system was seen by drivers to be a useful concept. Some drivers stated that CSW would be most useful on unfamiliar roads, at nighttime, or during difficult driving conditions. The acceptance of CSW was significantly variable across drivers.

This project has confirmed that road departure crash warning technology has the potential for reducing the number of crashes in the U.S. Together with other driver support systems, these may become the next wave of safety improvements on the nation’s highways.

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1 Introduction

This report presents the final results of the Intelligent Vehicle Initiative Road Departure Crash Warning System Field Operational Test (RDCW FOT). The project was conducted under cooperative agreement DTFH61-01-X-00053 between the U.S. Department of Transportation (U.S. DOT) and the University of Michigan Transportation Research Institute (UMTRI) and its partners Visteon Corporation and AssistWare Technologies, Inc. The program was administered by the U.S. Department of Transportation's Intelligent Transportation Systems Joint Program Office, under the light vehicle segment of the Intelligent Vehicle Initiative (IVI). Technical leadership at the U.S. DOT was provided by the National Highway Traffic Safety Administration (NHTSA), with administration by the Federal Highway Administration.

The purpose of the RDCW FOT project was to develop and field test a road departure crash warning system onboard light vehicles (passenger cars, vans, or light trucks), using lay drivers as a test population. By studying the driving performance of the test subjects with vehicles equipped with a road departure crash warning system and analyzing the subjective information provided by the drivers, the project sought to determine the suitability of introducing such a system into the U.S. light vehicle fleet.

The two critical objectives while analyzing the field test data were:

- an assessment of potential safety impacts of the RDCW system, and
- an assessment of the driver acceptance of such a system.

The RDCW FOT project was launched in late 2001 and testing was completed in 2005. The first phase involved the development and testing of a prototype RDCW system that provided an integrated set of driver alerts to address the following crash types:

- inadvertent drifts from the roadway, which can lead to striking an object on the shoulder (such as a parked car), an off-road object, or rolling over,
- inadvertent drifts out of a travel lane, which can lead to sideswiping adjacent traffic traveling in the same direction or running head-on into traffic traveling in the opposite direction , and
- traveling too fast into a curve, with the potential for losing control and departing the roadway.

A set of vehicle-level objective tests was developed in close cooperation with NHTSA and the National Institute for Standards and Technology (NIST). The conduct of these tests demonstrated that that the system met the requirements that had been developed for it in a repeatable fashion. A fleet of 11 prototype vehicles shown in figure 1.1 was then equipped with the RDCW system and an extensive data collection system.

Figure 1.1 Vehicle fleet

The RDCW FOT was then launched. Drivers were recruited from the general public in the southeast Michigan region were each allowed free use of a vehicle for four weeks. The drivers were allowed to travel as they chose, with only minor geographical restrictions to keep the vehicle within the U.S. with preferred use within the coverage of digital maps onboard. During the first week with the vehicle, the test subject did not experience RDCW crash alerts but instead was observed driving. The system was then enabled for the subsequent three weeks, with all driver alerts and controls made available. The subjects' driving behavior and performance was then captured again, this time possibly modified by their use of, and interaction with, the RDCW system. Data from seventy-eight of the drivers constitutes the data set that is analyzed here; nine other drivers drove a vehicle but their data was discarded for reasons described in section 5.

In-depth analyses of the data were conducted and are reported here. The data were also archived and shared with the US DOT's independent evaluator for this project, the Volpe National Transportation Safety Center (part of US DOT's Research and Integrative Technology Administration (RITA)). Eighty-three thousand miles of driving was captured in this data archive, with over four hundred signals collected at a rate of 10 Hz or higher throughout. Video from the forward scene was captured at moderate frame rates throughout the test, as was video of the driver's face. Both videos were recorded at higher rates for brief time periods surrounding events of interest.

These data are housed in relational database environments. Analysis tools have been adapted and improved from previous projects to allow the team to study both broad effects and episodic events. Drivers perceptions of the RDCW system were also captured using a variety of subjective instruments before and after their experience with the RDCW vehicle, resulting in a rich resource of subjective data that may be correlated to the corresponding objective driving data.

1.1 Approaches to system definition and experimental design

The definition and design of a crash warning system involves creating a complex set of integrated technologies that strike a balance among several goals, including maximizing the potential safety benefits, maintaining an acceptable level of nuisance alerts, using hardware components that are commercially viable, and creating a system that is sufficiently valued by the driver enough to promote the inclusion of the system as an original equipment feature.

The RDCW countermeasure was based on a partial set of technologies that existed within the project team; these technologies were then enhanced substantially with additional functions developed under support of this project. The definition of the RDCW system requirements was, indeed, a hybrid activity. Some requirements were defined by the commercial potential that the industry partners perceived for subsets of the overall function, such as a stand-alone lane departure system or other systems enabled by predictions of road curvature such as those delivered here by the curve speed warning system. Other requirements were defined by the goals of the US DOT in its creation of the project, which went beyond current-generation technology, especially in the need for the system to observe the roadside and modulate road-departure alerts based not only on lane position, but also on the potential for crashes with objects. Thus the project has succeeded in evaluating a system whose performance is likely representative of systems that will be fielded commercially in the near future, with some attributes of more advanced systems that may arrive in the years to come.

The methodology for evaluating the RDCW system was an experiment in which a representative driving population was exposed to the RDCW system under the individual drivers' natural conditions of travel and driving habits. Driving performance was closely observed via an extensive data collection regimen. By comparing individual drivers' performance with the system enabled (weeks 2 through 4) to their driving without it (week 1), there was a basis for studying surrogate measures of safety. By obtaining their subjective feedback of the system after their time with the vehicle, issues of driver acceptance could be studied.

Field operational tests under the IVI program do not attempt to base their safety analyses on crashes captured during the test. Crashes are so rare that the amount of driving time to capture a meaningful set of crashes would require the prohibitive costs of equipping enough vehicles with the technology under evaluation. In the U.S., although road departure crashes inflict a terrible cost overall, the average driver's expected exposure to any police-reported, road-departure crash is only once per 211 years (based on 1.10M crashes in the 2001 General Estimate Systems (GES) out of a registered driving population of 231,000,000 (NHTSA, 2005)). Drivers are assumed to depart the road much more often than reported to the police, but even a 100-to-1 ratio of actual road departures to police-reported crashes suggests that a viable and rigorous FOT program could not create enough events to support a direct evaluation of safety based on road departures in an FOT. This FOT itself captures the equivalent of approximately 7 years of driving. Indeed, there were no police-reported crashes other than a deer-to-car crash that was unrelated to this technology. Thus, the study of driving performance and potential safety impacts necessarily relies on surrogate metrics of driver performance using variables observed in the test. Fortunately, as the remaining sections suggest, analyses based on these measures using the limited set of driving data within the FOT can still lead to findings that are persuasive in their suggestions about drivers' usage and interactions with these systems. Thus the FOT is a useful tool for evaluating new or emerging technologies in "real-world" driving.

1.2 Project organization

The three partners that comprised the RDCW FOT project team each made major contributions to the project. UMTRI is a research institute that conducts research to promote the safety and efficiency of the highway transportation system. UMTRI served as the prime contractor, and its technical contributions are listed in table 1.1. Visteon Corporation is a leading Tier-1 supplier to automotive manufacturers worldwide, with global revenues of $18B in 2004. Visteon's participation was led by its Driver Awareness Systems group, headquartered in Van Buren Township, Michigan. The major roles of Visteon are outlined in table 1.1. AssistWare Technologies is a high-technology system developer based in Gibsonia, PA.

AssistWare has been a pioneer in vision-based automotive lane-tracking systems and other safety systems, and continues to market its commercial products in both the heavy and light vehicle segments. Table 1.1 highlights its contributions to the program.

Table 1.1 Roles and responsibilities of the FOT project team

UMTRI ▪ Prime contractor — Interfaced with USDOT; responsible for briefings and reports. — Coordinated and administered the partnership. ▪ Created FOT experimental design and executed FOT. ▪ Designed & fabricated data acquisition systems. ▪ Conducted analysis of FOT experiment data. ▪ Supported research for design of driver-vehicle interface.
Visteon Corporation ▪ Led system engineering and program management for the design, and fabrication of the RDCW system. Designed & fabricated curve speed warning system. ▪ Designed & fabricated driver-vehicle interface. ▪ Selected and acquired forward and side radar system. ▪ Designed and executed physical integration of all modules into the FOT vehicles. ▪ Designed and executed system verification testing.
AssistWare Technology ▪ Designed & fabricated lateral drift warning system. ▪ Designed & fabricated Situation Awareness Module.

Figure 1.2 shows the organization of the RDCW project team and its relationship to the US DOT and its representatives. As mentioned earlier, the US DOT engaged the Volpe Center as an independent evaluator. Not shown in the figure is the work done by the National Institute for Standards and Technology (NIST) for US DOT to support the development and conduct of vehicle testing.

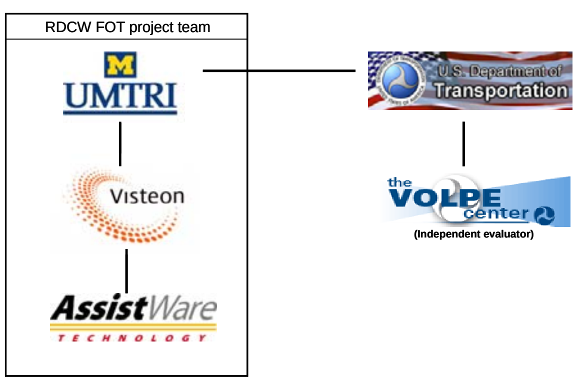

Figure 1.2 Organizational structure of the RDCW FOT team and relationship to US DOT

1.3 Technical work plan

The technical activities of the project were arranged in two phases with a total of ten tasks as listed in table 1.2. Phase I included the development of the system from concept through validated prototype vehicle and data system. This effort included an extensive system engineering effort following Visteon's Advanced Engineering Concept Development Process, which provided several outputs including:

- system architecture,
- system technical specifications,
- communications interface document, and
- procedures for validation testing.

Table 1.2 Project work tasks

	Phase I
1	Project management – Phase I
2	Develop and fabricate RDCW prototype vehicle
3	Develop and validate prototype data acquisition system
4	Validate and demonstrate the RDCW prototype vehicle
5	Prepare an FOT plan
	Phase II
6	Project management – Phase II
7	Fabricate FOT vehicle fleet
8	Conduct FOT experiment
9	Process and interpret data
10	Prepare the final report

Visteon and AssistWare collaborated with NHTSA and its representatives from NIST to finalize the testing procedures. Validation testing was conducted at the Transportation Research Center in Ohio, and a system demonstration was provided in Dearborn, Michigan.

Phase I also included the development and validation of the data acquisition system for the FOT, as well as the writing of an experimental plan for the FOT experiment. Upon joint agreement with the USDOT to move from Phase I to Phase II, a fleet of 11 prototypes were built with the RDCW system installed. UMTRI conducted the FOT experiment with the technical support of its partners, and data were collected and shared with the independent evaluator. Finally, the data were analyzed at UMTRI, and a final report documenting observations made from the data was generated in collaboration with the other partners.

1.4 Report overview

This final report focuses on the conduct and outcome of the FOT experiment itself. It consists of two volumes:

- Volume I: Main Technical Results. Volume I consists of an executive summary and ten chapters summarizing the objectives and design of the RDCW system countermeasure, the FOT experiment, and analyses of the data that address the effectiveness of the system in terms of safety and acceptance.
- Volume II: Appendices. Volume II consists of appendices with reference data that support sections within Volume I.

Within Volume I, there are nine sections that follow. Section 2 presents background material including a summary of the road departure crash problem in the US and relevant previous and simultaneous research projects. Section 3 gives a detailed description of the RDCW countermeasure, including descriptions of the crash avoidance function and its implementation onboard the vehicles. Section 4 presents the experimental design of the FOT itself, including a discussion of the field operational test as a methodology, as well as the details of the recruiting and handling of the test subjects. Section 5 gives an overview of the resulting data archive that is used in the subsequent sections. Section 6 presents results of analyses that express the exposure of the RDCW system (and the driver) to different driving conditions. Section 6 also lays the foundation for the proper normalization of data that is necessary to reach reliable conclusions in an experiment with many possible confounding factors. Section 7 summarizes the exposure of the drivers to the RDCW system, including overviews of how frequently the systems provided alerts and how often the systems were not available to provide alerts. Section 8 focuses on changes in driving performance or behavior that may be related to the presence of the RDCW system. Section 9 presents all results gathered from the data within the subjective instruments given to all drivers. This also includes further studies into changes in driver activities and behavior that may be related to the RDCW system. Finally, section 10 presents a summary of conclusions that are culled primarily from sections 6 through 9. References are provided after the conclusions section, as are important acknowledgments of the valuable contributions of many organizations and staff not listed on the title page of this report.

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2 Crash problem size and related research

This section reviews background material that provides context for the project. Section 2.1 presents the road-departure crash problem that motivates the RDCW system, and section 2.2 provides an overview of selected research programs on crash avoidance systems and other relevant research.

2.1 Road departure crash problem involving light vehicles

Highway crashes claim more than 42,000 lives annually in the U.S. Highway crashes rank as the leading cause of death for persons aged 3 to 33, and, for the overall population, represent the 7th most common cause of death and the leading cause that is not disease-related (Subramanian, 2005). Among highway crashes, road departure crashes are among the most severe. Single-vehicle, off-road crashes accounted for 1.10 million of the 6.32 million police-reported crashes, or 17.3 percent of those crashes. Single-vehicle, off-road crashes, however, accounted for 15,436 or 40.8 percent of all fatalities as shown in figure 2.1 (Emery et al, 2005).

Road departure crashes are defined as those in which the first harmful event occurs off the roadway. This includes inadvertent drifting off the road edge due to drowsiness, inattention, or intoxication, as well as crashes caused by loss of control while negotiating a curve. Additional crash types include road departures during maneuvers (such as completing left turns), road departures caused by evading another type of crash or by swerving around an animal or object, and slippery-road crashes.

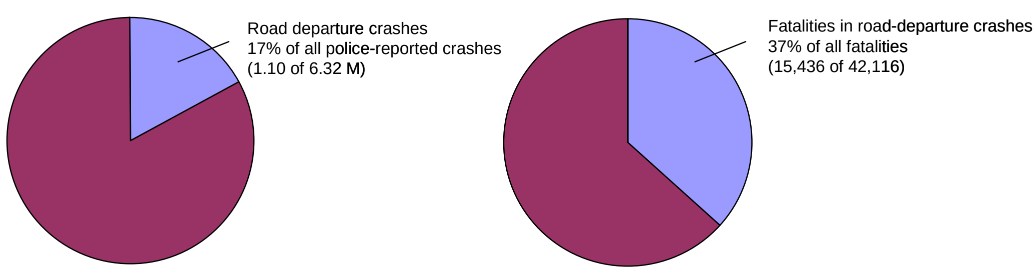

Figure 2.1 Relative contribution of single-vehicle, road-departure crashes to the U.S. crash population and fatality record (from Emery et al, 2005)

A study of the 1998 General Estimates Systems database was conducted specifically to define the target crashes of a road departure system (Najm et al., 2002). Key results from that work are presented here.

Najm et al., 2002, point out that there were 1,258,000 police-reported crashes in 1998 involving a single vehicle running off the road, excluding crashes where the vehicle was backing or where no impact occurred. Table 2.1 shows the number of crashes associated with the six leading scenarios defined by two dimensions: the pre-crash motion of the vehicle and the nature of the road departure. The set of crashes that are potentially amenable to a crash warning system, as envisioned by NHTSA, are those that fall into one of the shaded cells in table 2.1. These crashes add up to 621,000 crashes, so that, potentially, 49.4 percent of all single-vehicle roadway crashes may be addressed with the RDCW system. These will be considered the target crashes for the RDCW system for the purposes of this section.

The RDCW system may help drivers avoid other types of crashes as well. Multiple-vehicle crashes can result from a recovery maneuver that follows an inattentive driver's lane- or road-departure, e.g., an over-correction from the initial departure that results in the vehicle crossing into opposing traffic. The RDCW system may help prevent this and other types of multiple vehicles, however these are not considered in the analyses in this chapter.

Table 2.1 Number of crashes in leading road-departure pre-crash scenarios, from Najm et al., 2002 (shaded cells indicate targeted scenarios for a road departure crash warning system.)

	Going straight	**Negotiating a curve**	**Initiating a maneuver**	**All**
Departed road edge	348,000	111,000	66,000	**525,000**
Lost control	218,000	162,000	51,000	**431,000**
Total	**566,000**	**273,000**	**117,000**	**956,000**

Road-departure crashes are most common on surface roads, not on limited access highways. Based on analyses of Najm et al., 2002, there were 552,000 crashes from the targeted scenarios on non-freeways, while there were 70,000 crashes on freeways. Thus 89 percent of these crashes took place on surface roads. Table 2.2 shows that the percentage of crashes occurring on non-freeways within each of the three targeted scenarios is between 87 percent and 93 percent of the 552,000 crashes on surface roads.

Table 2.2 Percent of targeted crashes occurring on non-freeways

Targeted scenario	Percent of crashes on non-freeways
Going straight and departed road edge	88%
Negotiating curve and lost control	87%
Negotiating curve and departed road edge	93%
Weighted total	89%

Road departure crashes are also more common in rural settings according to Najm et al., 2002, given a definition of a rural crash as follows: A crash is said to occur in a rural setting if the jurisdiction noted on the police report has a population less than 50,000 persons (according to the U.S. Census's 1994, County and City Data Book). Based on that definition, and discarding the roughly 8 percent of crashes in which there was no determination of whether the setting was rural and urban, then overall, 69 percent of the targeted road crashes occur in rural settings.

Table 2.3 shows that the breakdown of targeted crashes also depends on the road type, so that when all targeted crashes are considered, 62 percent of freeway road-departure crashes and 70 percent of non-freeway road-departure crashes occur in rural settings. When the three individual targeted scenarios in table 2.3 are considered, it is seen that the relative fraction of crashes that occur when the driver is negotiating a curve is higher in rural settings: 86 percent of crashes involving loss of control on curves and 80 percent of crashes involving road-edge departure on curves occur in rural settings.

Table 2.3 Percent of targeted crashes occurring in rural settings (excluding the 8% of targeted crashes where the rural/urban setting cannot be determined)

Targeted scenario	Road type	Percent in Rural Settings
Going straight and departed road edge	Freeways	64%
	Non-freeways	59%
Negotiating curve and lost control	Freeways	60%
	Non-freeways	80%
Negotiating curve and departed road edge	Freeways	57%
	Non-freeways	86%
All 3 scenarios	Freeways	62%
	Non-Freeways	70%

For curve-speed warning, it will be useful to consider the fraction of freeway crashes associated with negotiating freeway ramps. This is important because as section 7 will show, freeway ramp-related alerts are a major subset of the nuisance alerts from CSW. These occur because CSW alerts for sharply curved ramps are often required well before the driver reaches the ramp itself, since the system is forced to anticipate whether the driver will take the exit or continue on the freeway.

Table 2.4 shows the percentage of curve-related, targeted crashes occurring on ramps, again based on data from Najm et al., 2002. A substantial fraction of the targeted curve-related crashes that occur on freeways occur on freeway ramps: 39 percent of those involving loss of control while negotiating curves and 27 percent of those where road-edge departure is the cause. Overall, more than one in three of the targeted road-departure crashes involving curve negotiation on freeways occur on ramps. Clearly, there is some warrant for the design of a CSW to include curves on ramps as part of the warning strategy. However, the number of actual freeway ramp-related crashes is just 10,425, out of the total of 622,000 targeted crashes (less than 2 percent).

Ramps do not play such a large role in non-freeway crashes, as shown in table 2.4. Only 2.6 percent of crashes on non-freeways are related to ramps associated with non-freeways. This may be due to the facts that ramps are less common on surface roads, and that speeds on surface roads are much lower.

Table 2.4 Percent of targeted crashes involving curve negotiation that occur on ramps

Targeted scenario	Freeways	Non-freeways	All roads
Negotiating curve and lost control	39.2%	3.7%	8.3%
Negotiating curve and departed road edge	27.4%	1.2%	3.0%
Both curve scenarios	35.9%	2.6%	6.1%

Figure 2.2 shows results derived from Najm et al., 2002, that indicate that crashes involving a driver going straight and departing the road edge are most common at lower posted speeds, with a small increase for posted speeds of 55 mph. Crashes involving curve negotiation, however, are most common on roads with posted speeds of 55 mph. Together, this suggests that the curve-overspeed problem is most common on higher-speed, rural, surface roads, while the case of drifting off a straight road is more common on surface roads with lower speed limits.

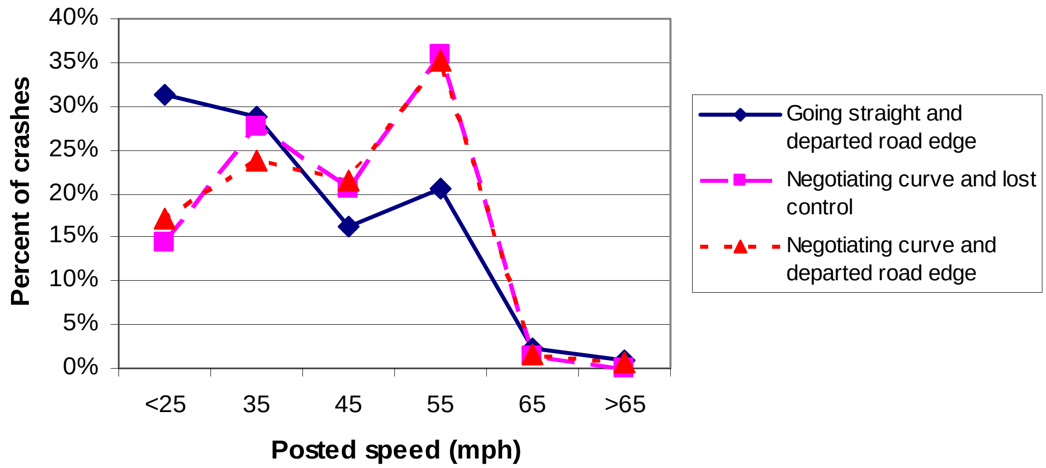

Figure 2.2 Number of targeted, road-departure crashes as a function of the posted speed

There have been studies of the involvement of speeding, intoxication, other impairments (e.g., drowsiness), and distraction in road departure crashes. Intoxication is a leading associated variable with drift-off crashes, and excessive speeding is most commonly linked with loss of control in curves. Environmental variables also play a part in road-departure crashes, especially with slippery road conditions associated with curve-related crashes. Distraction is not typically as influential a factor, although since crash data are based on police reports, distraction is often assumed to be significantly under-reported in those data.

2.2 Related research

The RDCW FOT project was created as part of the Intelligent Vehicle Initiative (IVI). The IVI effort itself was a continuation of an ongoing ensemble of inter-related programs within US DOT on crash avoidance technology that grew in scope in the early 1990s (USDOT 2005). These programs were intended to foster development of countermeasures that would address key crash types that earlier analyses had suggested could be amenable to crash-avoidance approaches. There were at least two precipitating factors leading to the interest in crash avoidance within the automotive industry and governing institutions: appropriate sensing technologies were suddenly projected to be within range of a commercially viable system, and the gains in safety achieved through improved crashworthiness, driver education, and enforcement, began to level out throughout the 1990s.

As described in section 2.1, road departure crashes represent a significant fraction of all crashes and a greater fraction of fatalities. The Run-off-road Specification

Program sponsored by NHTSA considered state-of-the-art automotive lane-tracking systems, digital maps, and GPS, and developed algorithms for driver alerts and estimates for potential safety benefits of such systems (Pomerleau et al., 1999). That program laid the foundation for the work in this report and included the approach of addressing a portion of road departure crashes by developing two, coupled countermeasures: a lane departure warning system, and a curve-speed warning system. To develop algorithms and demonstrate working prototypes, each countermeasure was addressed separately. Simulation models were developed to estimate the potential safety benefits of each. Overall, that effort estimated that a lane-departure warning system could prevent 10 percent of all passenger vehicle road-departure crashes, while a curve speed warning system could prevent an additional 11 percent of passenger vehicle road-departure crashes (Pomerleau et al., 1999)

Also directly relevant to the work of this report is research conducted by NIST for NHTSA on objective testing of lane-drift warning systems using vehicle-level tests. NIST developed a set of hardware for independent measurements of lateral positions and later developed a set of procedures as well (Szabo et al., 1999), (Szabo and Norcross, 2003).The RDCW FOT is not the only road departure crash warning FOT. A heavy-vehicle FOT with LDW is nearing completion, however, the results were not available for comparison with those reported in this document. That project was sponsored by the Federal Motor Carrier Safety Administration and was conducted by a consortium which included Mack Truck and one of the partners on the RDCW program, AssistWare Technology.

The IVI also continued to look at other crash types including rear-end crashes, lane-change crashes, and intersection crashes. The programs on rear-end crashes are perhaps furthest along, and include results on objective test procedures (Kiefer et al., 1999), algorithms (LeBlanc et al., 2001), advanced human factors testing (Kiefer et al., 2003), and field operational testing (General Motors, 2005, Ervin et al., 2005). Lane-change crashes are addressed in (Talmadge et al., 1999) and (Glassco et al., 2003) and, more recently, in the use of naturalistic data to study normal behaviors (Lee et al. 2004)

In addition, adaptive cruise control – especially in combination with a forward crash warning system – has been an active topic as well. Work on algorithms and driver acceptance (Fancher et al., 2000), field operational testing (Fancher et al.,1998)

(Ervin et al., 2005), and stability of the traffic stream with a fleet of equipped vehicles has been done (Fancher et al., 2003).

Other important and relevant research includes the Enhanced Digital Maps project, which examined the digital-map and vehicle-positioning requirements to support a suite of safety applications (CAMP, 2004). Digital maps that are available for automotive applications have been developed largely to support navigation requirements. An important relevant finding of that research is that, in the near-term, these digital maps will not be accurate enough to provide the location of the vehicle within a lane, even with the most accurate of GPS measurements. This is relevant because the RDCW system would benefit from knowing in which lane the host vehicle was traveling.

The Vehicle Safety Communications Consortium (VSCC) has also conducted a series of activities for NHTSA that explore the use of wireless technologies to enable or improve performance of advanced safety features. This research has included the demonstration of a curve speed warning system based on a roadside unit transmitting information about the geometry of an upcoming curve (CAMP, 2005). This approach would help overcome many of the difficulties of the autonomous (vehicle-based) system described in this RDCW FOT report, including the difficulty of upgrading and using digital maps with suitably accurate curvature information for this new application. However, there are currently no such wireless installations for use by the public, and their deployment is not yet a certainty. So, for the next decade or two, a fair expectation is that all crash avoidance systems will be autonomous.

Lane departure warning systems have been available in the U.S. as original equipment on heavy vehicles for several years. In addition, there has been a recent release of lane departure warning systems on a production passenger vehicle within the U.S. and Europe; the introduction in the Japan market occurred several years ago. Curve speed warning systems are not yet available on either light or heavy vehicles.

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3 RDCW Function and System Description

The Road Departure Crash Warning system (RDCW) developed by the FOT partners was a set of technologies that provided the driver with a set of alerts that were intended to prevent or mitigate many types of run-off-road crashes. This section describes the RDCW system's countermeasures, and the integration of that system onboard the fleet of vehicles used in the FOT.

Section 3.1 provides an overview of the RDCW system function, while section 3.2 introduces the system architecture and describes the key sensors supporting the function, including their integration in the vehicle. Section 3.3 introduces the driver controls and displays, while Section 3.4 presents further details of the lateral drift warning system. Section 3.5 presents a corresponding description of the curve speed warning system. A brief overview of the data acquisition system (DAS) used onboard the test vehicles is given in section 3.6. The remaining aspects of the integration of the RDCW system into the test vehicle fleet are given in sections 3.7 and 3.8. Greater detail on the DAS hardware and the broader aspects of data collection, processing, and archiving will be provided in section 5.

3.1 RDCW system overview

The RDCW function can be described as the combination of the lateral drift warning (LDW) system and a curve-speed warning (CSW) system. The LDW system provided alerts intended to assist the driver in avoiding run-off-road crashes that are caused by inadvertent drifts from the travel lane. Foremost among these crashes are run-off-road crashes. The LDW would also be effective in reducing the number of sideswipes and head-on crashes that would occur if the RDCW-equipped vehicle drifted from its travel lane into an adjacent lane of either same- or opposite-direction traffic.

When an LDW alert was provided, the expected response of the driver was to assess the situation and, if necessary, correct the vehicle's path primarily through steering. During lateral drifts that met the threat assessment criteria, the LDW would provide a single alert, with one of two displays provided, depending on the system's perception of the potential severity of the situation. The lower, "cautionary" level of LDW alert was a combination of visual and haptic alerts which was used if the vehicle was about to cross a dashed line, (suggesting movement into an adjacent travel lane), with no other evidence of an imminent risk of sideswipe collision. The higher level of LDW alerting was called the "imminent" level, and was a combination of visual and audible alerts that was used in all other situations in which the vehicle was drifting from its travel lane without a turn signal application. This includes all crossings of solid markings and those crossings of dashed markings in which a potentially threatening object was perceived (by radar) to be alongside or ahead of the vehicle in the direction of the lateral drift. A recent application of the turn signal or the brake pedal would temporarily suppress all LDW alerts.

The CSW system provided alerts intended to help the driver avoid traveling into a curve too fast for safe travel. CSW could be effective in reducing the occurrence of road departure crashes caused by excessive speed in curves. The system provided a one- or two-stage alert that prompted the driver to consider applying brakes in order to slow the vehicle and reduce lateral acceleration in the curve. The first alert stage of the CSW was a combination of visual and haptic alerts. If the perceived potential threat of curve over-speed continued, a second stage alert was provided, in which visual and audible alerts were given.

Each system allowed the driver to adjust a sensitivity setting that influenced the timing of the alerts. Neither system could be turned off by the driver. The CSW and LDW shared a visual display space, motors in the driver's seat pan for haptic cues, and an audio system. While they shared these driver-vehicle interface (DVI) mechanisms, the two warning functions used distinctly different alert icons, haptic cues, and audible alerts. The LDW and CSW functions are said to be integrated in part because they did share a common DVI. At a deeper level, however, there was synergy between the LDW and CSW, because each subsystem used intermediate data that the other subsystem provides.

The RDCW system was implemented onboard a fleet of 11 Nissan Altima 3.5SE sedans (model year 2003) purchased by the project team (see figure 3.1). A mid-sized sedan was selected since it would be a familiar platform for the largest number of drivers. The Altima platform was also

Figure 3.1 Nissan Altima 3.5SE

selected because it had an original-equipment CAN bus, and Nissan was willing to provide information about the bus message set. The ability to decode the CAN bus information allowed the team to efficiently capture important signals such as PRNDL position, vehicle speed, turn signal, brake signal, accelerator pedal position, headlamp status, cruise control status, and others. In addition to providing CAN message sets, Nissan provided technical information for purposes of the physical integration of RDCW onboard this platform. Nissan, however, was not involved in the definition or development of the RDCW system, nor in other facets of the project, and there is no relationship between the RDCW system and any Nissan crash avoidance system.

3.2 System architecture and primary sensors

This section presents the sensors used in the RDCW system and the high-level system architecture. The primary sensors and other supporting sensors used by the RDCW system are presented in table 3.1. For the purposes of this table, primary sensors are defined as those that are needed for a basic functionality, and supporting sensors are defined as those important to achieve levels of performance defined during the early stages of the program.

Table 3.1 Key sensors used by the LDW and CSW systems

Sensor	LDW system sensors		CSW system	
	Primary	Supporting	Primary	Supporting
Forward CCD camera	X			X
GPS		X	X	
Digital map		X	X	
Digital map look-aside database		X		
Vehicle speed		X	X	
Yaw rate gyro		X	X	
Driver brake switch	X			X
Driver turn signal switch	X			X
Forward-looking radars		X		
Side-looking radars		X		

The LDW system depended on a forward-looking, monochrome CCD camera to identify visual features at or near the lane edge. The image positions of the visual features were used to compute the lane position of the vehicle, lane width, and relative motion within the lane. The LDW also used a variety of other sensors (identified in table 3.1) to increase the accuracy and reliability of the conversion of image features into lane position and lane-information data. The LDW included a prediction about whether the vehicle would soon exceed a threshold function of lateral position and velocity, which would trigger an LDW alert. Furthermore, some sensors provided information that sometimes led to suppression of alerts when drivers may have been maneuvering intentionally. (The manner in which this was done is described in section 3.4).

The primary sensors of the CSW system included GPS (without differential correction), a yaw-rate sensor, and the Nissan production vehicle-speed signal. These, in combination with a digital map database provided by map supplier NAVTEQ, were used by the CSW to locate the vehicle on a roadway, observe upcoming curves, and decide whether the driver would need to decelerate soon to reduce the vehicle speed in order to avoid exceeding the CSW's threshold for lateral acceleration in the curve. There are other measurements not included in table 3.1 that played smaller roles in the decision-making regarding LDW and CSW alerts. These include an ambient temperature sensor, wiper-state indication, and others.

Figure 3.2 shows a depiction of the fields of view of the radar and vision sensors. Two forward-looking, long-range, 77-GHz scanning radars were mounted in place of the original-equipment fog lights, with each radar canted out slightly to observe the adjacent lane(s) or roadsides, while still providing overlap between the fields of view so that all vehicles ahead could be observed. Two side-looking, 24-GHz radars were each mounted behind the fascia forward of the front wheels. These side radars had fields of view that were approximately 120 deg wide, centered about the lateral axis of the vehicle. The physical installation of both types of radar is shown in Figure 3.3.

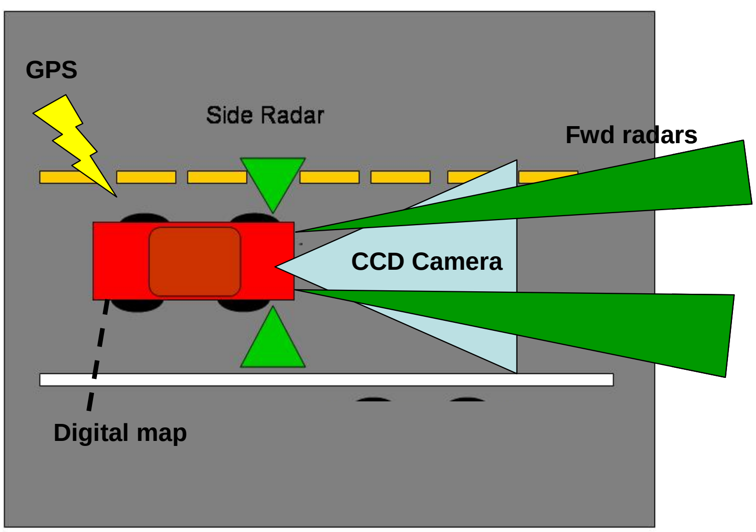


Figure 3.2 Radar and camera coverages

Figure 3.3 Physical installation of the forward and side radars

The forward-looking LDW camera was a small “thumb” camera mounted inside the cabin near the top of the windshield just to the passenger side of the rear-view mirror. The camera was mounted behind a composite shroud to reduce reflections and to discourage tampering by the participants.

The RDCW system architecture is shown schematically in figure 3.4 on the next page. The system consisted of several processing systems linked by data buses, including the CSW and the LDW modules shown on the left of the figure. The CSW and LDW modules communicated by RS232 serial link with the Situation Awareness Module (SAM). One of the SAM’s functions was to serve as a central communications node, and one part of that function was passing information from the CSW and LDW to the so-called RDCW CAN bus, which is connected to both the DVI, the Remote Diagnostic Unit (RDU), and the FOT DAS. The CSW and LDW sent information relating to the threat levels as well as several intermediate variables that were used by the DVI to make final decisions about whether to issue driver alerts. Data passed from the DVI and RDU, through the SAM, to the CSW and LDW included items such as the current sensitivity settings and ambient temperature.

The SAM also served as a gateway to pass along information from the Nissan vehicle CAN bus to several other modules, including the LDW, CSW, DVI, and DAS. This information included signals such as speed, brake status, turn-signal status, and ABS state.

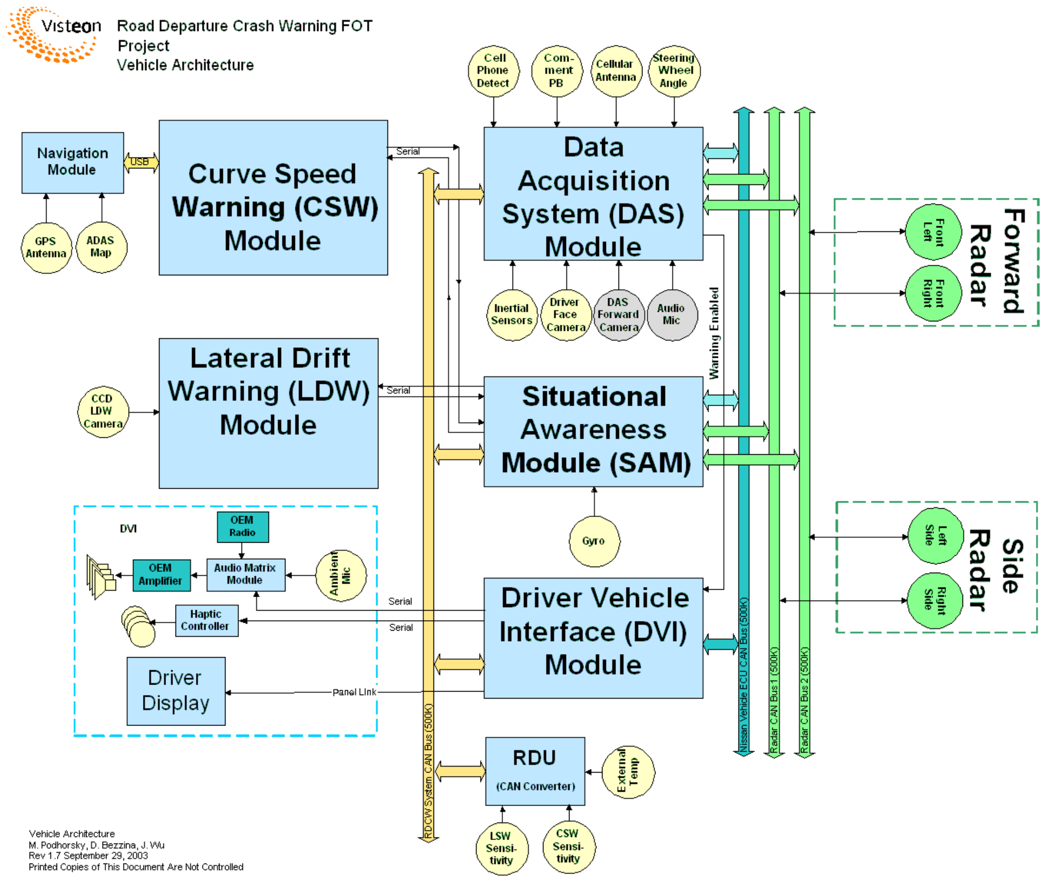


Figure 3.4 Schematic diagram of the RDCW system architecture

Another major function of the SAM was to use signals from the four radars onboard the vehicle (shown on the right side of the figure) to locate and map radar-observed objects alongside and in front of the vehicle. This map consisted of a set of values that is described as the *available maneuvering room* (AMR) beside and in front of the vehicle. (See section 3.4 for more detail on AMR.) AMR was used by the LDW to modulate warning thresholds according to the current observation of perceived threats, as well as to generate a "memory" or record of perceived threats observed repeatedly at the same location. This memory was created by the SAM in the form of the so-called *look-aside database*. Thus, the SAM had the ability to learn about the presence or absence of roadside features at particular geographical locations and adjust the available maneuvering room estimates accordingly.

The DVI module controlled the outputs of the RDCW system to the driver. The DVI used the requested threat levels and intermediate information from the CSW and LDW to make final decisions about whether an alert should be provided and, if so, the level of the alert to be displayed. These decisions considered threat levels as well as other variables such as vehicle speed, road class, and wiper status.

The RDU was an interface from the driver's sensitivity switches to the DVI module. The RDU also served to decode the ambient temperature sensor mounted in the engine compartment and transmitted the information onto the RDCW CAN bus.

The DAS unit recorded all signals on the RDCW CAN bus as well as sub-sampled data from the radar units. In addition, the DAS recorded information from the LDW forward camera, a camera observing the driver's face, an accelerometer, steering wheel angle sensor, and additional sensors described in section 3.6.

3.3 Driver displays and controls

This section describes the general nature and the implementation of the driver controls and driver displays used in the RDCW system. The emphasis of this section is to describe the details of the displays and controls, while Sections 3.4 and 3.5 provide insight into the logic that determines whether or not a driver alert is provided, and how the driver inputs influence this decision.

Two separate controls are provided for the driver so that they could adjust the sensitivity of the LDW and CSW alerts separately. The controls consist of two rocker switches that each allows the driver to choose one of five sensitivity settings, ranging from "1" (providing the latest alert) to "5" (providing the earliest alert). The location of the controls is on the dashboard, just to the left of the steering wheel, as shown in figure 3.5.

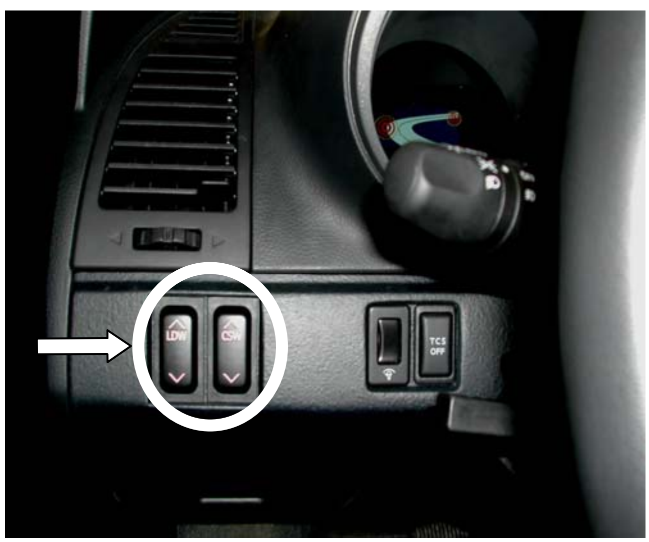


Figure 3.5 Driver controls for LDW and CSW sensitivity

Driver alerts were provided using visual, audible, and haptic modalities. The visual alerts were included primarily to confirm for the driver the nature of the alert, and were not expected to serve as a primary attention-getting modality.

Figure 3.6 shows the location of the visual displays on the instrument panel. The original-equipment tachometer display was removed and replaced with a reconfigurable display. The original telltales that appeared in this location (such as battery, cruise status, etc.) were replicated at the bottom of the new display.

Figure 3.6 Location of DVI visual display in the instrument cluster

Figure 3.7 shows the basic elements of the visual display for the RDCW system including displays for the sensitivity setting and the type and level of alerts for both the LDW and CSW system.

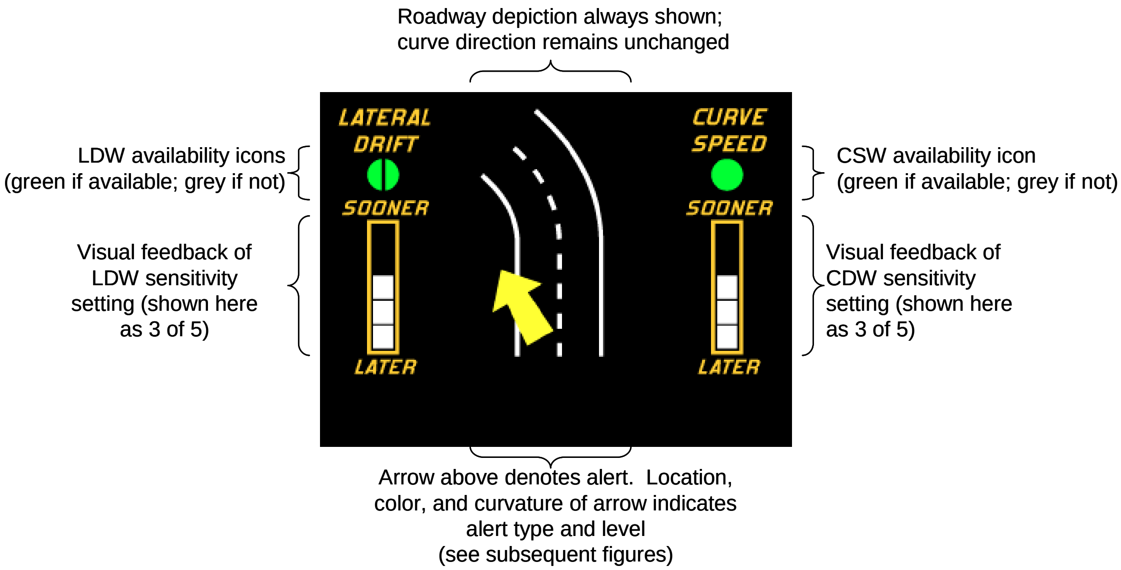


Figure 3.7 Basic elements of the visual display

Figure 3.7 also shows availability icons that allowed the driver to observe when the CSW or the LDW systems were available to provide an alert. Each icon changed color from gray to green when the system became available. The LDW icon had two semi-circular halves, indicating the availability of the left and right side alerts, respectively.

Figure 3.8 shows the displays for the LDW alerts, including the visual, audible, and haptic modalities. The DVI visual display occasionally delivered messages about the system status. For example the text message “RDCW Service Required” was given to let the driver know that the system would not be available for the remainder of the trip due to a technical difficulty.

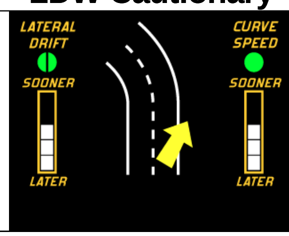
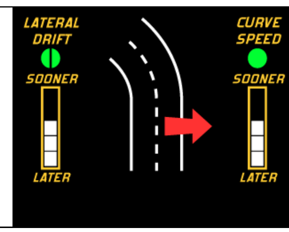
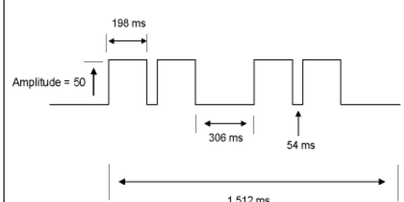
	LDW Cautionary	LDW Imminent
Visual		
Haptic		NA
Auditory	NA	3 pairs of tones, i.e., “beep-beep, beep-beep, beep-beep”

Figure 3.8 Displays for LDW alerts

Audible alerts were provided by interfacing with the eight-speaker system that is original equipment on the vehicles. An audio matrix switch system was installed with the original output of the sound system as one input, and the DVI alerts as another input. In this way, the volume on the radio/CD system could be reduced somewhat when alerts were provided at the same time that the sound system was on a high volume setting.

Haptic alerts were provided by motors in the driver’s seat pan. Figure 3.9 on the next page shows the location of the haptic motors that were inserted into the seats for this project. During early evaluations of the DVI, some drivers found the seat back motors unsettling, so only the four motors in the seat pan were active in the FOT.

During the first week of a driver's exposure to the system, the system was in a baseline mode with both sensitivities set to the median level of 3. During this week, alerts were computed and recorded by the DAS "in the background," but no alerts were presented to the driver. Furthermore, no visual icons relating to RDCW were shown; instead, the display simply showed the RDCW FOT logo.

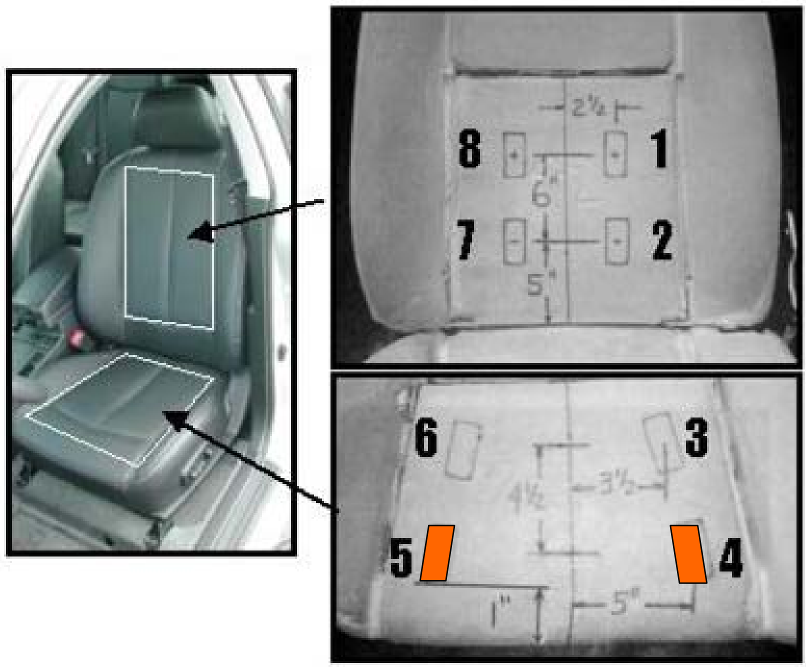


Figure 3.9 Location of haptic motors in the driver's seat (only the four motors in the seat pan were used)

As mentioned earlier, the LDW provided one of two alert types during a relevant drifting event. The timing of the LDW alerts was influenced by the driver's setting of the sensitivity for LDW. The cautionary LDW alert consisted of a visual icon on the instrument cluster (figure 3.7) as well as a vibration of the two motors on the side of the seat pan that was toward the direction of the lateral drift Figure 3.8 shows the pulse schedule used, which was intended to evoke the feel of a rumble strip. The visual icon was a yellow arrow pointing in the direction of the drift.

The imminent LDW alert consisted of a visual icon and an audible signal emanating from those of the vehicle's speakers that were also toward the direction of the lateral drift. The LDW imminent-alert audible tone was designed to be reminiscent of the sound of tires on a rumble strip, and consisted of a series of three pairs of tones, and the visual icon was a red arrow on the display that pointed in the direction of the perceived drift.

In cases where a CSW alert was provided, there was typically one or two alerts provided. The CSW would first issue a lower-level, cautionary alert that consisted of a sustained haptic vibration of the two motors at the front of the seat pan (figure 3.9), plus a visual icon, as shown in figure 3.10. In most cases, should the system believe the driver was continuing toward the curve without sufficient deceleration, a second imminent alert was provided. This alert combined a voice message, “Curve! Curve!” with a visual icon that is shown in figure 3.10.

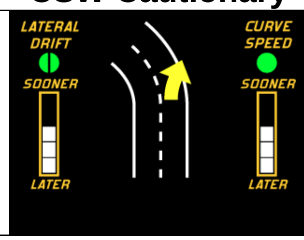
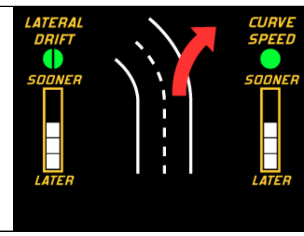
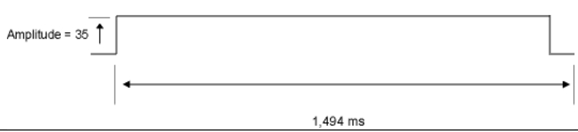
	CSW Cautionary	CSW Imminent
Visual		
Haptic		NA
Auditory	NA	Voice: “Curve! Curve!”

Figure 3.10 Displays for CSW alerts

3.4 LDW Implementation

This section describes conditions in which an LDW alert was provided. The LDW functionality was the result of several modules, as described in section 3.2. The core sensor of LDW was the monochrome CCD camera that observed painted lane markers or other non-painted visual features that delineated the lane. The LDW observed lane markers forward of the vehicle to approximately 30 m. The LDW system was based on the commercially available SafeTRAC® system from AssistWare, with several extensions to take advantage of the additional data available within the RDCW system. AssistWare conducted the technical development of the LDW system.

LDW issued a single alert when a potentially unsafe lateral movement was underway. All alerts were suppressed under the following conditions:

- vehicle speed was less than 25 mph,
- turn signal had been applied within the past 5 seconds,
- brake had been applied within the past 5 seconds,
- travel was on a neighborhood street or similar, low-speed and low-traffic volume road,
- confidence of lane tracking was inadequate for issuing an alert, and
- driving was at night with wipers on.[1]

If none of these conditions applied, a lower-level cautionary alert was given when crossing a dashed marker without a perceived object alongside the vehicle (either stationary or moving). In all other lateral drift situations, the imminent alert was given.

The LDW alerts were issued when the lane position of the vehicle at some point in the near future was expected to exceed a threshold. The threshold was modulated to reflect both the driver's selection of sensitivity for the LDW, as well as the presence of currently- or previously-observed objects alongside the original lane of travel. Specifically, there were up to four inputs considered in setting this threshold:

- road type, which was used to set a default threshold,
- driver's selection of LDW sensitivity,
- current radar observations of distances to stationary or moving objects in the adjacent lane or on the roadway edge, and
- a geo-coded memory of objects observed alongside the travel lane on previous traversals of the current road segment by that driver.

These data were used to create the set of intermediate variables that identified the available maneuvering room (AMR) for the vehicle. As illustrated in figure 3.11, these boundaries (i.e., the AMR values) were defined for both right- and left-hand sides in each of several zones that began directly beside the vehicle and extended forward a distance equivalent to 3.5 seconds of headway. Each AMR value was initialized to a default setting that depended on the class of road, the type of boundary and the current LDW sensitivity setting. Each value could then be reduced (AMR restricted) in accordance with perceived threats identified either by current radar data or by data stored in the look-aside database.

[1] Several drivers in fact received alerts in these conditions because the original software strategy did not prevent the suppression of alerts under all conditions.

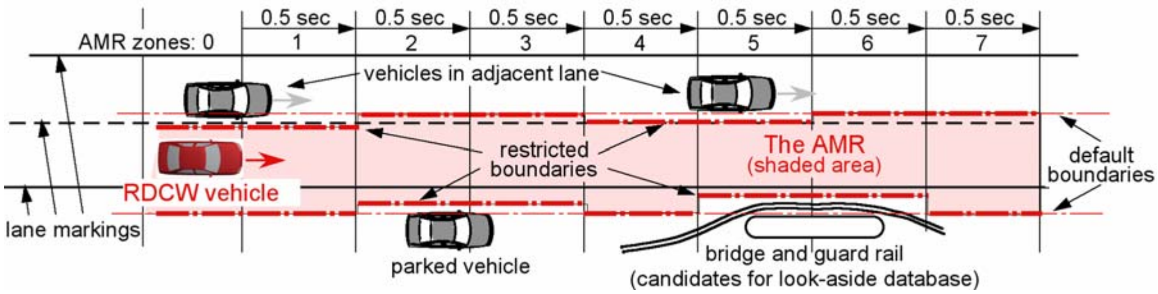


Figure 3.11 The concepts of the zones and boundaries of the available maneuvering room

The exact manner in which these items were used to compute the threshold was complex. As a rule of thumb, however, a slowly drifting vehicle with the median LDW sensitivity setting and no indication of a nearby object in the lateral direction of drift would provoke an LDW alert approximately as the outer edge of the tire crossed a solid lane marker. If the lane marker was dashed, the alert was delayed until the outside of the tire reached approximately 1 foot (0.13m) beyond the lane edge. Radar-based objects served only to draw in the threshold or raise the level of the pending alert. In the latter case, of course, the alert became an imminent-level alert if it was not one already.

3.5 CSW Implementation

The CSW system provided alerts intended to help drivers avoid entering or driving through curves at speeds too fast for safety. Therefore, the system intent was to provide warnings that allowed an unaware driver enough time to react to the alert, respond by braking, and slow the vehicle so that the lateral acceleration would not exceed a designated threshold. Nominally, a threshold of 0.25g on anticipated lateral acceleration was used, and the CSW assumed that the upcoming curve had no superelevation. As a comparison, the U.S. guidelines for highway design calls for a combination of curve radius, superelevation, and posted speed that leads to lateral accelerations parallel to the pavement banked curve of no more than 0.17 g at most speed (AASHTO, 1984). AASHTO, however, does recommend highway design that leads to lateral accelerations lower than 0.17g on higher-speed curves. Therefore both the CSW and the AASHTO guidelines recognize that safety and comfort require lateral accelerations well below the accelerations sustainable by tires on paved road surfaces in dry conditions and in most wet conditions. Therefore, the CSW system was not attempting to avoid the onset of friction loss, but, more conservatively, was attempting to keep drivers within the range of lateral accelerations associated with normal curve-taking, so that no unusual challenge to maintaining control through the curve would develop.

The CSW system was developed by Visteon for this project and included four stages of onboard processing: vehicle positioning, most-likely-path (MLP) estimation, curvature calculations, and threat assessment. All of these took place within the CSW module shown in the architecture diagram of figure 3.4. The output of these processes included a threat level and request for CSW alert. This requests was sent via the SAM to the DVI module. The DVI applied some final considerations, such as considering the minimum speed at which an alert is provided (18 mph). The CSW module itself was implemented on a Clarion AutoPC Joyride™ platform, a commercially-available navigation unit. The Joyride hosted portions of the vehicle-positioning computations and all the MLP estimation and threat assessment algorithms.

Vehicle positioning was based on the use of GPS information, vehicle speed, and yaw rate to locate the vehicle on a particular road segment of one of the digital maps in the CSW database. Two digital maps supplied by NAVTEQ were used for vehicle positioning. The primary map was a recent release by NAVTEQ called the *APS1* map. Relative to earlier NAVTEQ maps, the APS1 map includes improvements in geometric accuracies as well as additional attributes of roadways, such as the number of lanes. This map was available for use in the seven southeastern Michigan counties. The second CSW map was based on a previous-generation NAVTEQ map, termed the *SDAL* map in this report. The SDAL map that was compiled for this project included all of Michigan and large areas of the adjacent states of Illinois, Indiana and Ohio. The great majority of FOT travel took place within the area of the higher-quality, APS1 map. Moreover, FOT subjects were requested to restrict their travel to the area covered by the two maps, and approximately 98 percent of FOT travel was, indeed, within this area (see section 6).

The estimation of the *most likely path* (MLP) was the prediction of which of possibly many roadway branches the vehicle would follow in the near future. Consider the case in which a vehicle traveled on a freeway and approached a sharply curved exit ramp: the system needed to decide whether to warn the driver to slow for the turn on the ramp, or whether to inhibit the warning because the system believed the driver was likely to continue on the freeway past the ramp. The GPS and the digital map did not provide accurate enough information to place the vehicle within a lane. Other research has established that this is beyond the state of the art of existing maps that were originally constructed for navigation purposes, even with differential GPS onboard the vehicle (CAMP, 2005). Thus the MLP estimation used lane boundary-information to aid in identifying which lane the vehicle was within. In addition, to help predict the path, MLP estimation considered several variables, including turn-signal application, lane-boundary type (dashed vs. solid), road class (from the map), and lane-change information.

Given the most likely path, the digital map shape points were used to create an estimate of the curvature of the roadway. Finally, *threat assessment* considered the outputs of the MLP estimation and other information in order to recommend to the DVI whether an alert should be provided. The primary inputs to CSW threat assessment, of course, were vehicle speed, driver brake and turn-signal activity, and assumptions regarding the unaware driver's response time and likely deceleration rate, and the selection of the lateral acceleration threshold. Furthermore, the threshold on anticipated lateral acceleration was reduced if the outside temperature was near or below freezing and the wipers were active. Finally, the threshold was modulated somewhat depending on the driver's activity and sensitivity setting, but for most purposes, the threshold may be considered to be 0.25 g. In addition, alternative paths and their confidence, as defined by the MLP estimation, were considered.

A central design issue for CSW systems in general is the handling of roadway branches, especially freeway exits and surface road turn lanes. This includes consideration in both the MLP estimation and the threat assessment. Because branches are common occurrences during driving, and because drivers do not consistently use turn signals to indicate their intention to branch, the CSW system has to decide whether to risk annoying a driver by issuing an alert on the possibility that they may branch. This is exacerbated by the fact that branches often have curvatures that are rather high, since by nature they often lead the vehicle to a different heading, and the curve design often presumes the vehicle has slowed from its original throughway travel speed. The philosophy of the CSW system used in this FOT was to provide maximum safety coverage for the driver by considering the curves on branches as threats. This was driven in part by the crash statistics (section 2) that show that loss of control or road-edge departure on freeways often occurs on ramps. To reduce the nuisance impact, the system would often provide only cautionary-level alerts and not imminent-level alerts when the alert was based on a curve on a branch ahead, unless there was evidence that the driver was branching. Other cues such as turn signals or lane boundaries were sometimes used to delay alerts in potential branching situations, in an attempt to reduce nuisance alerts.

3.6 Data acquisition hardware for the FOT experiment

The purpose of the data acquisition system (DAS) was to collect data, onboard the vehicles, to support analyses of the experiment by the FOT team and the independent evaluator. The DAS was not part of the RDCW countermeasure system, although it did service one aspect of the operation of the RDCW: the RDCW system observes the state of a DAS signal to determine whether or not the displays and warnings were to be presented to the driver.

The DAS was developed and managed by UMTRI and collected data from the RDCW CAN bus, two radar buses, two video streams, audio stream and several other instruments installed to monitor other aspects of the experiment. These sensors monitored two axes of vehicle acceleration, vehicle location (via differential GPS separate from the RDCW GPS), steering wheel angle, pitch angle, roll angle, roll angle rate, instrumentation space temperature, and outputs from a cellular phone antenna. The output of the DAS was composed of (1) the set of complete data files, stored onboard the vehicle and later off-loaded at UMTRI, that contained all the numeric, audio, and video data, and (2) smaller data files, transferred to UMTRI via cellular modem each time the ignition was turned off, that contained summary and diagnostic data gathered during the previous trip. These later files, and the cellular transfer mechanism allowed near-real-time monitoring of the use and the health of the RDCW vehicles.

More details about the nature of the data collected will be presented in section 5.

3.7 Integration of RDCW system into the vehicle

Earlier sections have shown the integration of driver controls and displays into the vehicle, as well as the mounting of the forward and side radars. This section describes the highlights of the remaining integration of the RDCW countermeasure and the data system into the vehicle, which was engineered and executed primarily by Visteon Corporation.

The computing modules were concentrated in an enclosed instrumentation space located in the trunk, directly behind the back seat and beneath the rear deck of the cabin. An aluminum chassis was used to secure the hardware and a power and signal distribution module runs laterally across the vehicle to provide power and signal connectivity to the modules. Figure 3.12 shows the instrumentation space populated by the modules, as seen from the passenger cabin when the rear seats are folded down.

Figure 3.12 View of instrumentation space: looking rearward with rear seats in their folded-forward configuration

Figure 3.13 shows that the FOT subject had use of a portion of the original trunk space for luggage or other goods. The instrumentation space was not accessible to the test subjects: the trunk space was separated from the instrumentation space by a panel that is locked, and the rear seats were locked in their upright positions before the subject took possession of the vehicle.

Figure 3.13 Remaining trunk space after instrumentation space was enclosed

Moving forward from the instrumentation space, there were several sensors located within the cabin besides the DVI elements discussed in section 3.3. A monochrome CCD camera viewed the driver's face from the nearby A-pillar (the roof-supporting element between the windshield and the driver's side window). Figure 3.14(a) on the next page shows the installation of the camera (the diameter is approximately 1.5 inches (2.9 cm)).The camera had its own infrared illumination to capture nighttime images. A *comment button* and receiving microphone were provided for test subjects who wished to make verbal comments during their time with the car. The button was located just to the left of the heating controls, as shown in figure 3.14(b). The microphone was installed in the headliner of the cabin near the inside rear-view mirror. In addition to recording the driver's comments, the microphone was used detect background noise for the process of modulating the volume of audible warnings.

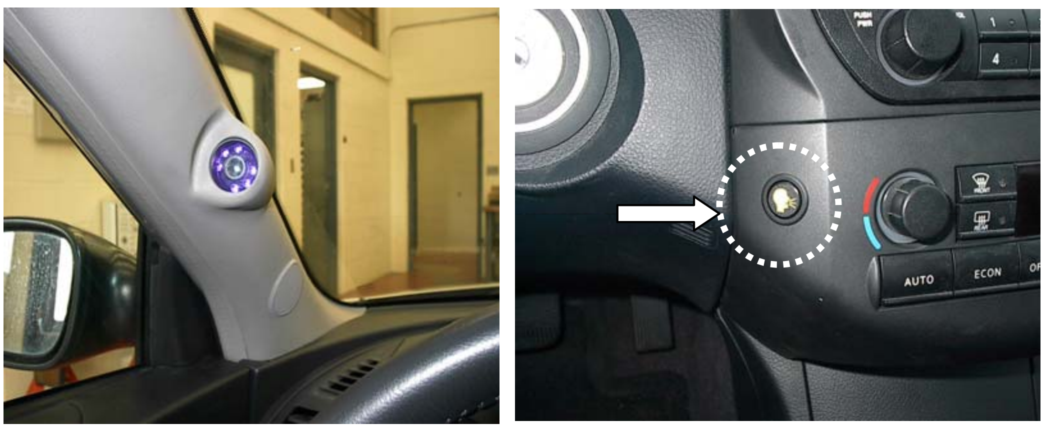


Figure 3.14 Selected cabin sensors: (a) Driver face camera and (b) driver comment button.

Also within the cabin were a steering-angle sensor, a two-axis accelerometer (mounted under the gearshift, within 2 inches of the CG), and a cellular phone detector. The cellular phone antenna had been intended to provide data that would help find periods of driver cell-phone activity. Due to the nature of such detectors, however, the output was also sensitive to any nearby cell-phone activity, including the ongoing sideband "pinging" that updates the assignment of phones to cell towers, so that the utility of the detector was minimal.

Three antennas related to RDCW and the DAS were located on the vehicle. The antenna for the non-differential GPS used in the RDCW was a small cylinder approximately 3 in (7.5 cm) wide, mounted in a centered position on the lid of the trunk. The differential GPS antenna used in DAS data collection was a rectangular antenna approximately 4 in wide x 6 in long x 0.5 in high (10 cm x 15 cm x 1.3 cm), centered on the roof. The DAS cellular modem communicated via a standard add-on cellular antenna that was affixed to the rear window.

3.8 RDCW Fleet fabrication

A fleet of 11 vehicles was equipped with the RDCW system and DAS for the FOT experiment (see Section 1) These vehicles were put through various tests of sensors, subsystems, and system-level performance measures before being driven hundreds of miles by RDCW professionals. Throughout this period, the data collected by special engineering development DAS or the FOT DAS were examined to find and repair issues.

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4 Test Methodology

This section addresses the experimental method with two major themes. First, a discussion in Section 4.1 lays out the concepts of behind the FOT method used to evaluate a driver-interactive technology, such as the RDCW system. This addresses the reasons for a naturalistic test – that is, a test in which drivers are free to travel as they wish, with minimal restrictions – as well as the requirements and constraints to successfully conduct the FOT test. This includes consideration of the complexities of driver-system-environment relationships, and the management of those in the testing and analysis phases.

A second theme is a description of the operational procedures used in this FOT. From the driver's perspective, there are three days in their 26-day FOT experience that serve to highlight their involvement in the research study. They are as follows:

- Day 1: Drivers arrived at UMTRI having been briefed on the phone about the nature of the FOT and an overview of the RDCW system. The two hours that they then spent at UMTRI before taking possession of the test vehicle provided them with the knowledge and experience with the RDCW system to launch them confidently into their 26-day participation. For the first six days of their use of the vehicle, the system does not provide driver alerts, but records the driver's baseline driving data and the "silent" decisions of the RDCW system.
- Day 7: Without any contact with researchers at UMTRI, the second time that the car was started this day, the RDCW system was enabled automatically. The system remained enabled for the remainder of their driving experience.
- Day 26: Drivers returned the test vehicle to UMTRI and participated in a debriefing session which included the completion and discussion of an extensive questionnaire about their experience, as well as the review and analysis of approximately 12 videos from situations in which they had received alerts.

Section 4.2 addresses the operational procedures of executing the FOT test. This includes a discussion of the recruitment and management of test participants, the maintenance and management of the fleet of test vehicles and their onboard systems, and the transferal of onboard data to off-board data servers. Section 5 will provide an overview of the data archives generated from onboard data acquisition, as well as off-board collection of subjective data and ancillary objective data.

4.1 FOT as a test methodology

The RDCW FOT project is one of a series of FOT programs conducted for the U.S. Department of Transportation to study driver assistance systems (U.S. Department of Transportation, 2005). The FOT is one of many test and evaluation procedures available to guide the development and evaluation of such systems – see Table 4.1. The test methods are listed in approximate chronological order for a typical application, and not all applications require the full list of tests. The FOT method, as a late-stage, pre-deployment method on the list, is the only method currently available to estimate real-world outcomes with insight into their likely mechanisms. It is also the largest undertaking in terms of scale, scope, detail and quantity of data, and in its analysis requirements. Post-deployment analyses of crash data can be very useful in evaluating the approximate influence of a technology on crashes, but at times it is difficult to isolate the effects of a single technology or understand the mechanisms.

The underlying FOT concept is illustrated in figure 4.1; vehicles, drivers and the driving environment are brought together in a way that is intended to be representative of the population as a whole. A "treatment" affects the driving process and its effects are evaluated from a variety of detailed measurements of observed vehicle and driver behavior – speed, acceleration, lane position, steering and braking inputs, use of turn signals etc. In the case of RDCW the treatment is the driver assistance system, providing a range of feedback and warning cues, intended to improve safety performance in respect of potential run-off-road crashes. Because of the wide variation among individuals' travel patterns and driving performance, as measured by most any metric, the analysis of the treatment's effects are usually done "within-subject," that is, by comparing each driver's baseline data to their RDCW-enabled data. The 78 set of comparisons are then subjected to statistical techniques to look for RDCW influences, also accounting for important environmental factors that may directly or indirectly influence the outcomes. The research presented in this report does not include the final safety impact evaluation (this work is to be conducted separately by the Volpe Center).

Drivers' perceptions of the "treatment" are also gathered during the FOT in order to assess the likely penetration of the technology into the fleet. This is especially important in driver assistance system work, as the acceptance of drivers is considered necessary to allow deployment. Drivers will ultimately bankroll the inclusion of these technologies onboard passenger vehicles, and without a reasonable level of acceptance, even a government-mandated technology would not last long in the field.

The need for a random or representative set of drivers is embedded in Figure 4.1. The variability between drivers of driving performance metrics is large, as all FOT projects demonstrate. Furthermore, the outcomes on the right side of the figure depend not only on the technology and the driver, but on direct effects of the vehicle and environment, as well as the interactions of the vehicle and environment with the system under test. This report will show that these effects are very substantial and may exceed the effects of crash warning systems. Thus, unless those direct and indirect effects are known rather well, there is a requirement that the testing include a broadly representative set of drivers (and thereby, environments).

As knowledge about these relationships accumulates, in part because of available FOT databases, it will be possible in the near future to conduct FOTs with targeted driver populations that are not purely representative of all populations or driving environments, but rather selected to enhance the productivity of the testing. The remainder of this subsection, however, addresses the state of knowledge of road departure systems in naturalistic use as it was when this project began, so that the methodology here does require a random and representative sampling of drivers in a naturalistic test as a required surrogate for representative driving.

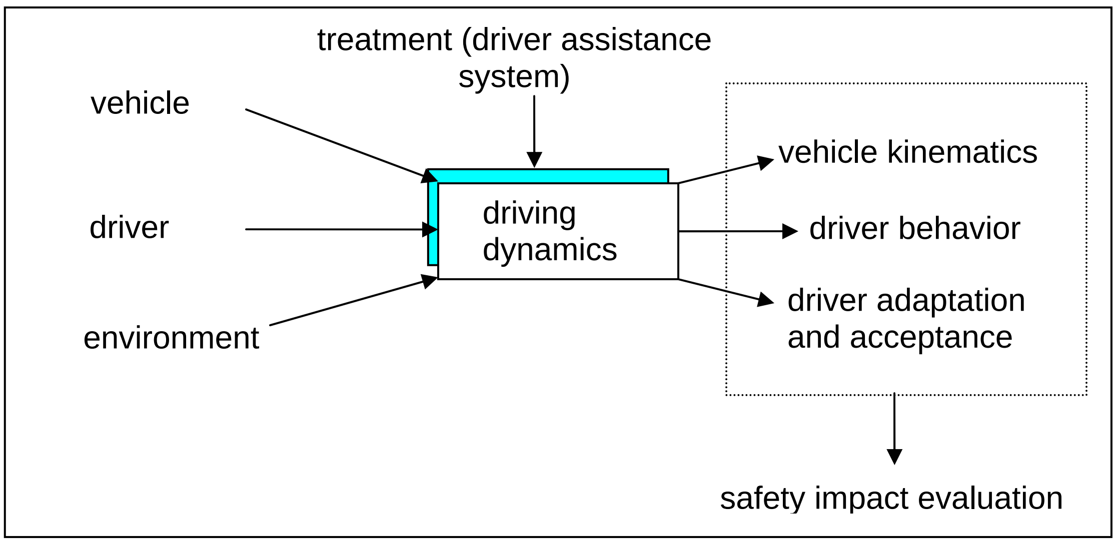


Figure 4.1 FOT concept.

The "environment" input should be regarded in a very general way, comprising both systematic and random effects. It encompasses the physical highway infrastructure, the surrounding traffic, other driving conditions, and the physical, psychological and social factors that influence the specific behavior of any particular driver. In the current FOT methodology, it was crucial that the experiment was as unbiased as possible in terms of the inputs shown on the left side of the figure; for example, if drivers were accompanied by a researcher during the experiment, the potential interaction between treatment and “social effect” (e.g. wanting to please the researcher) had the potential to overwhelm the main effect of the driver assistance system.

On the output side, it could be argued that only the objective vehicle kinematics are important – run off road crashes happen when cars drive off the road, not when the driver likes or dislikes the sound of some beeps. But, in practice, the size and scope of the FOT does not allow for simple counting of run-off-road events, or even near misses – the number of vehicle miles traveled is insufficient, and so indirect measures of vehicle kinematics much be used, such as the standard deviation from lane center position, or use of turn signals when carrying out lane changes. Furthermore, the duration of the FOT is insufficient to directly infer long-term behavioral effects, and these need to be inferred from objective evaluation of short-term driver adaptation, and from subjective evaluation of acceptability.

The FOT method embodies a very simple experimental design concept, aimed at providing an essentially unbiased sample of normal driving. This implies the vehicles, drivers and environment are to be representative of the population in question. For some factors this is quite easy to achieve – for example the group of subject drivers is balanced for age and gender. Drivers are also chosen via random sampling, to avoid possible bias in terms of experience, attitudes, education etc. Self-selection of the eventual participants, however, is of course a potential source of bias that is not understood and therefore has gone uncorrected. On the other hand, cost and operational considerations limit the range of vehicles that can be used – to a single vehicle model in the case of RDCW - and also limit the geographic region. Both these factors imply a systematic bias in the experiment: people in one region driving a particular car model will typically drive differently to people in another region with a different car model. Such biases are unavoidable, but are largely irrelevant provided the statistical interaction between the “treatment” and the bias factor is small compared to the main effect of the treatment. The magnitude of the bias factor itself is then largely irrelevant to the conclusions of the FOT.

To achieve a representative driving environment, there is a clear need for a broad range of driving conditions – road class, weather, traffic density, mean speed, posted limits, line marking quality etc. While an ideal situation might be to stratify the driving conditions to be proportionate to that of the population as a whole (e.g. driving distances under each set of conditions being proportional to that of the general population), to do so would involve a degree of orchestration that would undoubtedly impose its own artificial aspect to the test, and therefore bias. The essential point is that "normal driving" is conditional upon an array of other factors in a driver's life that influence key parameters such as concentration, urgency and risk taking. In an FOT, the decisive environmental factor to replicate as faithfully as possible appears to be the social and psychological environment of the driver – which means that the experimental subjects should be forgetful of the fact they *are* experimental subjects, at least as far as this is possible. Therefore, the subjects are provided with the "robust prototype" vehicle to use in their daily routine, very much as they would use their own vehicle.

Once the need for "free and unaccompanied" driving is established as the key requirement of the FOT, many other aspects of the conduct of the experiment follow automatically. For example, environmental factors such as road class, traffic density, and mean speed are not controlled or balanced. But they can be monitored quite easily, and their influences can be inferred from the FOT data, provided there is sufficient exposure in the experiment. This allows those influences to be "controlled" by appropriate normalizing analyses to account for those influences. By contrast the psychological and social factors that also influence how the driver interacts with the system cannot be so easily monitored, so all care is taken to ensure lack of bias. Clearly there is some residual source of bias, since drivers do know they are participating in an experiment and that the vehicle is a temporary loan; but this bias is clearly of a lower order than biases that would be introduced in testing a lay driver with an experimenter in the vehicle, or testing by a development engineer who knows how the system has been designed to perform.

The FOT experience can be controlled to some extent, and each subject is exposed to four separate phases of activity:

- initial familiarization with the vehicle and the driver assistance system
- control period, with the system disabled, as the subject becomes more familiar with the vehicle, and also acclimatizes to the experimental situation
- comparison period with the system operational
- an extended interval with the assistance system enabled, sufficient for the subject to undergo any behavioral adaptation (for example additional risk taking, or increased likelihood to engage in secondary tasks)

When a technology is new or novel, the ideal duration of these activities cannot be decided a priori, either in terms of elapsed time, driving time or mileage traveled.

If any such ideal exists, it would be strongly dependent on the aptitude and motivation of individual drivers. In practice, for RDCW, the duration of these phases has been determined by the practical need for test exposure across a large number of subjects, constrained by an economic size of vehicle fleet. Also as a practical matter, there has been no formal separation between the third and fourth phases. Further details are given in subsequent sections.

There are many other practical considerations for the operational success of an FOT. The major ones are listed as follows:

- robust prototype test vehicles, sufficiently mature to be representative of an eventual commercial system of the type,
- low level of false alerts or other system dysfunction,
- low level of intrusion from experimenters into the driving experience of test participants,
- sufficient driver exposure to the designed operation of the assistance system
- wide breadth of driving conditions (physical environment),
- robust sensing and data acquisition systems, transparent to the subject and yielding sufficient data for subsequent analysis, and
- powerful data management and analysis tools.

The analysis of FOT data is in some sense an experiment within an experiment – Figure 4.2. The fact that test exposure is largely uncontrolled means that analysis is largely conducted by first identifying important contextual influences, such as the influence of road type on turn signal use, and then controlling the analyses for the contextual variables in order to create a "controlled" subset of data to compare the output variables. Furthermore, the analysis is also burdened by a relative ignorance of the baseline driving behavior itself, so that there is often a sizable effort to identify and parse out driving scenarios or events that are considered key to the conclusions, even while those scenarios or events were not well understood when the test began. Thus, while basic hypotheses are expressed before the test begins, the detailed hypotheses that underlie the specific analyses are often formed during analysis, and their details are iteratively developed.

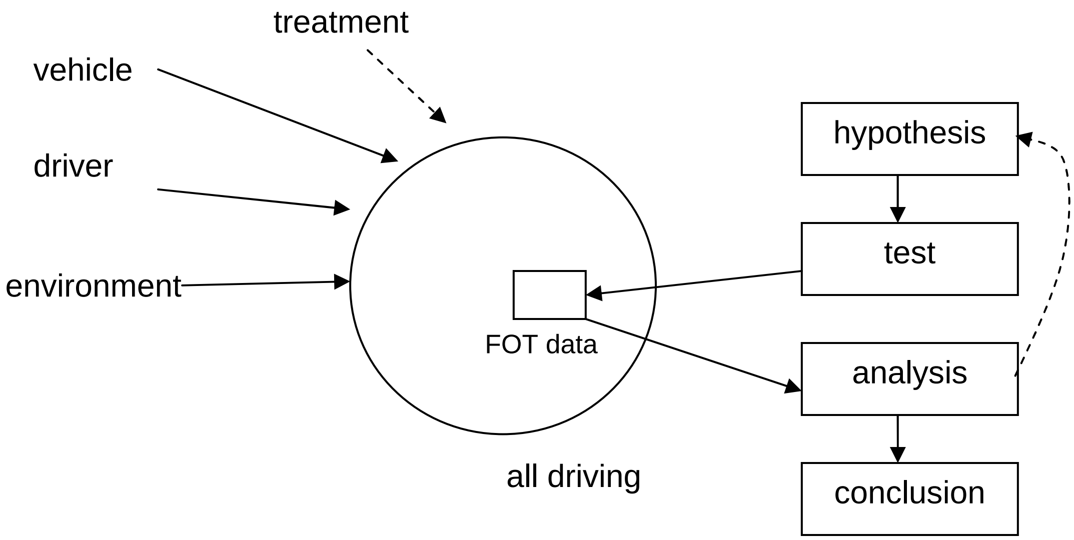


Figure 4.2 FOT data analysis: an experiment within an experiment.

This reflects both the power and potential limitation of the FOT methodology. Its major strength is that no prior hypotheses or predictions are required in the main FOT experiment; they are essentially deferred until the secondary experiment where the rich data stream is queried and analyzed – the FOT data becomes a surrogate for real driving behavior. The associated cost is that the FOT requires large-scale data gathering, and the use of powerful data query tools. This turns out not to be a fundamental problem except for the narrower class of driver assistance systems that operate only as intervention systems in rare events, such as pre-crash warning systems; scarcity of relevant data would then render the method ineffective. In the case of RDCW, the systems tested included relatively common advisory warnings as precursor to imminent alerts, and shortage of data was not seen as a major problem.

Table 4.1 Array of test methods used in the design, development and evaluation of driver assistance systems

Test	Purpose	Duration and Scope	Drivers	System Maturity	Data Type/ Richness
Baseline Driving - test track	design – alert timing and quality (nuisance)	moderate	lay[1]	no working system needed	objective / moderate
Baseline Driving - road	design – threat detection algorithms and alert timing	moderate to very large	lay[1]	no working system needed	objective / rich
HMI Design - simulator	design – HMI	small	lay[1]	basic alert timing and HMI mockup	objective, subjective / low
Functional Performance - test track (1)	development – refinement of HMI and alert timing	moderate	lay[1]	early prototype	objective, subjective / moderate
Functional Performance - test track (2)	development – sensing, data processing and nuisance alerts	small	engineer	early prototype	objective / low
Functional Performance - road	development – sensing, data processing, alert timing and nuisance alerts	moderate to large, extended over time, often unstructured	engineer	advanced prototype	objective / high
Decision Gate - road and track	overall system acceptance, program decision gate	small	management	advanced prototype	subjective / minimal
System Verification - track (some road)	design verification – overall objective system performance	moderate	engineer	advanced prototype	objective /
Pilot tests (1) - road	design verification and final development – acceptance for usability and performance	small	lay[1]	advanced prototype	objective, subjective / moderate to high
Pilot tests (2) - road	design verification and final development – acceptance for usability and performance	small to moderate	lay	robust prototype	objective, subjective / high
FOT	evaluation of acceptance, performance and safety impact	very large	lay	robust prototype	objective, subjective / high
Post-deployment crash analysis	safety impact	very large	lay	commercial systems	objective / low

[1] accompanied by test engineer or human factors specialist

4.2 Pre-FOT pilot testing

In order to identify and mitigate RDCW and data system issues, fine-tune system functionality, and explore preliminary driver perceptions, a multi-stage sequence of pilot tests was conducted. The first two stages (Stages 1 and 1.5) involved laypersons who drove an RDCW-equipped vehicle along a predetermined route while accompanied by UMTRI research staff. Using the results of these tests, minor modifications to the RDCW system were made in preparation for a short FOT-style pilot test (Stage 2). Stage 2 pilot testing involved laypersons who drove RDCW-equipped vehicles for a 12-day unsupervised period. For the first four days of driving, the RDCW system was disabled. Beginning on the fifth day, the drivers experienced the RDCW system for a total of eight days before returning to UMTRI and completing a post-drive questionnaire. A more detailed description of the entire pilot testing sequence can be found in Appendix A.

4.3 Test participant management

There were several stages of recruiting, training, and handling the test participants in the study. These are summarized in this section.

4.3.1 Human use approval

Approval for the use of human subjects in research for the FOT was granted by The University of Michigan Behavioral Sciences Institutional Review Board (IRB). A separate approval from the University's IRB was obtained in order to conduct focus groups.

4.3.2 Recruitment and screening

With the exception of the first ten drivers who were recruited through local newspaper ads, drivers were recruited with the assistance of the Michigan Secretary of State's office. Six thousand licensed drivers were selected at random for possible participation in the FOT. The drivers were selected from among the licensed population living in the following nine counties in southeastern Michigan: Ingham, Jackson, Lenawee, Livingston, Macomb, Monroe, Oakland, Washtenaw, and Wayne. From this randomly selected pool of 6,000 drivers, smaller random samples of names were selected to receive informational postcards. The postcards did not give specific details about the study, but stated that the recipient had met some of the criteria necessary to participate in the study. Additionally, the postcards stated that drivers would have the use of a new car and would be compensated for their time (each driver was paid $250 for their participation). A toll-free number was provided for interested persons to learn more about the study and determine if they qualified.

A total of 1,963 postcards were mailed resulting in 238 people (12.1 percent) calling to inquire about the study. A research associate provided these callers with an overview of the study and screened all interested persons. A minimum-annual-mileage threshold was required for a driver to qualify; this reduced the chance that test vehicles would be used in an unproductive manner. This minimum value was determined using mean values reported in the year 2001 National Personal Transportation Survey (NPTS). The NPTS reports average annual mileage by driver age and gender for U.S. drivers. The qualifying criterion was to report mileage not less than 25 percent below the NPTS reported average for an age and gender category. In addition, the following were grounds for excluding individuals from participating in the FOT:

- The individual had been driving for less than two years.
- The individual was unable to drive a car equipped with an automatic transmission without assistive devices or special equipment.
- The individual had been convicted of any of the following in the past 36 months:
    a. Driving while their operator's license was suspended, revoked, or denied.
    b. Vehicular manslaughter, negligent homicide, felonious driving or felony with a vehicle.
    c. Operating a vehicle while impaired, under the influence of alcohol or illegal drugs, or refusing a sobriety test.
    d. Failure to stop or identify after a crash (includes leaving the scene of a crash; hit and run; giving false information to an officer).
    e. Eluding or attempting to elude a law enforcement officer.
    f. Traffic violation resulting in death or serious injury.
    g. Any other significant violation warranting suspension of the license.
- The individual acknowledged the need for, but fail to use, corrective devices such as eyeglasses or hearing aids.
- The individual was currently taking any drugs or substances which could impair their ability to drive.
- The individual was unable to commit to being the only individual to drive the research vehicle.

- The individual was unable to schedule a four-week period of driving predominantly within the CSW coverage area (north-central U.S.), particularly during the first week of their exposure.

Individuals that met all qualifications and were needed to satisfy the experimental design received a brief overview of the field test. The final selection of drivers was dependent upon the person's availability per the test schedule. If individuals found the conditions of participation to be generally agreeable, a specific date and time was arranged for the driver to visit UMTRI to pick up an RDCW vehicle and to go through an orientation. Note that drivers were also informed during the recruitment process that they would receive payment for their participation.

4.3.3 Pre-launch orientation

Prior to a driver's arrival at UMTRI, the driver received a mailing containing several items. Each driver received, and was required to read, an information letter that outlined the study procedures, protocol, risks, and benefits. The information letter is in Appendix B. Furthermore, drivers were required to acknowledge their awareness and acceptance of these conditions by signing an informed-consent form, found in Appendix C. In addition to these materials, drivers also received the following: a demographic background questionnaire, a driver behavior questionnaire (DBQ), a driving style questionnaire (DSQ), a sensation seeking scale (Zuckerman, 1978), a locus of control scale (Rotter, 1966), a driving risk perception questionnaire, and a dilemma scenarios questionnaire. These instruments are described further in section 5.2.1, and may be found in their entirety in Appendices D through K.

At the orientation, drivers were introduced to the RDCW-equipped vehicle as well as the LDW and CSW functions and controls via an 18-minute training video. (See Appendix L for the transcript of the orientation video.) The drivers were then given a hands-on overview of the test vehicle and the RDCW system, followed by an on-road accompanied test drive. A demonstration of the driver interface was given prior to the test drive, so that drivers could observe the LDW and CSW warning icons and system-state messages before experiencing them in real traffic. The test drive lasted about 25 minutes and included both local roads and expressways so that drivers were exposed to the RDCW functionality. A copy of the training video and written instructions about the use of the RDCW system was placed in each test vehicle's glove compartment so that drivers could review the materials if needed. Lastly, drivers were reminded to page an on-call researcher with any problems or questions throughout their participation.

4.3.5 Communication with test participants in the field

During the FOT, two researchers carried pagers which shared a common number. Researchers were available 24 hours per day. Drivers were instructed to contact a researcher if they were involved in a crash, had mechanical or RDCW system problems, or simply had questions about the RDCW system. A cell phone was placed in each test vehicle so that drivers could conveniently contact researchers. On a limited number of occasions, UMTRI researchers had to initiate contact with drivers. A driver was contacted in the event of one of the following conditions:

- An RDCW system component failure was detected by remote monitoring by RDCW researchers (as described in section 4.4.5). If a component failure was suspected while the vehicle was in the field, the driver was contacted to make arrangements to provide him or her with another RDCW vehicle.
- System software upgrades were required. Drivers were contacted and software upgrades were completed by research personnel at the RDCW vehicle's location.
- Lack of activity. If an adequate flow of data was not being observed via remote monitoring, drivers were contacted to inquire whether or not they were driving the RDCW vehicle (see section 4.4.5).

Of the 87 drivers that participated in the FOT, twelve were given a new vehicle at least once during their test period. Two of the twelve drivers were later excluded from the study and one driver was given a new vehicle twice. The reasons and count (in parentheses) for a vehicle exchange were: a) CSW communications fault (3); b) LDW communication fault (4); c) front radar failure (2); d) side radar failure (3); and e) DAS failure (1).

4.3.6 Debriefing

At the conclusion of their 26-day RDCW driving experience, drivers returned the test vehicle to UMTRI. During a two-hour debriefing session, drivers completed an extensive questionnaire (Appendix M) investigating their experiences with and impressions of the RDCW system. While the driver completed the questionnaire, a researcher prepared to show the driver video from a sample of alerts from their time with the RDCW vehicle. Via the remote data monitoring system, the researcher would have known, prior to the arrival of the driver at UMTRI, the number, type, and time/date of RDCW alerts that had been received by the driver during their RDCW driving experience. The researcher reviewed the accompanying forward camera and face camera video for these alerts to select between 10 and 12 alerts to be replayed to the returning driver.

Once drivers had completed the questionnaire, the researcher discussed their responses with them and drivers were provided an opportunity to offer further amplification and clarification where necessary. Lastly, the alert-event videos were replayed for the driver. Detailed feedback concerning the usefulness of each of the alerts was elicited via a five-point utility rating scale (as described in Section 9.2). At the conclusion of the debriefing, each driver was paid $250 for his/her participation.

4.3.7 Focus groups

Upon completion of their debriefing, drivers were invited to participate in one of four focus group sessions. The focus groups provided drivers with the opportunity to expand on their answers to the detailed questionnaire and provide additional information about their experience with the RDCW system. Additionally, conversations with other focus-group members often supplied added insights into their experiences with the RDCW system. Each of the four separately-held focus groups lasted approximately two hours, and an average of six drivers participated in each group. The same 46 questions were asked at each session. A complete list of the questions may be found in Appendix N. Drivers were paid $60 for taking part in a focus group.

4.4 Test fleet management and monitoring

The fleet of 11 RDCW-equipped test vehicles was used over a 10-month period to collect data, per the original experimental design for the FOT. That design, which was ultimately completed, called for 78 drivers distributed evenly by gender and across three age groups (ages 20-30, 40-50, and 60 and older). To this end, there were typically eight to ten vehicles in the field, with another vehicle at UMTRI as a backup, in case one of the fielded vehicles had a known or suspected failure and a quick exchange was needed.

Maintenance and monitoring of the FOT fleet of 11 RDCW-equipped vehicles was vital to the success of the FOT and safety of its participants. Careful monitoring of the fleet was required given the experimental RDCW system installed in the vehicles, as well as the mileage expected for them. This section provides details regarding the overall management of the test fleet including vehicle scheduling, launch, and routine maintenance of vehicle and system health. The monitoring of vehicles in the field is also discussed.

4.4.1 Validating test vehicle operation

Over the course of the operational field test, each vehicle underwent two types of tests: characterization tests and checkout tests. The characterization tests were performed once per vehicle, and occurred between the time that the vehicle was received by UMTRI from Visteon and its release to the first participant. (Prior to this delivery, Visteon Corporation – as the partner responsible for fabrication and release of the vehicle system - executed more thorough validation tests of the RDCW functions.)

Checkout tests, as the name implies, were performed each time a vehicle was released for use by a participant. The checkout tests were much more limited in scope than the characterization tests. Various aspects of the RDCW system were exercised, and, based on the response, adjustments or corrections were made. If the needed adjustments were relatively minor (e.g., camera focus/aim, side-radar replacement or aim) they were done by UMTRI's staff. However, when the required repairs were more substantial (e.g., faulty display, replace/aim forward radar), they were made by Visteon or AssistWare. Objective data were collected during these exercises. Throughout the checkout process, the experimenter also observed the display interface and ensured that the proper settings and warnings were shown.

4.4.2 Preparations for vehicle launch

During each week of the FOT, a rotation of one to four vehicles typically occurred. Vehicles were returned by test subjects on Monday or Tuesday, and the same test vehicle was often released to another test subject on Thursday or Friday. (Sometimes the vehicle was retained at UMTRI as the backup vehicle, and the previous backup vehicle released to a subject.) Therefore a normal turn-around period for a vehicle was two or three days. A detailed agenda of tasks addressing the vehicle, RDCW, and data-system aspects was followed during that period to ensure a consistent and complete preparation. A summary of these activities is shown in Table 4.2, and many of the tasks are described in more detail in the following discussion.

Table 4.2. Vehicle-turnaround activities

Task description
(1) Upload data from first driver onto data server.
(2) Perform vehicle maintenance tasks. • verify safety, readiness, and functionality of all vehicle systems; • ensure presence of driver equipment (e.g., emergency tools, maps, etc.); • ensure presence of documentation (e.g., instructions, insurance, etc.); • perform periodic maintenance per OEM schedule; • clean vehicle.
(3) Perform system maintenance tasks • clear the lookaside database to erase geographical memory of roadside obstacles • verify that recent data confirms proper operation of RDCW subsystems
(4) Verify functionality of the RDCW system and create permanent record of the system behavior using a predefined set of driving maneuvers.
(5) Verify data system operation, and re-initialize system for the next driver.

4.4.3 Vehicle maintenance

Routine vehicle maintenance and repair work combined UMTRI staff effort and work that was done at authorized Nissan service shops. For special needs, Visteon was also directly involved. The maintenance tasks were carried out through the following sub-tasks:

- UMTRI inspection — complete automotive check to ensure safe and proper function of the vehicle. At that time, conformance with standard maintenance schedule and procedures set by the manufacturer were verified.
- OEM maintenance — any repairs, if needed, and dealer-level periodic maintenance (e.g., recall campaigns) were performed by authorized local Nissan service shops. Given the unique aspects of the test fleet relative to the OEM configuration, UMTRI arranged for work at dealers who were specially acquainted with the nature of the vehicles.

One vehicle did sustain major damage from a deer-to-car crash while traveling at 78 mph (figure 4.3), and others had minor damage due to events such as a driver running over landscaping rocks alongside a driveway and another vehicle damaged by flying debris while traveling on a freeway. None of these events were relevant to the RDCW system and are mentioned only in the context of fleet maintenance.

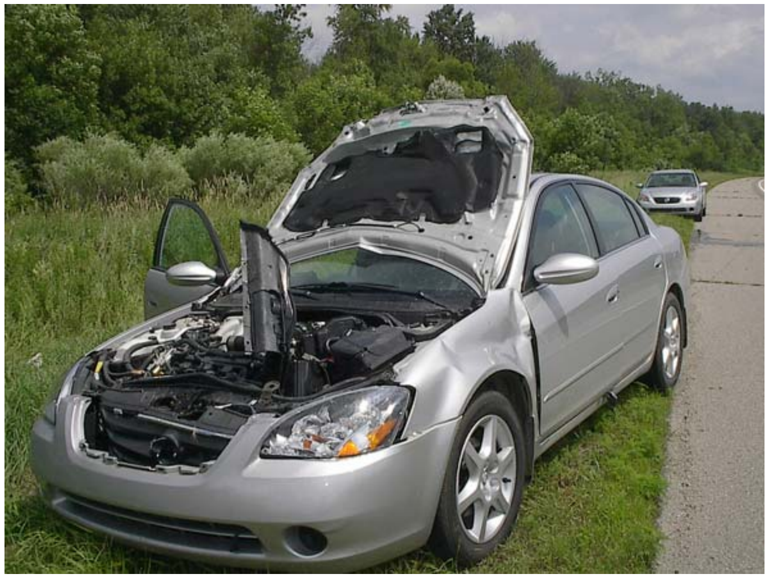


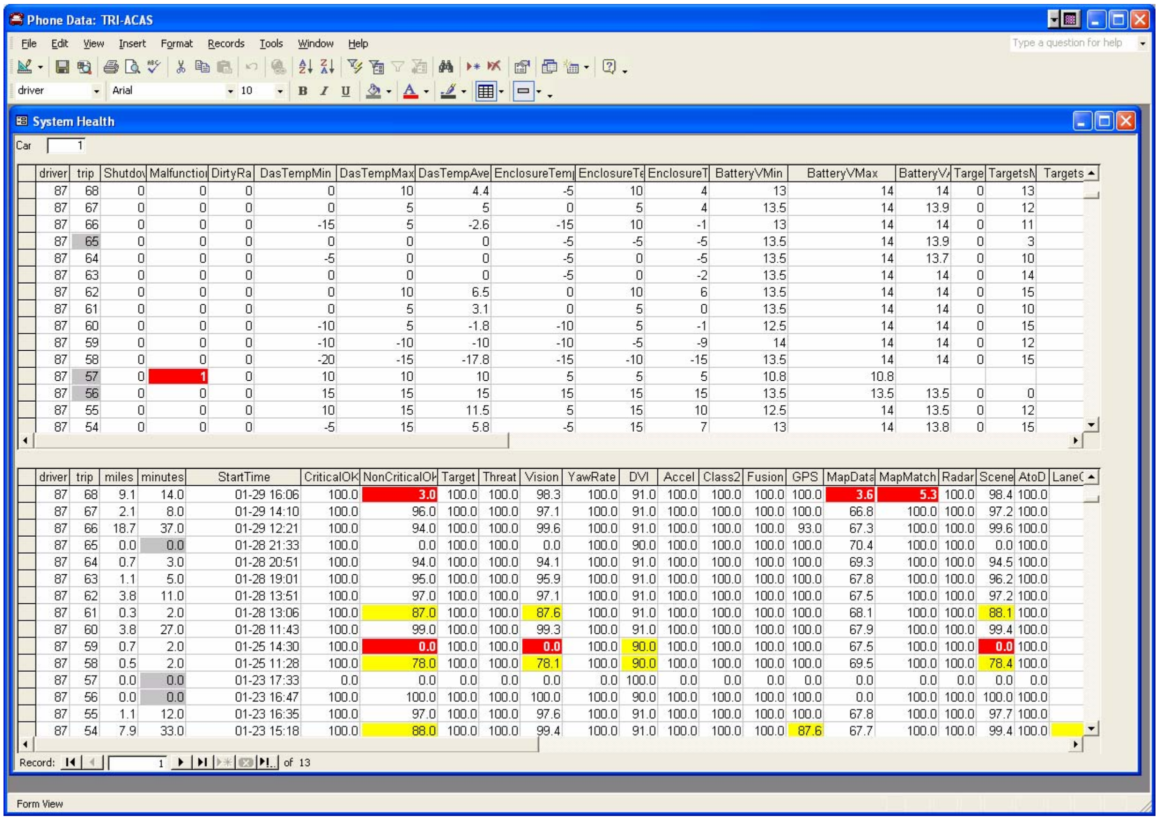
Figure 4.3 Test vehicle damage from a collision with a deer

4.4.4 RDCW system maintenance

Prior to release of a vehicle to the next participant, the integrity of the RDCW system was tested via the checkout tests to ensure both the safety and proper functioning of the system. When problems were found, UMTRI staff attempted to solve them and make repairs under Visteon's and AssistWare's guidance. When necessary, the more complicated repairs were made by Visteon or AssistWare.

4.4.5 Monitoring vehicles in the field

To allow researchers to monitor the "health" of the vehicle, RDCW system, and the data acquisition system (DAS), the DAS would automatically use a cellular modem to transfer a subset of the collected data files to servers at UMTRI. The transfer was attempted after every ignition-off event, and was based on a leased cellular digital packet data (CDPD) service. At the lab, programs were scheduled to run every 20 minutes to automatically upload the files to a database for processing, viewing and scrutiny either in-house via the UMTRI intra-net or remotely using the Internet. This automation and remote access allowed the UMTRI engineers to continuously monitor the system status while the vehicles were in the field, regardless of their location. The FOT partners and the USDOT also had access to this password-protected website. A sample page from the display is shown in figure 4.4.



driver	trip	Shutdo	Malfunctio	DirtyRa	DasTempMin	DasTempMax	DasTempAve	EnclosureTem	EnclosureTe	EnclosureT	BatteryVMin	BatteryVMax	BatteryV	Targe	TargetsN	Targets
87	68	0	0	0	0	10	4.4	-5	10	4	13	14	14	0	13	
87	67	0	0	0	0	5	5	0	5	4	13.5	14	13.9	0	12	
87	66	0	0	0	-15	5	-2.6	-15	10	-1	13	14	14	0	11	
87	65	0	0	0	0	0	0	-5	-5	-5	13.5	14	13.9	0	3	
87	64	0	0	0	-5	0	0	-5	0	-5	13.5	14	13.7	0	10	
87	63	0	0	0	0	0	0	-5	0	-2	13.5	14	14	0	14	
87	62	0	0	0	0	10	6.5	0	10	6	13.5	14	14	0	15	
87	61	0	0	0	0	5	3.1	0	5	0	13.5	14	14	0	10	
87	60	0	0	0	-10	5	-1.8	-10	5	-1	12.5	14	14	0	15	
87	59	0	0	0	-10	-10	-10	-10	-5	-9	14	14	14	0	12	
87	58	0	0	0	-20	-15	-17.8	-15	-10	-15	13.5	14	14	0	15	
87	57	0	1	0	10	10	10	5	5	5	10.8	10.8				
87	56	0	0	0	15	15	15	15	15	15	13.5	13.5	13.5	0	0	
87	55	0	0	0	10	15	11.5	5	15	10	12.5	14	13.5	0	12	
87	54	0	0	0	-5	15	5.8	-5	15	7	13	14	13.8	0	15	

driver	trip	miles	minutes	StartTime	CriticalOK	NonCriticalOk	Target	Threat	Vision	YawRate	DVI	Accel	Class2	Fusion	GPS	MapData	MapMatch	Radar	Scene	AtoD	LaneC
87	68	9.1	14.0	01-29 16:06	100.0	3.0	100.0	100.0	98.3	100.0	91.0	100.0	100.0	100.0	100.0	3.6	5.3	100.0	98.4	100.0	
87	67	2.1	8.0	01-29 14:10	100.0	96.0	100.0	100.0	97.1	100.0	91.0	100.0	100.0	100.0	100.0	66.8	100.0	100.0	97.2	100.0	
87	66	18.7	37.0	01-29 12:21	100.0	94.0	100.0	100.0	99.6	100.0	91.0	100.0	100.0	100.0	93.0	67.3	100.0	100.0	99.6	100.0	
87	65	0.0	0.0	01-28 21:33	100.0	0.0	100.0	100.0	0.0	100.0	90.0	100.0	100.0	100.0	100.0	70.4	100.0	100.0	0.0	100.0	
87	64	0.7	3.0	01-28 20:51	100.0	94.0	100.0	100.0	94.1	100.0	91.0	100.0	100.0	100.0	100.0	69.3	100.0	100.0	94.5	100.0	
87	63	1.1	5.0	01-28 19:01	100.0	95.0	100.0	100.0	95.9	100.0	91.0	100.0	100.0	100.0	100.0	67.8	100.0	100.0	96.2	100.0	
87	62	3.8	11.0	01-28 13:51	100.0	97.0	100.0	100.0	97.1	100.0	91.0	100.0	100.0	100.0	100.0	67.5	100.0	100.0	97.2	100.0	
87	61	0.3	2.0	01-28 13:06	100.0	87.0	100.0	100.0	87.6	100.0	91.0	100.0	100.0	100.0	100.0	68.1	100.0	100.0	88.1	100.0	
87	60	3.8	27.0	01-28 11:43	100.0	99.0	100.0	100.0	99.3	100.0	91.0	100.0	100.0	100.0	100.0	67.9	100.0	100.0	99.4	100.0	
87	59	0.7	2.0	01-25 14:30	100.0	0.0	100.0	100.0	0.0	100.0	90.0	100.0	100.0	100.0	100.0	67.5	100.0	100.0	0.0	100.0	
87	58	0.5	2.0	01-25 11:28	100.0	78.0	100.0	100.0	78.1	100.0	90.0	100.0	100.0	100.0	100.0	69.5	100.0	100.0	78.4	100.0	
87	57	0.0	0.0	01-23 17:33	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
87	56	0.0	0.0	01-23 16:47	100.0	100.0	100.0	100.0	100.0	100.0	90.0	100.0	100.0	100.0	100.0	0.0	100.0	100.0	100.0	100.0	
87	55	1.1	12.0	01-23 16:35	100.0	97.0	100.0	100.0	97.6	100.0	91.0	100.0	100.0	100.0	100.0	67.8	100.0	100.0	97.7	100.0	
87	54	7.9	33.0	01-23 15:18	100.0	88.0	100.0	100.0	99.4	100.0	91.0	100.0	100.0	100.0	87.6	67.7	100.0	100.0	99.4	100.0	

Figure 4.4 FOT vehicle system status monitoring form

Each page of the form displays the trips of a car, ordered with the most recent first. Values that are out of normal range are color-coded to indicate the severity of a possible problem. Very short trips are not checked (but are indicated by a grey background on trip number in the top form or on duration in the bottom form).

4.4.6 Uploading onboard data

Upon returning to UMTRI, the driver was escorted to a room where they began to complete their post-drive questionnaire. Technicians then moved to upload the onboard data. Carts equipped with a 13.8 volt DC power supply, network switch, mode control switch, keyboard, mouse and LCD monitor were used to provide maintenance and download facilities at UMTRI for the data system.

Figure 4.5 shows the network, power, and mode connections to the DAS via the small access door in the trunk-enclosure panel.

Figure 4.5 Data upload connection

Each computer in the DAS maintained a database that included a table that catalogued the names and sizes of all data files. Once the cart was connected to the DAS and the UMTRI building network, a program copied the files to the RDCW file server and then loaded the numeric data into the a Microsoft SQL Server database.

Scheduled routines on the database server were then run during low-usage periods to automatically perform secondary data processing tasks that could not be run on the DAS itself in real time. Finally, all data files from the archiving server were backed up to tape and moved offsite for permanent storage. Finally, at intervals several weeks apart, all the raw data from the onboard system as well as all subjective data was forwarded to the independent evaluator.

5 Overview of Data Archive

This section provides an overview of the data archive from the FOT experiment. Several appendices are referenced to provide readers with additional details.

The elements of the FOT data archive include objective data and subjective data. *Objective data* is defined as those data that are measured or that represent factual information. Table 5.1 shows that objective data includes data collected onboard the vehicle as well as factual data from external (off-board) sources, such as information about the driver's age and gender or attributes of highways traveled in the FOT. Objective data also includes data created in post-processing, although this is so voluminous and detailed that there will be little discussion of this component. Section 5.1 focuses on describing the nature of the objective data, which largely supports analyses in sections 6, 7, and 8.

Subjective data is defined as data gathered directly from the test participants that involves their individual personal perspectives. This includes responses to a set of pre-drive subjective instruments that addresses their perspectives on aspects of being a driver, per se, as well as broader issues such as ratings on scales describing sensation-seeking attributes. Section 5.2 is dedicated to summarizing the instruments used to collect the subjective data. This data is the basis for analyses of driver acceptance in section 9.

Table 5.1 FOT data archive

Objective data archive	Subjective data archive
<u>Onboard data:</u> • Numerical data (data database) • Video data • Audio data <u>Off-board data:</u> • Driver biographical information • Highway Performance Monitoring System data <u>Post-processed data:</u> • Post-processed results • Corrections	<u>Pre-drive driver responses to:</u> • Driver Behavior Questionnaire (DBQ) • Driver Style Questionnaire (DSQ) • Sensation-seeking scale • Driving risk assessment questionnaire • Locus of control scale • Driving dilemma scenarios questionnaire <u>Post-drive responses to:</u> • Post-drive questionnaire • Post-drive debriefing • Focus group questions

The distinction of objective data versus subjective data is presented mostly to describe the organization of this report, particularly in the presentation of the data archive in this section and in presenting results in sections 6 – 9. There are data that do not fit neatly into one category, such as the data describing drivers' reactions in the vehicle to alerts that occur (e.g., whether they are startled), or audio data that captures the driver's self-prompted comments about the system. Furthermore, the data categories are closely coupled in the sense that the driver influences almost all the objective data – for instance, through their selection of roadway environments and their driving performance – as well as directly providing responses that constitute the subjective data. Much of the subjective data are likewise influenced by experiences that are described in the objective data. Thus the labels of objective and subjective data do not imply fundamentally separate data archives.

The size of this data archive is substantial. The database that houses the numerical data is a collection of 89 tables containing over 54 billion data elements and is slightly more than 204 GB in size. The tables range from a few thousand to over 261 million rows of data depending on the collection frequency for that data subset. The video data volume is only 135 GB due to a scheme of adaptively sub-sampling images in both space and time, as well as compression efficiency exceeding 90 percent. The total of all objective and subjective data – not including post-processed data – is approximate 350 GB.

5.1 Objective data archive

This section describes the objective data elements listed in Table 5.1.

5.1.1 Onboard data: numerical data

An archive was created of roughly four hundred channels (signals) of data collected onboard the RDCW test vehicles. These data signals were collected by the DAS from two types of sources: CAN buses serving the RDCW system, and *FOT sensors* installed on the vehicle. The DAS recorded signals from three of the four CAN buses involved in the RDCW system, including the RDCW project CAN bus and the two radar buses. The Nissan vehicle CAN bus was not directly observed, but rather the SAM system passed along key information from that bus. (See section 3.2 for descriptions of the system architecture.). The FOT sensors were a separate set of sensors not used within the RDCW system, but installed to record aspects of the experiment (see section 3.6 for a description of the sensors).

Table 5.2 summarizes the types of data that were collected, along with the source of the data from the DAS's perspective. In summary, the numerical data captures virtually all signals moving between the RDCW components described in section 3, as well as many signals made available by the RDCW system solely for data collection. Furthermore, additional FOT video and sensor inputs complement the RDCW data set.

Table 5.2 Overview of onboard data collection

Data	*Sources*
Vehicle and driver identifications	Pre-set values
Vehicle position, heading, and motion– speed, yaw rate, accelerations, pitch and roll angle and rates, GPS (differential and non-differential)	CAN bus and FOT sensors
Driver control inputs –steering wheel angle, throttle input, brake switch, turn signal, headlamp state, cruise control state and set speeds, LDW and CSW sensitivity settings	CAN bus
RDCW driver displays – LDW and CSW alerts and levels, availability icons	CAN bus
RDCW intermediate values – e.g., lane position, warning thresholds, road geometry estimates, threat locations, vehicle-centered object map	CAN bus
Roadway environment – road type and attributes, urban/rural setting	Onboard digital map via CAN bus, plus post-processing, HPMS database
RDCW system and subsystem health and diagnostics information, as well as subsystem version numbers	CAN buses
RDCW radar data – forward radar data, side radar data	CAN buses
Video – forward driving scene and driver-face views	LDW camera, FOT sensors
Audio from the driver comment button – dictated messages from driver	FOT sensors

The DAS collected all numerical data at 10 Hz, except for a set of analog FOT sensors measuring vehicle motion which are logged at 20 Hz. The DAS recording operated by observing the CAN bus and FOT sensor inputs at regular intervals based on a 20 Hz cycle, and for the 10 Hz signals, records the last value observed at that moment. Therefore the data are not synchronous, since the data sources that are broadcasting onto the CAN buses operate at their own cycle rates, based on their own internal clocks. Thus data stamped by the DAS may have originated from the source 0.1 sec or more before the time of the DAS time stamp. In the case of analyzing this system, this effect was not found to be troublesome.

The radar signals were the only numerical signals that were sub-sampled in time. This was because the two forward radars operate at 20 Hz (and each are capable of reporting many radar tracks with several signals each) and the two side radars operate at 50 Hz. These two systems are observed by the RDCW system at full rates, but the data collection system observes each at 10 Hz. Since the RDCW system processes radar data outputs with algorithms that require persistence of targets, this sub-sampling is not likely to miss meaningful targets that influence the RDCW system.

The complete data set is listed in Appendix P. A representative set of numerical data is now presented for illustration in Table 5.3. These data were grouped into a single database table that was often the starting point for analysis calculations. Hundreds of other less commonly-used signals were stored in other database tables.

Table 5.3 Channels of the *Data* table and their definitions

Signal name	Description	Original Source	Units
Driver	Driver identification code	Pre-set	None
Trip	Trip index	DAS	none
Time	Time in centi-seconds since DAS application launch	DAS	csec
RdcwDisabled	Are driver alerts provided?	DAS	none
AccelPedal	Accelerator pedal position	Vehicle bus	Unitless
Brake	Brake switch active	Vehicle bus	None
Engaged	Cruise control active	Vehicle bus	None
Speed	Vehicle speed	Vehicle bus	m/sec
YawRate	Yaw rate	SAM	deg/sec
Latitude	Latitude from DGPS	DAS	deg
Longitude	Longitude from DGPS	DAS	deg
GpsHeading	Heading - DGPS	DAS	deg
GpsNew	New DGPS data this sequence	DAS	none
GpsSpeed	Speed from DGPS	DAS	m/sec
GpsTime	Millisecs in week from DGPS	DAS	msec
NumberOfSats	Number of DGPS satellites	DAS	none
LaneOffset	Vehicle offset from lane center	LDW	m
LaneOffsetConf	Lane offset confidence	LDW	%
LaneWidth	Lane width estimate	LDW	m
FodLeft	LDW Future offset distance (projected lane position), left	LDW	meters
FodRight	LDW Future offset distance, right	LDW	meters
FodThresholdLeft	LDW Future offset distance threshold for alert, left	LDW	meters
FodThresholdRight	LDW Future offset threshold, right	LDW	meters
LdwAlertStatus	Ldw alert status information	LDW	none
LdwTimeStamp	Ldw time stamp	LDW	csec
LdwSensitivity	Ldw sensitivity setting	DVI	none
LdwUnavailable	Ldw Unavailable	DVI	none
LdwUnavailableLeft	Ldw Unavailable Left	DVI	none
LdwUnavailableRight	Ldw Unavailable Right	DVI	none
AmrLeft1	LDW Avail Maneuvering Room, left, bin 1 (see Sec 3)	SAM	Meters
AmrLeftConf1	LDW Avail Maneuvering Room, left side, confidence., bin 1	SAM	None
AmrLeftSource1	LDW Avail Maneuvering Room, left side, sensor source, bin 1	SAM	None
AmrRight1	LDW Avail Maneuvering Room, right side, bin 1	SAM	Meters

Table 5.3 ***(Continued)*** **Channels of the** ***Data*** **table and their definitions**

Signal name	Description	Original Source	Units
AmrRightConf1	LDW Avail Maneuvering Room, right side confidence, bin 1	SAM	None
AmrRightSource1	LDW Avail. Maneuvering Room, right side, sensor source, bin 1	SAM	None
CPOI	CSW upcoming curvature point of interest (CPOI) index	CSW	None
CpoiCurv	CSW CPOI curvature	CSW	1/m
CpoiDistance	Distance to CPOI	CSW	Meters
CswSensitivity	CSW sensitivity setting	DVI	None
CswStatus	CSW status byte (health, flags)	CSW	None
LookAhead	CSW Lookahead Distance	CSW	m
MapUsed	Map used for CSW	CSW	none
MaxCurv	Max upcoming curvature	CSW	1/m
MlpConfidence	CSW Most-likely-path (MLP) confidence	CSW	none
PomNotVerified	CSW map matching success	CSW	none
CswUnavailable	CSW Unavailable	DVI	None
RadarStatus	SAM radar health byte	SAM	none
RdcwStatusByte3	Rdcw status flags	RDCW	none
RdcwStatusByte4	Rdcw status flags, continued	RDCW	none
SamTime	SAM time stamp	SAM	dsec

5.1.2 Onboard data: video and audio

Video and audio data were captured to support analyses addressing the key objectives of the FOT. Signals from two black-and-white CCD cameras were captured onboard the DAS, including the signal from the LDW camera that viewed the forward driving scene, and a second camera installed specifically to capture the driver's face. The images were time-stamped for later use in analysis, in conjunction with time-stamped numerical data. The driver face camera was mounted on the A-pillar, as shown in section 3.2, and included a set of infrared LEDs that provided nighttime illumination of the driver's face in an area of the spectrum that was invisible to drivers. The audio data that was collected originated from a solid-state microphone that was part of the RDCW system's means for adapting audible warnings to ambient noise. The microphone was installed in the headliner near the windshield.

Video recording was triggered by a set of inputs, some of which were adaptive to RDCW events. The forward-scene images were collected from the LDW camera, which was a NTSC camera used in the commercial implementation of the SafeTRAC ® system that LDW was based upon. The camera provided interlaced-field images at 30 Hz. The video signal was split within a video amplifier, with one output fed to the LDW system and another fed to the DAS. Within the DAS, images from this camera were captured in two different modes. First, forward video was recorded at two frames per second whenever the vehicle was moving. Second, when an RDCW alert was requested by the DVI (including those ‘silent’ alerts during the baseline RDCW-disabled week), video was logged at 10 Hz, with four seconds of this higher-rate video captured before the event (using a buffering system) and four seconds after the alert. Table 5.4 summarizes this information.

Table 5.4 Forward, face and audio data storage rates and trigger windows

Loop and store series	*Nominal Rate, Hz*	*Triggered rate, Hz*	*Trigger window pre, s*	*post, s*
Forward video	2	10	4	4
Face video	0.5	10	4	4
Face video – exposure	5	n/a	0	5
Audio—alert	48K	48K	4	8
Audio—comment button	48K	48K	0	30

The forward image captured by the DAS was also sub-sampled spatially. This was to keep the video data volume to levels that allowed post-test analysis to be very efficient and user-friendly, instead of unnecessarily slowing analysis tools down by the burden of full-frame, 30 Hz data. The hypothesis behind this is that the sub-sampled rates and image sizes captured the information of interest. The result of this is that a search on the numerical data will call up the nearest image set within a few seconds of real time, and then allow the video to be played in either direction in real time or up to 10 times real time speed. Only one of the two interlaced fields of the forward images were recorded (i.e., every other row), and furthermore, a subset of the 240 rows in that field were recorded. Thus the recorded image had the full azimuth range of the camera (approximately 42 degrees), but the image had a reduced horizontal field of view, as seen in figure 5.1.When displaying these images, additional rows were generated to fill in for the field that is omitted – this was done by duplicating recorded rows or interpolating between neighboring rows.

Figure 5.1 Sample recorded image from forward-scene camera

The images from the driver-face camera were captured using three different modes. First, the signal was recorded at 0.5 Hz whenever the data system was running – this included time when the vehicle was at rest, as well as all moving-vehicle times. Second, when an RDCW alert was requested, the data rate increased to 10 Hz for eight seconds, with four seconds of data recorded before the triggering event (i.e., the timing was identical to that used with the forward-scene camera signal). Third, a batch of 50 driver-camera images, spaced 0.2 seconds apart (or 5 Hz), were collected five minutes into each trip, and then every five minutes thereafter. These serve as "exposure" video clips that will be analyzed in section 8 for clues about the RDCW system's influence on when, and how often, drivers engaged in non-driving behaviors such as talking on cell phones. The driver-face camera images were also cropped when they are recorded; an example of the images captured is shown in figure 5.2.

Figure 5.2 Sample recorded image from driver-face camera

Although, video analysis in this FOT was done by visual means only (i.e., no automatic image processing was used), the importance of video for event validation can not be overstated. Efficient analysis of a data set this size requires sub-setting these data into events that capture the driving environment and the kinematic scenario of interest. Video, although not used to define the events, allows the validation of the selected events and ensures that the subsequent analysis is not contaminated by other scenarios that may have met the same requirements used to find the scenario of interest.

Audio was captured based on two distinct triggers. First, an RDCW alert triggered audio data collection. Second, as described in section 3, drivers were able to press a driver comment button on the dashboard, which would then record any comments that they offered. The details of the audio recording durations were given earlier in Table 5.4.

5.1.3 Completeness of onboard data

This section addresses three topics that involve the completeness of the data onboard the FOT vehicles. First, the reasons are given for discarding the data collected from nine of the 87 drivers who were given an RDCW test vehicle. The remaining 78 drivers' data sets, of course, comprise the data set analyzed in this report, and it was always the objective to collect data for 78 drivers. Second, for the 78 drivers whose data were retained, a subset of trips for each driver were labeled as *invalid trips* for the purposes of analyzing the onboard data. A discussion is given for the criteria used to label a trip invalid, as well as summarizing the fraction of travel that invalid trips represented. Finally, an estimate is made of the amount of data that was lost in the data collection process. Together, these topics are presented to suggest to the reader that the data used for the analyses reported in the subsequent sections of this report are sufficiently representative of the selected test sample.

In addition, Appendix Q summarizes significant errors that occurred in the collection of the onboard numerical data signals, with corrective steps that were taken. The data archives at UMTRI and at the USDOT include these corrections. A few signals were not able to be corrected, as the appendix describes.

5.1.3.1 Selecting driver data sets

The FOT experimental design called for 78 drivers distributed evenly in the six age/gender cells. To achieve this goal, drivers were continually recruited to fill those cells and the recruitment adapted to compensate for drivers who quit the study, were excused for technical or behavior reasons, or for data sets that were later discovered to be substantially incomplete. Table 5.5 presents a summary of travel time and distance for all 87 FOT drivers who were released with a test vehicle, as well as for the final set of 78 drivers used in analysis. The specific reasons for dismissal are given in Table 5.5. Near the end of the experiment, there were two extra drivers who were released with a test vehicle in order to ensure that their particular cells would be complete. When they completed the test, data from one driver per cell was discarded, based on insufficient data in one or both segments of their testing.

Overall, a total of 2,983 hours and 98,671 miles (157,874 km) were logged for all 87 drivers. This was reduced to 2,696 hours and 89,794 miles (143,670 km) when the data from the nine drivers were excluded in order to meet the experiment objectives.

Table 5.5 Summary of invalidated drivers and trips

Travel data for all 87 drivers	Trips	Hours	Miles
	12,431	2,983	98,671
Statistics of discarded driver sets	**Trips**	**Hours**	**Miles**
Subject withdrew, no post-drive questionnaire	265	64	2,069
CSW outage and lost DAS data packets	245	54	2,002
Low LDW availability due to calibration loss	420	75	1,453
Extra driver in age/gender cell	66	29	1,005
Deer/vehicle crash	36	17	690
Extra driver in age/gender cell	54	15	627
Subject lived outside of mapped area	88	13	527
Irregularities in the use of the vehicle	158	16	360
DAS malfunction: loose power controller	27	5	144
Subtotals	1,359	287	8,878
Travel data for the 78 drivers - final data set	**Trips**	**Hours**	**Miles**
	11,072	2,696	89,794

5.1.3.2 Valid trips as the basis of analysis

For the remaining 78 valid drivers, an analysis of their trip data was performed to remove trips that were either problematic due to a faulty sub-system or sensor or were deemed invalid for some other clear reason (e.g., video indicated that someone other than the subject was driving the car). Also, included in this group of invalid trips, were trips with zero distance traveled. In total, the invalid trips constitute 209 hours and 10,380 km of driving and reduced the data set of the 78 valid drivers by 7.2 percent as measured by reduction in travel distance.

The final valid-data set used in the analysis sections of this report consisted of data from 78 drivers, 9582 trips, 2487 hours and 82,773 miles 1(33,290 km) (see table 5.6).

Table 5.6 Summary of trips that are not used in subsequent analyses

Reason for invalidating trip	Trips	Hours	Miles	% of all miles
CSW off-line > 1 percent of trip	295	87	3,166	3.5%
LDW off-line> 1 percent of trip	131	39	1,599	1.8%
Front radar off-line > 1 percent of trip	150	36	859	1.0%
Low LDW availablity due to calibration loss	32	10	375	0.4%
Side radar off-line > 1 percent of trip	26	8	275	0.3%
SAM thread frozen>1% of the time and V>18 mph	23	6	206	0.2%
Driver was not the test subject	2	0	4	0.0%
Enabled trip during the first week	1	0	2	0.0%
Zero-distance trips	830	23	-	0.0%
All invalidated trips	1490	209	6,488	7.2%
Resulting valid driver and trip set:	9,582	2487	82,773	92.8%

5.1.3.3 Rate of successful data collection

In general, the collection and logging of data during operations by the subject drivers was robust, with the data from approximately 97 percent of all miles driven recorded by the DAS. This estimate is based on comparing the travel distance recorded on the DAS with that recorded by the vehicle's odometer, and includes all 87 drivers. Note that this underestimates the success of data collection in the 78 driver set used for analysis, since two drivers' data sets were discarded precisely for problems with the data collection system. (These errors were due in both cases to a power control microcontroller unseating from its connector because the connector was not screwed down.)

The bulk of the missed travel distance is thought to be the travel that occurred before the DAS completed its boot-up cycle, which was on the order of one minute. A study was conducted to look at whether certain vehicles' data system were more prone to errors, and there was no evidence of a problematic unit.

5.1.4 Other objective data sources

5.1.4.1 Driver biographical data

Driver biographical data includes information such as age, zip code, estimated income, education, occupation, and the make and model of their primary vehicle. This information was gathered from the Michigan Secretary of State's Office (age, zip code, per section 4.2). Other data was provided by the drivers themselves. Appendix D includes a table that contains much of the biographical data acquired.

5.1.4.2 HPMS database

To augment the data collected onboard each vehicle, an additional data source was added to the main database and used to support the evaluation of the RDCW system. This was the Michigan component of the Highway Performance Monitoring System (HPMS) database from the Federal Highway Administration. The 2003 Michigan HPMS database contains some 98 fields characterizing approximately 122,000 miles of public road. Michigan's HPMS data collection is part of an annual nationwide inventory system of certified, public-road mileage. These data reflect the extent, condition, performance, use and operating characteristics of the public roads. Data fields drawn for project use included road-segment length, functional class, urban/rural designation, and traffic volume. The HPMS was joined to the other RDCW data using map coordinates (latitude and longitude).

5.1.5 Derivation of road type

Discerning the type of road being driven by the RDCW vehicles during the FOT was handled in the CSW module using both of the digital maps that were onboard. These maps were supplied by NAVTEQ and included a "SDAL" map and a newer map called the advanced product set (APS1) that covered the seven counties in southeastern Michigan in which most driving occurred. The final road types used in this report are a derivation of the underlying roadway classification system used by NAVTEQ. This section details the process used to derive the road type distinctions used in the analysis of the RDCW data.

The on-board signals derived from the digital maps that were used included a *Ramp* flag (true if on a ramp) a *Limited Access* flag (true if on a limited access road), and an attribute of the current roadway called *Function Class*. In NAVTEQ terminology the Function Class is an integer-valued attribute assigned to all roads, and is defined as follows:

- Function Class 1—Roads with very few, if any, speed changes. Access to the road is usually controlled. These roads allow for high volume, maximum speed traffic movement between and through major metropolitan areas.
- Function Class 2—Roads with very few speed changes that allow for high volume, high speed traffic movement. These roads are used to channel traffic

to Class 1 roads for travel between and through cities in the shortest amount of time.

- Function Class 3—Roads which interconnect Class 2 roads and provide a high volume of traffic movement at a lower level of mobility than Class 2 roads.
- Function Class 4—Roads which provide for a high volume of traffic movement at moderate speeds between neighborhoods. These roads connect with high functional class roads to collect and distribute traffic between neighborhoods.
- Function Class 5—Roads whose volume and traffic movement are below the level of any higher class levels.

Using a combination of the NAVTEQ Function Class and the Ramp and Limited Access flags the UMTRI road type definitions were defined and used in the analysis of the data and the derivation of the exposure experience for the FOT subjects. Figure 5.3 shows the mapping used to derive the road type designation used in the analysis.

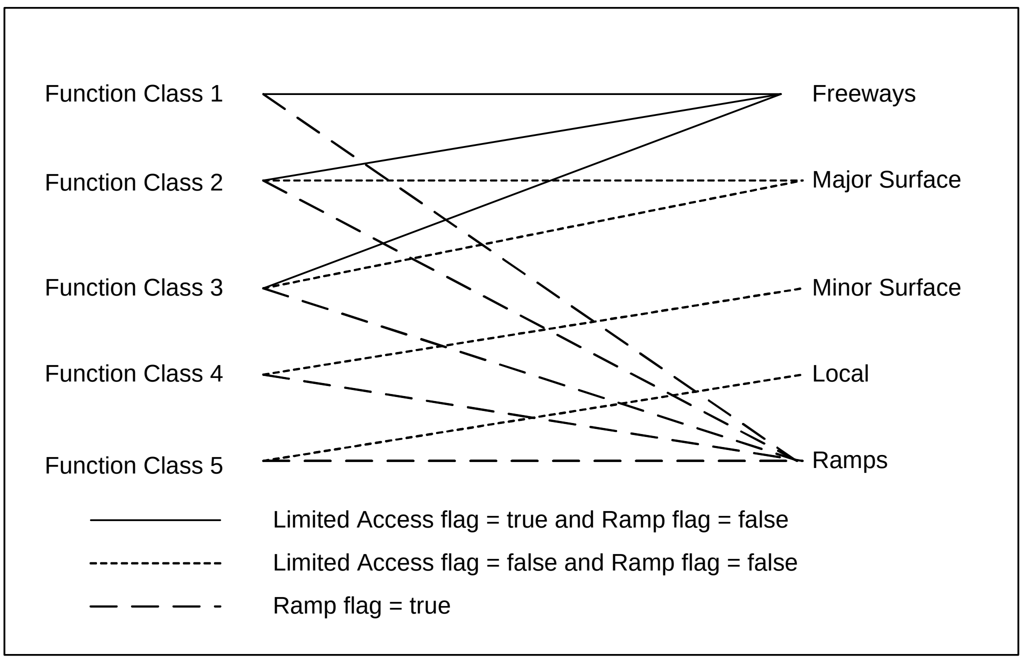


Figure 5.3 Definition of UMTRI road type classifications

5.2 Subjective data archive

This section provides an overview of key portions of the subjective data archive, as presented earlier in Table 5.1. Section 5.2.1 addresses the separate data elements, while section 5.2.2 discusses the completeness of the data.

5.2.1 Subjective instruments

5.2.1.1 Driver behavior questionnaire (DBQ)

The DBQ is a 24-item questionnaire that was given to drivers before they were released with the test vehicle. The DBQ itself is attached as Appendix E. The DBQ was developed in Great Britain, and evaluates features of drivers' self-reported behaviors while driving. Each item on the questionnaire is a 5-point Likert-type scale that lists a particular behavior and asks the driver to indicate whether they engage in that behavior "never, hardly ever, occasionally, quite often, frequently, or nearly all the time." Because all of the questions ask about "negative" driving behaviors, lower scores on the DBQ represent positive attributes.

The version of the DBQ used in this study is one that was modified to better reflect the spelling, grammar, and driving situations present in the United States (Parker, Reason, Manstead, and Stradling, 1995). The items on the questionnaire can be grouped together to examine three types of driver behaviors: errors, lapses, and violations (Reason, Manstead, Stradling, Parker, and Baxter, 1991). Errors are failures or misjudgments of an unintentional nature or the failure of a planned action to achieve its desired consequence. Errors are sometimes dangerous for other drivers. Lapses are more harmless events which result from inattention or slips in memory. Violations are deliberate acts which break social norms such as speeding or running a stop sign (Parker, et al., 1995). Errors and violations are the two that are theorized to contribute to road accidents (Reason et al., 1991).

Subscale scores for lapses, errors, and violations were developed by averaging the respective scores for all items that were included in the given factor. Thus the errors subscale consisted of the average score from questions 4, 9, 13, 14, 17, 21, 22, and 24. The lapses subscale consisted of the average score from questions 1, 5, 6, 7, 11, 18, 19, and 20. Finally, the violations subscale consisted of the average of questions 2, 3, 8, 10, 12, 15, 16, and 23.

5.2.1.2 Driver Style Questionnaire (DSQ)

The DSQ was also administered before the driver was released with a test vehicle. The DSQ is shown in Appendix F, and is a 15-item questionnaire also developed in Great Britain that evaluates features of drivers' self-reported style while driving. The DSQ is structured almost identically to the DBQ (with 5-point Likert-type scales and the same anchors). However, not all items are scored the same way; some are reverse-coded (which is described in greater detail below).

As with the DBQ, the version of the DSQ used in this study was a modified questionnaire that better reflect the spelling, grammar, and driving situations present in the United States. The items on the DSQ can be used to evaluate six factors of drivers' style: focus, calmness, social resistance, speed, deviance, and planning (French, West, Elander, and Wilding, 1993). "Focus" relates to one's ability to drive cautiously and ignore distractions (items 7, 11, and 12). The ability to stay calm in dangerous and quick-paced situations is measured by the "calmness" scale (items 1, 18, and 15). The "social resistance" scale measures the driver's preference for being given advice about driving abilities (items 3 and 10). The "speed" scale contains questions related to whether one drives fast and/or over the posted limit (items 4, 6, and 13). The "deviance" scale relates to behaviors that are inconsiderate of other drivers and often dangerous, like passing on the right or running a red light (items 5 and 14). Finally, "planning" contains questions regarding a driver's tendency to plan ahead before setting out for a trip (items 2 and 9). The DSQ was constructed to include questions about behaviors related to accidents, decision-making styles, and reactions to advice that others give (West, Elander, and French, 1992).

Scores for the six factors consist of averages across the items belonging to each factor. However, because of the reverse-coding for some items, not all factors follow the same relationship. Thus for the "focus" and "planning" subscales, higher scores represent positive attributes.

5.2.1.3 Other pre-drive measures

Four other measures were collected. They included the sensation seeking scale (Zuckerman, 1994), the locus of control scale (Rotter, 1996), a driving risk assessment questionnaire, and a driving dilemma scenarios questionnaire. These four measures were not directly used in any subsequent RDCW FOT analyses, but were administered to RDCW drivers to facilitate other research projects. Therefore, although they can be found in Appendices G through K, they are not described in detail here.

5.2.1.4 Post-drive questionnaire

When the drivers completed their scheduled time with the vehicle and returned to UMTRI, they each completed an extensive questionnaire investigating their experiences with and impressions of the RDCW system. Most of the questionnaire took the form of seven-point, Likert-type questions with a few multiple choice and open-ended questions. Appendix M includes both the questionnaire itself, along with statistics of driver responses that will be analyzed and reported upon in section 9 of this report.

5.2.1.5 Post-drive review of alert events

Drivers were each shown 10 to 12 alerts that occurred during their time with the RDCW vehicle. These were selected by a researcher to include, when possible, an equal number of LDW and CSW alerts. The drivers were asked to view the video of the events, which were accompanied by a map showing the geographical location of the events, and answer two questions about the utility of the alert. The details of the data set are presented in section 9.2, which also reports on the conclusions drawn from those responses.

5.2.1.6 Focus groups

Each of the four focus groups was held on a weekday evening, and they were structured similarly. A set of 46 questions were posed to the test participants, each of whom had completed their experience with the test vehicle and had already completed all other post-drive materials (an average focus group had six drivers). The events in each of the four focus groups were captured on video as well as within complete transcripts of the sessions captured by a court stenographer. The questions that were used are listed in Appendix N.

5.2.2 Completeness of subjective data

Each driver completed the post-drive questionnaire at the end of his/her 26-day driving experience. Drivers were instructed to write “NA” for “not applicable” next to any question which did not apply to their driving experience with RDCW. For example, there were cases in which drivers did not change the LDW or CSW sensitivity settings and, therefore, skipped questions pertaining to changing sensitivity (questions, RDCW5-RDCW7, RDCW9-RDCW14). Additionally, some drivers did not notice any of the visual warnings presented by the RDCW system and consequently were unable to answer the questions asked concerning the visual warnings. The most common questions which were skipped were the questions which asked the drivers to report the maximum amount that they would pay for a combined RDCW system (RDCW36), or the LDW (LDW49) and CSW (CSW49) systems separately. Several drivers reported having no idea how much currently available automotive features cost.

Table 5.7 contains a complete list of the questions for which there is missing data and the number of drivers who did not provide an answer.

Table 5.7 Questions for which there is missing data and the number of respondents who skipped the question.

Question	Number of drivers who did not respond		Question	Number of drivers who did not respond
RDCW5	4		LDW13	2
RDCW6	5		LDW14	3
RDCW7	3		LDW15	3
RDCW9	5		LDW22	1
RDCW10	2		LDW24	3
RDCW11a	1		LDW27	1
RDCW11b	1		LDW29	1
RDCW11c	1		LDW30	1
RDCW11d	1		LDW37	2
RDCW11e	1		LDW39	3
RDCW12	8		LDW49	8
RDCW13	4		CSW3	2
RDCW14a	1		CSW4	1
RDCW14b	1		CSW5	2
RDCW14c	1		CSW6	1
RDCW14d	1		CSW9	2
RDCW14e	1		CSW10	2
RDCW15	1		CSW11	2
RDCW20a	1		CSW12	3
RDCW21	1		CSW13	2
RDCW32c	1		CSW14	2
RDCW32e	1		CSW15	3
RDCW33	1		CSW22	3
RDCW36	9		CSW25	1
LDW1	1		CSW37	2
LDW3	1		CSW39	4
LDW9	2		CSW40	1
LDW10	2		CSW46c	1
LDW11	2		CSW46d	1
LDW12	3		CSW49	9

6 Exposure of the RDCW System During the FOT

This chapter is intended to set the context for those that follow by describing the relevant operating conditions to which the RDCW systems were exposed during the RDCW FOT. These conditions —the conditions to which the *systems* were exposed — relate not only to the nature of the driving environment but also to the driving behavior of the 78 individuals who used the RDCW systems. Section 7, which reports on RDCW events that drivers experienced, is necessarily based on the exposures reported in this section.

Driving in the FOT took place primarily in the lower peninsula of Michigan with minor amounts in Ohio, Indiana, and Illinois, all geographically flat country. The bulk of the driving was in urbanized southeast Michigan. Driving was spread over approximately ten consecutive months (May, 2004, through February, 2005), seven of which (May through November) were dominated by above-freezing temperatures and three (December through February) by sub-freezing temperatures. The latter constituted a winter season with record total snowfalls in southeast Michigan. Moreover, the 78 individuals who comprised the test subjects were, in fact, individuals with their own peculiar patterns of driving behavior.

This chapter will describe these and other characteristics of the FOT driving environment quantitatively.

6.1 Overall exposure of the FOT fleet

6.1.1 Travel time and distance, and the number of trips

There were a total of 9,582 valid trips in the RDCW FOT. Those trips covered 82,773 miles (133,290 kilometers) and took a total of 2,487 hours. Table 6.1 presents these figures and also shows that, for each category, approximately 25 percent of trips took place during the first week of each individual's driving while RDCW was disabled and 75 percent took place with RDCW enabled during the subsequent three weeks for each individual.

Table 6.1 Summary of travel volumes

	Distance kilometers (miles)		*Time, hours*	*Trips*
RDCW disabled	37,653	(23,382)	699	2,502
RDCW enabled	95,637	(59,391)	1,788	7,080
Total	133,290	(82,773)	2,487	9,582

6.1.2 Trips and trip distance

Table 6.1 showed that there were 9,582 valid trips. These trips varied in length from well under a mile to a maximum of 297 miles (478 kilometers). (Recall, trips of zero distance are not included in valid trips.) Figure 6.1 presents histograms showing both the distribution and the cumulative distribution of trip distance. The figure shows the distribution heavily favors short trips such that, while the average trip was 8.6 miles (13.9 km), the median trip was just 4.0 miles (6.4 km), and more than 14 percent of trips were shorter than 0.6 miles (1 km). Three percent of the trips were less than 100 m. Less than 2 percent of trips were longer than 50 miles (80 km).

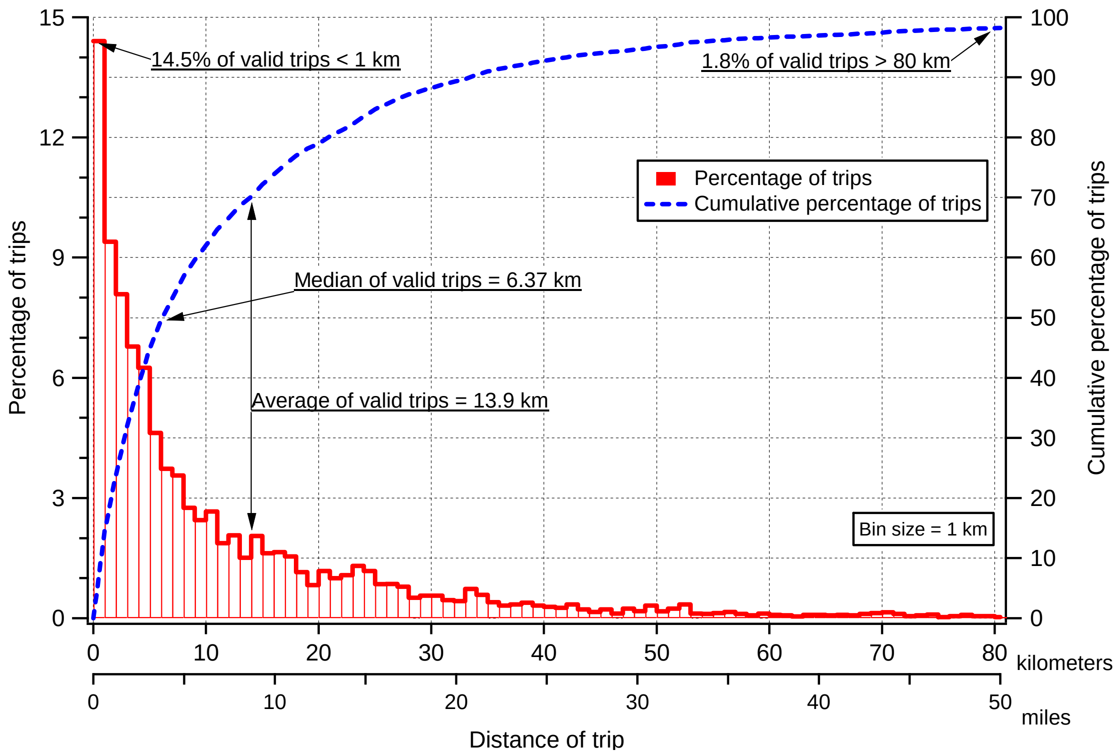


Figure 6.1 Histograms of trip distance

6.1.3 Chronology and seasonal factors

Figure 6.2 shows the accumulation of travel distance chronologically. It illustrates that travel distance was accumulated rather consistently over the 10-month period of the FOT. The figure also shows the chronology of average daily travel temperature[1] over the course of the FOT. These data indicate that the first seven months of the

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[1] Average daily travel temperature is the pooled, time-weight average of the temperature experienced by FOT vehicles while in use during a given day. Temperature measurements were derived from the on-board, outside-temperature sensor with certain corrections (see section 5).

FOT were dominated by driving in above-freezing temperature conditions while the latter three months were dominated by driving in freezing conditions. Although it can not be observed directly from this graph, it is noted that approximately 22 percent of travel by distance took place in below-freezing conditions.

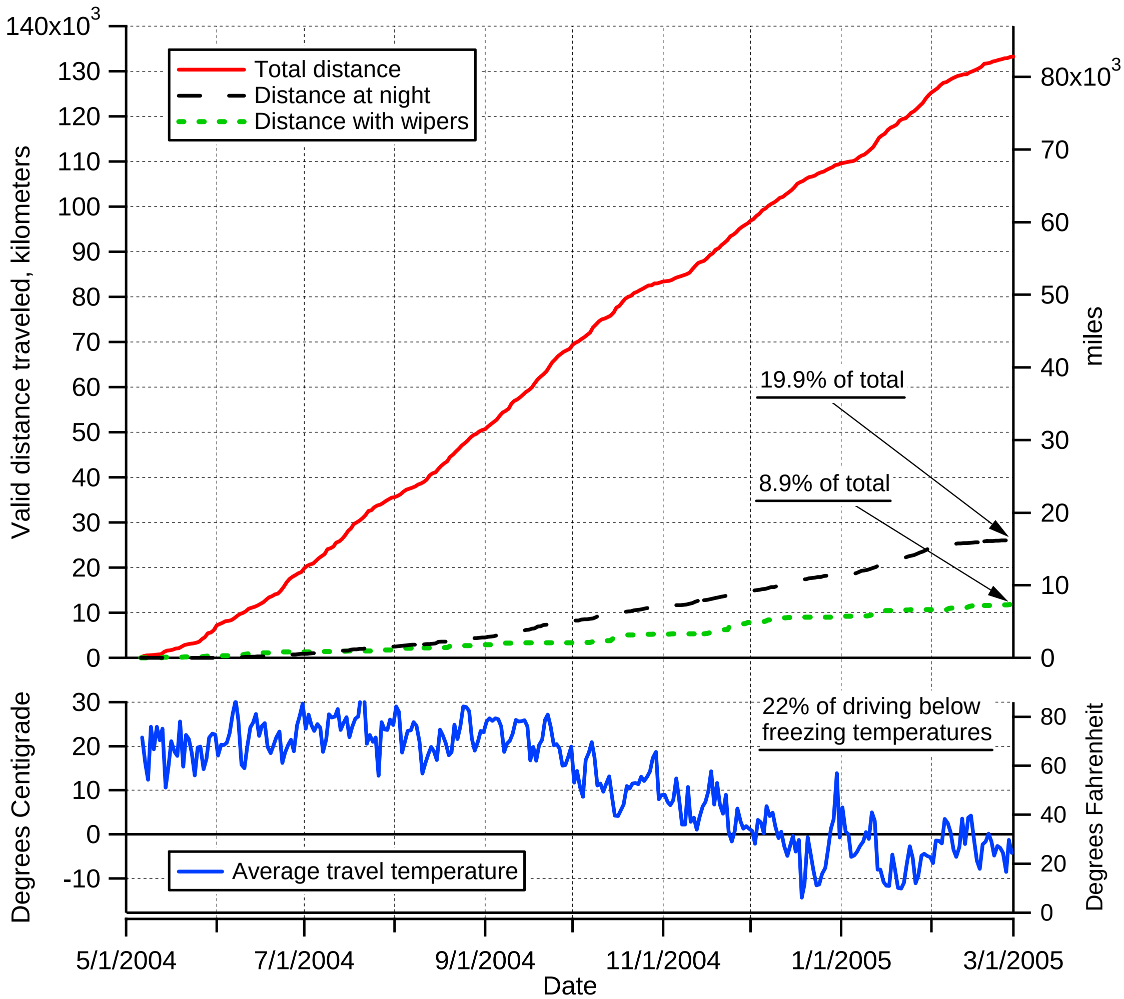


Figure 6.2 The chronology of the accumulation of travel distance and of temperature conditions

Finally, this figure shows that about 20 percent of travel (by distance) occurred at night[2] and about 9 percent was with wipers on (an approximate surrogate for wet-road conditions). Of course, travel at night accumulated more quickly through the winter months: about 50 percent of nighttime travel took place in the first 6 months

[2] The divisions between day and night used herein are based on the conventional definition of civil twilight, i.e., the moment at which the solar zenith angle is 96 degrees (6 degrees below the nominal horizon). GPS position and time were used as the basis for calculating solar zenith angle for each individual vehicle.

and the other 50 percent in the last 4 months. The months of October and November, 2004, had the most rapid accumulation of distance with wipers on.

6.1.4 Locale, routes and map systems

Figure 6.3 shows the geographical location of travel during the FOT and also the distribution of travel according to the CSW-mapping areas. On the left, the map of travel routes shows that most travel was in the lower peninsula of Michigan with just a few forays east to the Cleveland, Ohio area, west into the Chicago, Illinois area and south through Indianapolis to Seymour, Indiana.

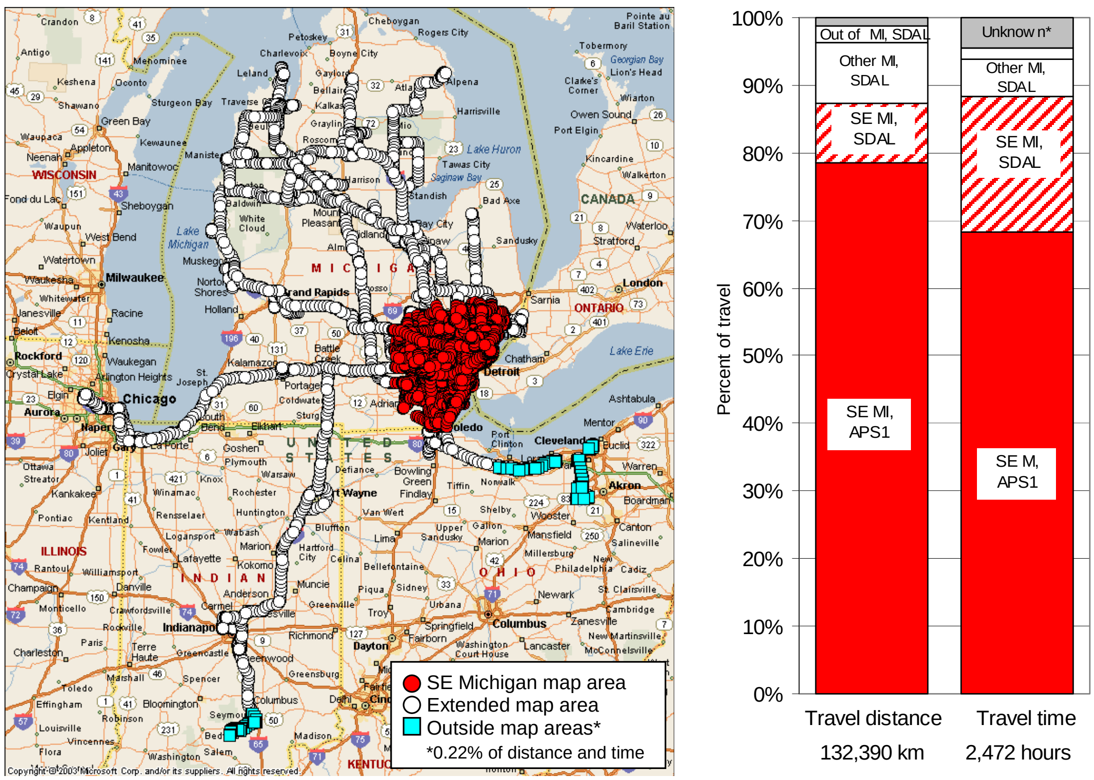


Figure 6.3 FOT travel by route and by CSW-mapping areas

The map also indicates the CSW-mapping areas: (1) In red circles, the seven southeastern counties of Michigan are the area where the APS1 map was available for CSW. As described in section 3.5, this map is the most recent released by NAVTEQ and is more accurate and contains more attributes than the previous NAVTEQ map (the so-called SDAL map). The APS1 map was only available in the seven southeast Michigan counties at the time of the FOT launch, and was available for all but the *local* classification of roads in these counties. (2) In white circles, the SDAL map of the CSW covered most of the rest of FOT travel (including travel on local roads in the seven counties, not visible on the map). (3) In blue squares, a small amount of travel to the extreme east and extreme south fell outside the areas of both of the CSW maps.

On the right in figure 6.3, the column graph shows the distribution of FOT travel (by distance on the left and time on the right) according to location and CSW map type. Some 87 to 88 percent of FOT travel was in the seven counties of southeast Michigan (SE MI), the majority of that using the APS1 map (roads other than *local* roads). Most of the remaining travel was on the SDAL map (both inside and outside of Michigan). A few percent of travel distance and time is shown as *unknown*, which includes travel outside the map areas, but is dominated by travel within the map areas but on unmapped "roads," i.e., parking lots, private roads, newly constructed (and as yet unmapped) roads, etc.

6.2 Driving environment and driving behavior

Numerous items regarding driving environment and driver behavior are important to characterizing the exposure of the RDCW system during the FOT. Several will be addressed in this section.

6.2.1 Travel by type of road

Figure 6.3 revealed that most of the FOT driving took place in southeast Michigan. Since this is a heavily urbanized area, it is not surprising then, that most FOT driving took place in an urban environment. Figure 6.4 shows the distribution of FOT travel by rural and urban roads.[3] (The HPMS data on which this figure is based was queried only for Michigan. Thus, all travel outside Michigan is designated as unknown.) By either time or distance, about 80 percent of FOT travel was in an urban setting.

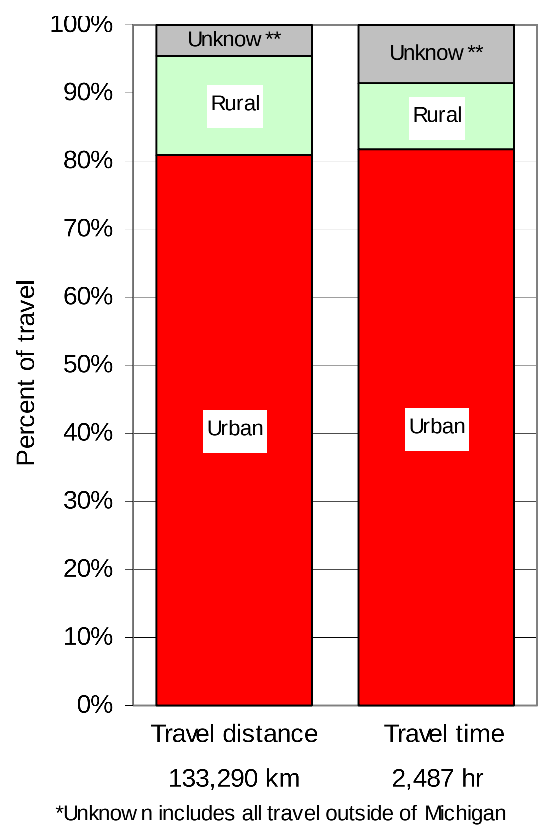


Figure 6.4. Distribution of travel by rural and urban environments

[3] The distinction between rural and urban environments was made by superimposing the vehicle's GPS position onto the Michigan database from the FHWA's Highway Performance Monitoring System (HPMS). Avoiding elaborate explanations, "urban" locations correlate well with the locations of the yellow or orange markings traditionally used to designate urban areas on hard-copy road maps.

Figure 6.5 shows the distribution of FOT travel by *road type*. (See section 5.1.5 for a description of the UMTRI *road-type* categories.) The figure shows that the fleet covered about 40 percent of its distance on freeways, but spent only about 20 percent of its travel time on freeways. Of course, only a small portion of distance and time was spent on ramps, and the remainder of fleet travel was fairly evenly split among the three types of surface roads. A small, but appreciable fraction of travel was on *unknown* roads, which are predominately parking lots and other private, unmapped roads. Another small portion of this category is travel during which the location of the vehicle can not be established, e.g., during system boot or other times when GPS data are not available.

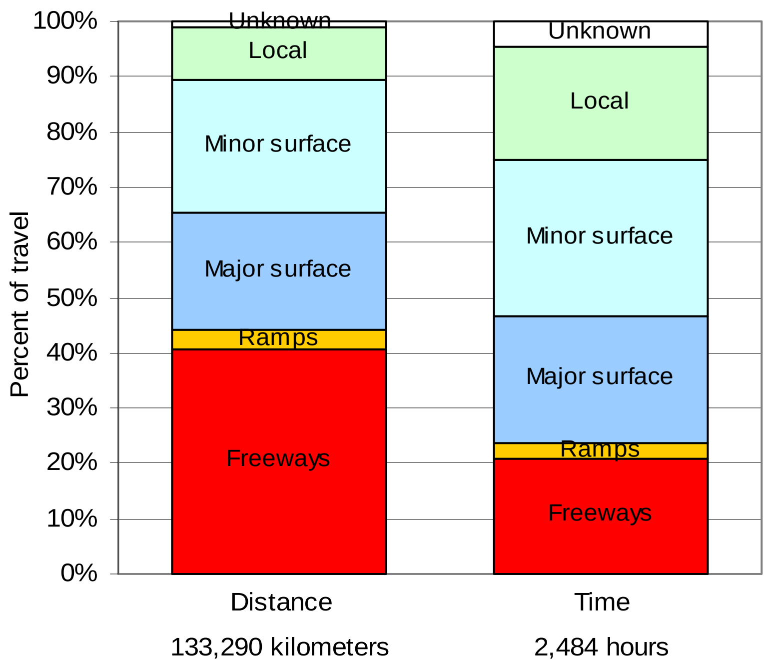


Figure 6.5 Distributions of travel distance and travel time by road type

6.2.2 Travel by speed

Hand in hand with exposure by road type is the matter of exposure by speed. Figure 6.6 presents the distribution of travel time (while moving) by speed for the six road types and also for the combination of all types. The figure shows just what could be expected:

- Freeway travel was primarily in the range of 70 to 75 mph (110 to 125 kph).
- The distribution of speed on ramps was relatively flat, ranging from freeway speed to very slow speeds.

- Speeds on both major and minor surface roads tended to center in the range of 40 to 45 mph (or 60-to-70 kph).
- Travel on local roads tended to be below 30 mph (50 kph).
- Travel on “unknown” roads (mostly parking lots) was typically at very slow speed.

Across all roads, the distribution of speed shows three peaks, the highest being in the 40 to 45 mph (60-to-70 kph) range (from major and minor surface roads) and the two lower peaks at freeway speeds and at very slow speeds.

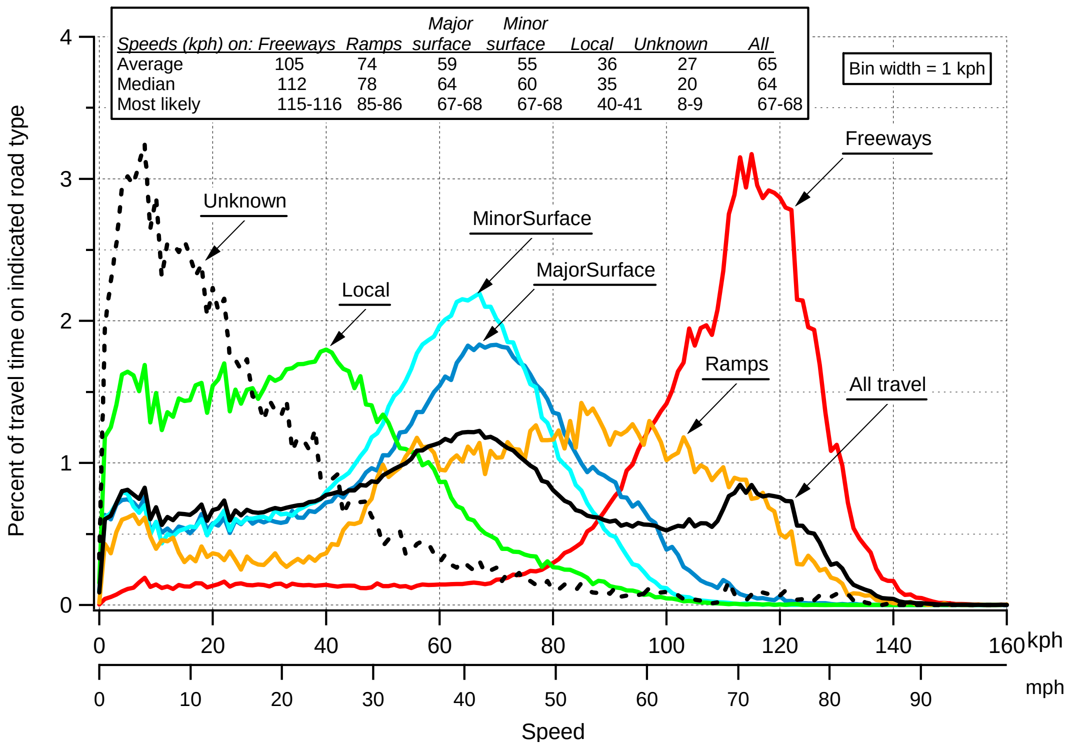


Figure 6.6. Distribution of speed while moving by road type

Figure 6.6 is only for travel time *while the vehicle was moving*. Figure 6.7 on the next page provides the complimentary information: the portion of travel time with the vehicle moving by road type.

As could be expected, the portion of travel time spent moving is nearly 100 percent on freeways but steadily declines with the progression toward the more minor types of roads. Over all, the RDCW FOT fleet was in motion about 81 percent of the time the vehicles’ ignitions were on *during valid trips* (or more precisely, 81 percent of the time the DAS systems were active during valid trips). Note, however, that valid trips exclude trips of zero distance. Therefore, time in motion was actually something less than 81 percent of the time the vehicles were in use.

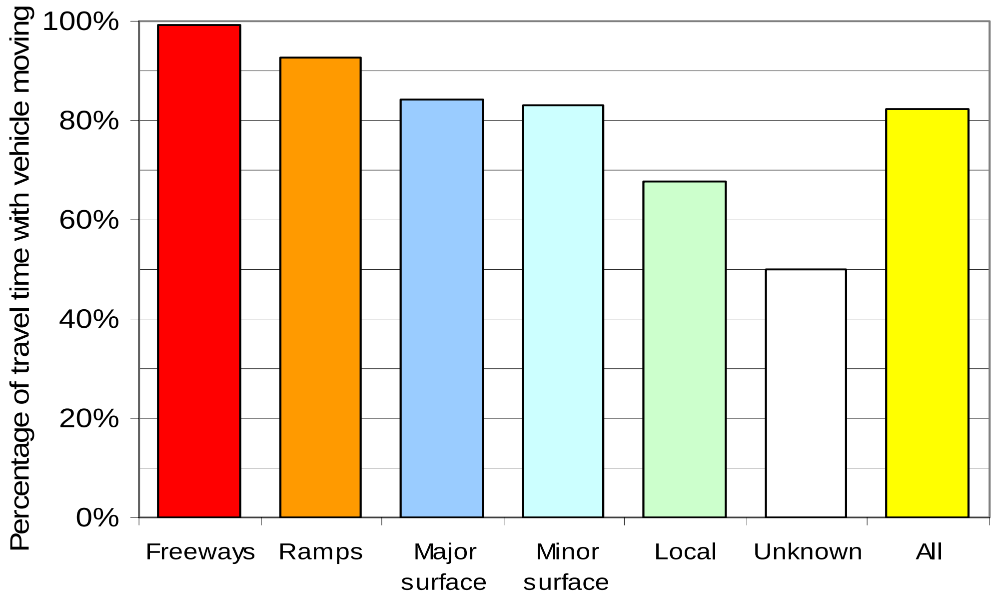


Figure 6.7. Percentage of travel time with vehicle moving (> 0.3 m/s = 0.7 mph) by road type

Both the CSW and LDW systems have features that disable their warning functions below a threshold speed. For CSW, the threshold speed is 18 mph (29 kph). For LDW, the threshold is 25 mph (40 kph).

Figure 6.8 shows that the RDCW FOT fleet traveled at speeds above 25 mph (i.e., above both systems thresholds) for 92 percent of distance traveled and 60 percent of travel time, and above 18 mph (the CSW threshold) for 96 percent of distance traveled and 67 percent of travel time.

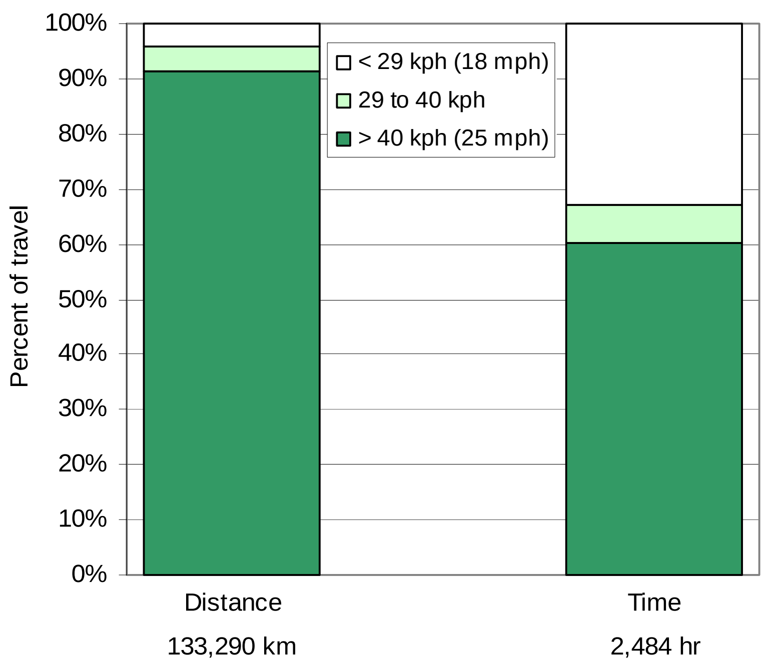


Figure 6.8 Time and distance travel relative to LDW and CSW threshold speeds

6.2.3 Repetition of driving routes

Some of the drivers of the RDCW FOT were highly repetitive in terms of the routes they drove. Presumably, these people did much or most of their driving in their daily "commute," as defined by their daily routine. Other drivers were not characterized by highly repetitive routes. Perhaps much of their driving was on a few long trips, or, for example, they might have been traveling sales people who did not have many repeat trips to the same customers in their four-week period with an FOT vehicle.

Regardless, of why it happened, repetitive or non-repetitive driving is of interest with respect to drivers' experiences with the CSW system in as much as those reactions could be expected to be dependent on how familiar the driver is with the road being traveled. This is examined in some detail in section 7.4.4.

To assess this repetitive quality, all roads traveled during the FOT were broken down into roughly 100-meter segments. Each driver's travel was then characterized according to the distribution of travel distance by the number of traversals of individual road segments. Figure 6.9 presents this distribution of FOT travel distance by the number of traversals (traversals being counted on a per driver basis) of the road segment.

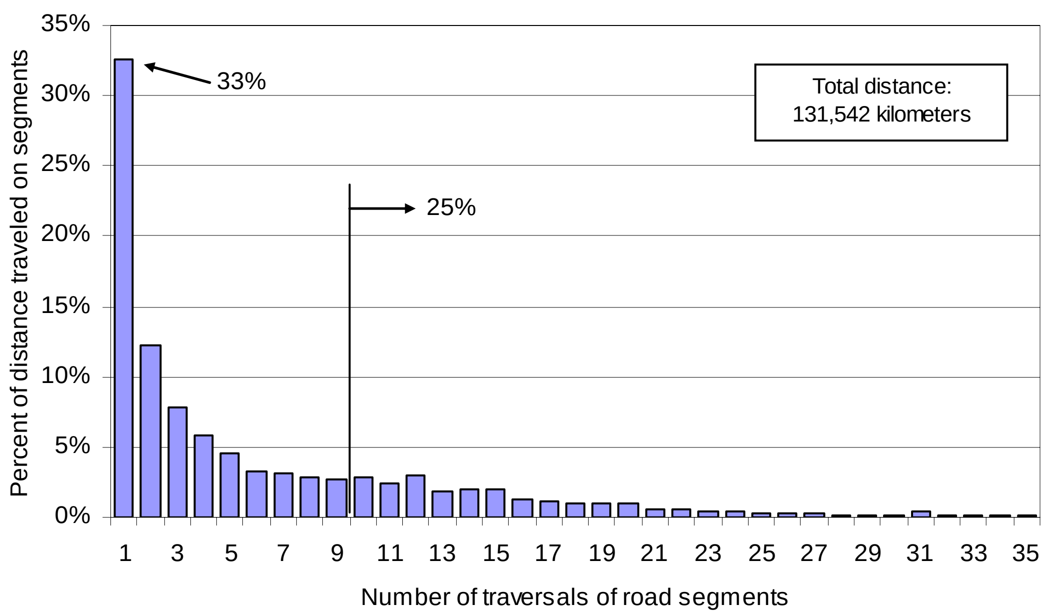


Figure 6.9 Distribution of travel distance by number of traversals: average for the FOT fleet

Starting at the far left, the first bar of the graph shows that a third of the FOT travel distance was accumulated on road segments that individual FOT drivers traversed only one time. Moving to the next bar, about 12 percent of the distance traveled was on segments that were traversed by individual drivers twice. And so forth, and so forth. In summary, 31 percent of travel was on segments traversed (by individuals) between 2 and 5 times, 12 percent on segments traversed (by individuals) between 6 and 9 times, and 25 percent of travel was on segments traversed (by individuals) more than 10 times. The distribution shown in figure 6.9 is for all valid FOT travel. In section 6.3.3, it will be shown that this distribution varies greatly among individual drivers.

6.2.4 Ambient lighting

Figure 6.2 (in section 6.1.3) indicated that 80.1 percent of FOT travel by distance occurred in daylight and 19.9 percent after dark. Since travel speed is not particularly biased by day/night influence, the split in travel time was similar: 80.6 to 19.4.

The importance of the quality of ambient lighting, however, extends beyond this simple binary characterization. The ability of the LDW system to identify lane markings can be influenced by the quality of ambient lighting. One important factor can be the position of the sun relative to the view of the LDW camera.

Figures 6.10 and 6.11 show the distribution of FOT travel time as functions of elevation of the sun above the horizon (solar elevation angle) and the magnitude (absolute value) of the car-to-sun azimuth angle, respectively. Both figures are only for travel when solar elevation > 0 degrees (1815 hours or 73 percent of travel time).

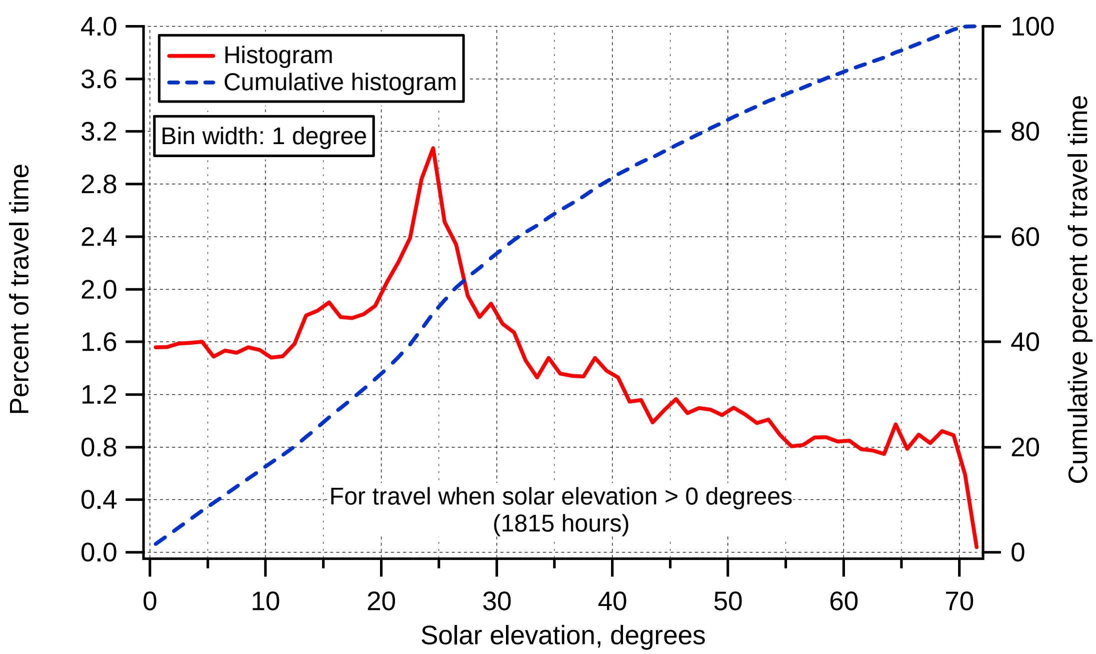


Figure 6.10 Histogram and cumulative histogram of FOT travel time by solar elevation angle

Figure 6.10 presents both a histogram and a cumulative histogram of driving time by solar elevation. The histogram clearly shows a bias for driving while solar elevation was in the 12 to 32 degree range. The cumulative histogram shows that about 40 percent of (the 1815 hours of) driving took place with solar elevation in this 20-degree range of 12 to 32 degrees; about 20 percent took place with solar elevation less than 12 degrees; and the remaining 40 percent took place with solar elevation in the range of 32 to 72 degrees.[4] Figure 6.11 shows that driving was rather evenly distributed with respect to car-to-sun azimuth with a modest bias for driving away from the sun (i.e., magnitude of the azimuth > 90 degrees).

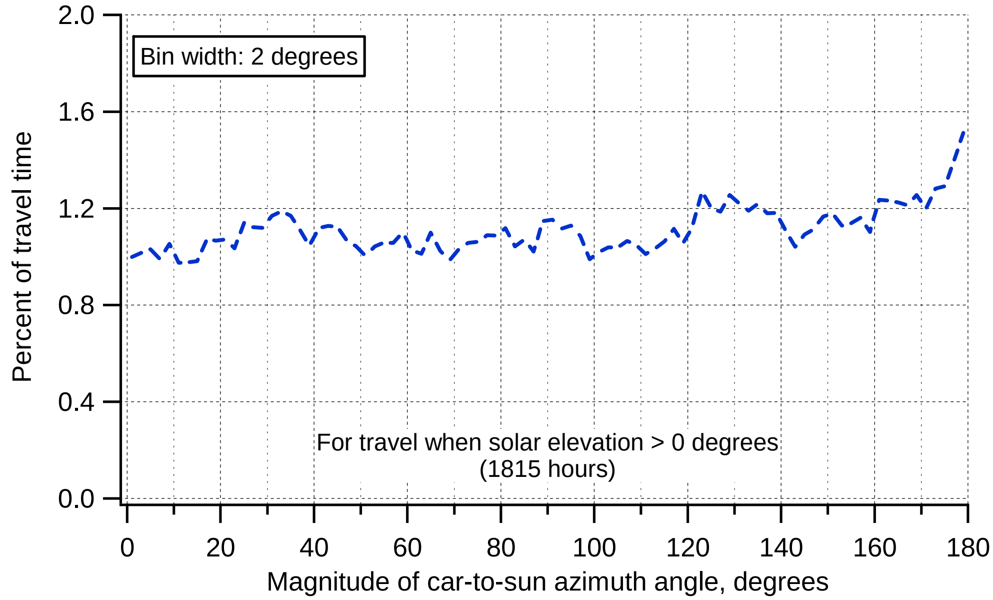


Figure 6.11 Histogram of FOT travel time by car-to-sun azimuth angle

The data of figures 6.10 and 6.11 are combined in the 2-dimensional histogram of figure 6.12 on the next page. This figure shows that, in general, there is little interplay between the two distributions. That is, within any given range of azimuth, the distribution by elevation is similar in form to that of figure 6.10.

[4] At the summer solstice, solar elevation reaches a noon-time maximum of about 70.5 degrees at the northern edge of the APS1 map and nearly 72 degrees at the southern edge this map (see figure 6.3).

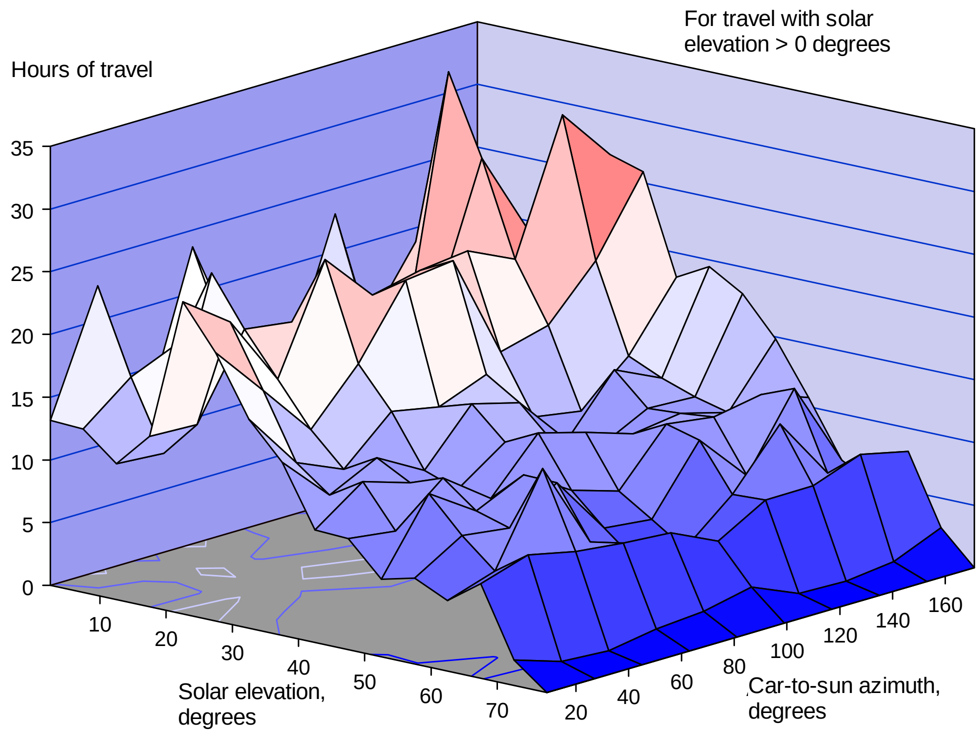


Figure 6.12 Two-dimensional histogram of travel time by solar elevation and azimuth angles

6.3 The range of exposure properties among the individual drivers

The previous sections have considered exposure qualities in terms of totals or averages across the entire test fleet. But, of course, none of the 78 individual drivers of the FOT were *average*. Indeed, the range of driving behavior across these 78 individuals was large and, in particular, it was large relative to the influence that could be expected due to other driving-environment factors , *including* the introduction of a driver-assist system such as the RDCW system. This section describes the variation of selected travel characteristics across drivers.

6.3.1 Travel distance, travel time and number of trips

Figure 6.13 presents the distributions of total travel distance, travel time and the number of trips for the 78 individual drivers. Table 6.2 that follows, provides summary statistics for these distributions.

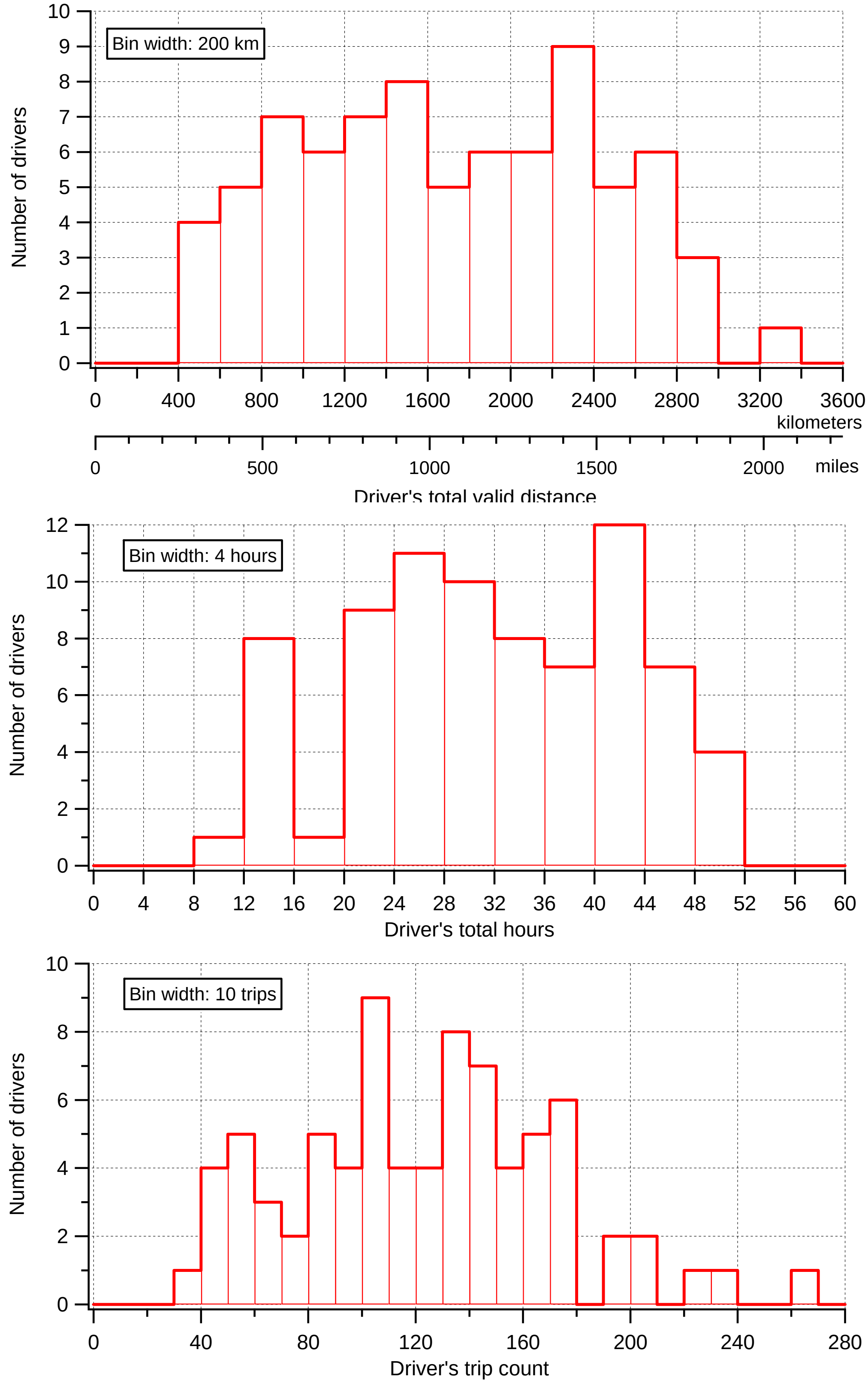


Figure 6.13 Distributions of travel distance, time and number of trips by driver

Table 6.2 Statistics for individual driver's travel distance, time, and trips

	Total distance, kilometers (miles)	*Total time, hours*	*Number of trips*
Average	1709 (1062)	31.9	123
Median	1665 (1035)	31.7	127
Maximum	3307 (2055)	51.1	266
Minimum	455 (283)	9.5	36

On average, a single driver traveled 1062 mi (1709 km) in 31.9 hours and 123 trips. But four drivers traveled less than 373 mi—one as little as 283 mi —while another driver traveled 2,055 mi (a ratio of 7.2:1 from maximum to minimum). Similarly, the maximum and minimum for travel times were 51.1 and 9.5 hours, respectively (5.5:1), and for the number of trips: 266 and 36 (7.4:1). Moreover, these six extreme measures involved four different individuals. (One individual accounted for the maximum distance and time, another for the minimum time and minimum number of trips. Two others accounted for the maximum number of trips and the minimum distance, respectively.)

6.3.2 Travel by road type

Averaged across the fleet, 37 percent of the distance traveled was on freeways. However, figure 6.14 shows that this measure ranged very broadly across drivers.

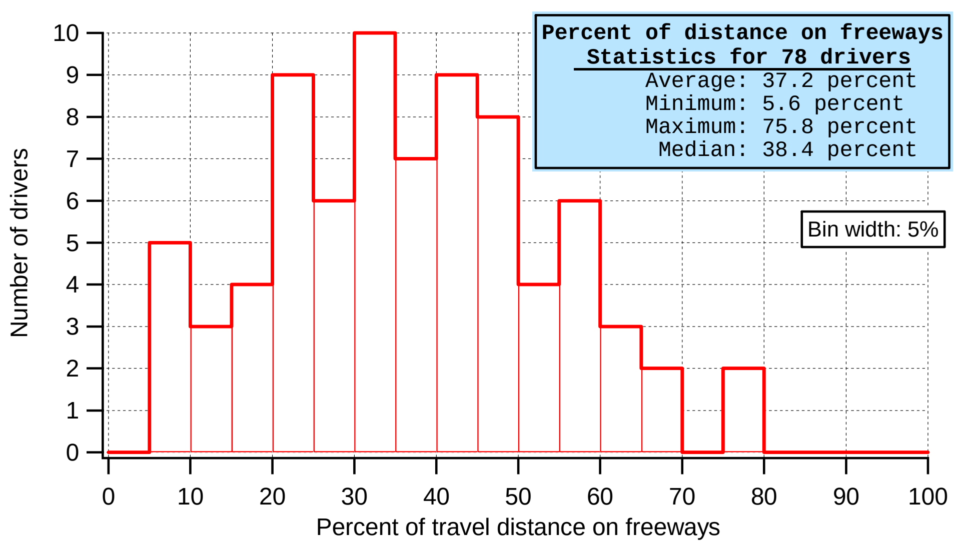
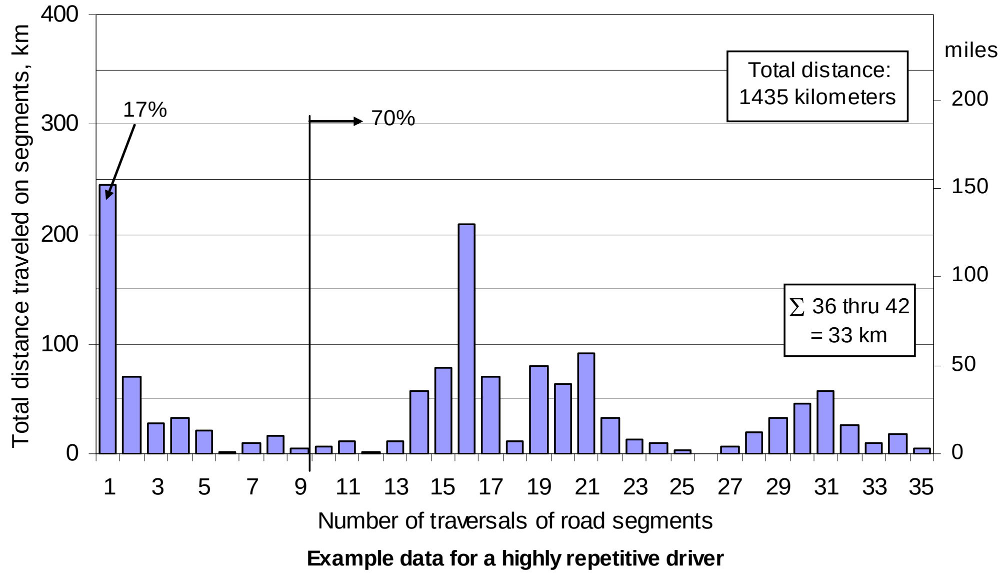


Figure 6.14 Distribution of the percentage of travel distance on freeways for individual drivers

For five individuals, less than 10 percent of their travel (by distance) was on freeways while for two other individuals, more than 75 percent of their travel was on freeways. Since driving styles and the driving environment are typically so different on freeways than on surface roads, this difference across drivers could substantially influence an individual's use of, and reaction to, RDCW.

6.3.3 Repetition of driving routes

Figure 6.9 (section 6.2.3) presented the overall distribution of distance traveled by number of traversals of the road segment. But like others, this property varied widely among drivers. Figure 6.15 compares this distribution for a highly repetitive driver with the distribution for a very non-repetitive driver.



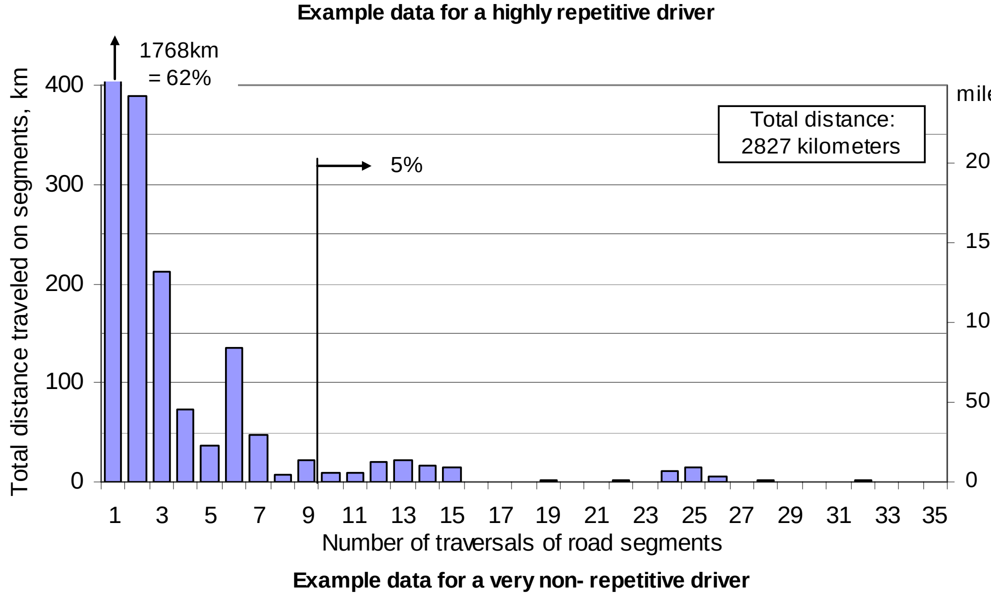


Figure 6.15 Example data for one highly repetitive driver and one very non repetitive driver[5]

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[5] A relatively high concentration of travel in the range of roughly 12 to 18 repetitions (strongly apparent in the top graph and weakly so in the lower graph) is characteristic of many drivers. It is likely that this

The repetitive driver accumulated only 17 percent of his distance on single-pass road segments but the non-repetitive driver accumulated 67 percent of his distance in single passes. Conversely, the repetitive and non-repetitive drivers, respectively, accumulated 70 percent and 5 percent of their total distance on segments that they traversed 10 or more times. Figure 6.16 presents the distributions of these two measures (percent of distance on single-traversal segments and percent of distance on more-than-10-traversal segments) for the 78 drivers. By each of the respective measures, 5 or 6 drivers stand out as highly repetitive or very non-repetitive.

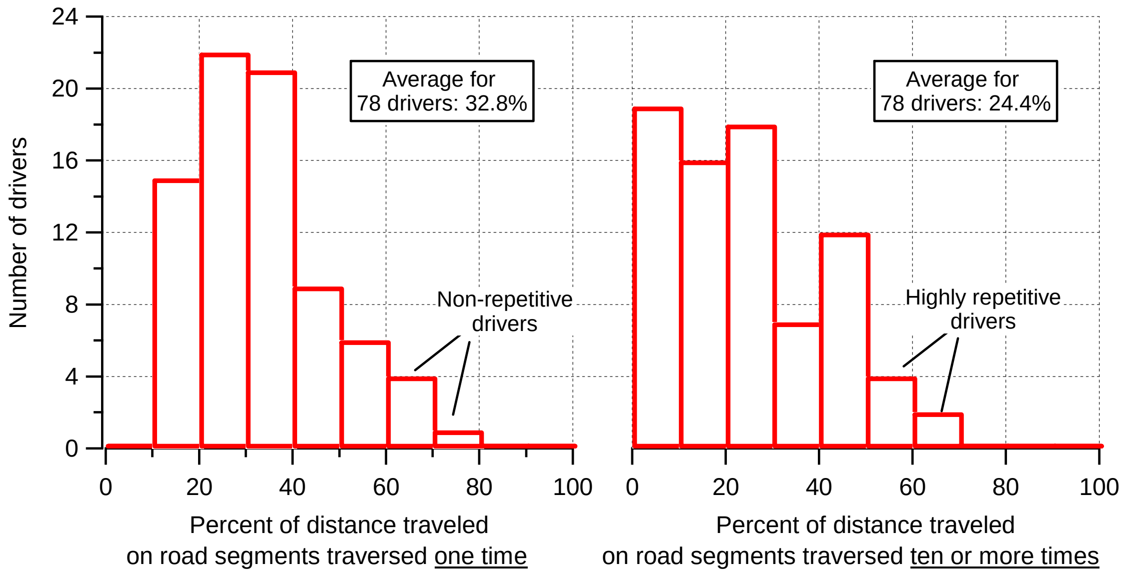

Figure 6.16 Distributions of repetitive driving measures across drivers

6.3.4 Daytime/nighttime driving

Figure 6.2 (section 6.1.3) indicated that about 80 percent of the total FOT distance was traveled during the day and 20 percent at night. Figure 6.17, however, that the distribution of this characteristic among individuals was quite skewed in as much as 5 of the FOT drivers did less than 50 percent of their driving (by distance) during the day.

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is related to the fact that drivers typically had the RDCW car for a bit less than 4 weeks total and typically 18 weekdays. Given a repeated work-day travel pattern, and perhaps a day or two of taking a different route, this is not a surprising result. Also, what might be called "the second harmonic" of this phenomenon that is apparent at double the number of repetitions is not unusual.

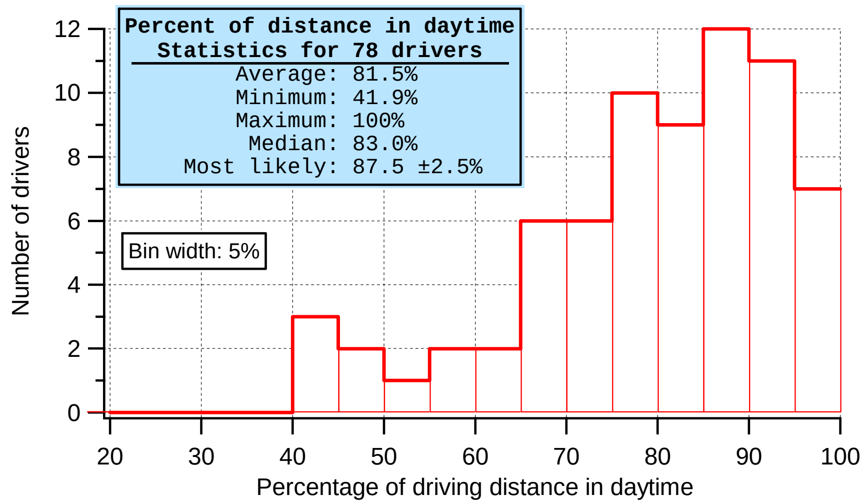


Figure 6.17 Histogram of the percentage of travel distance in daytime

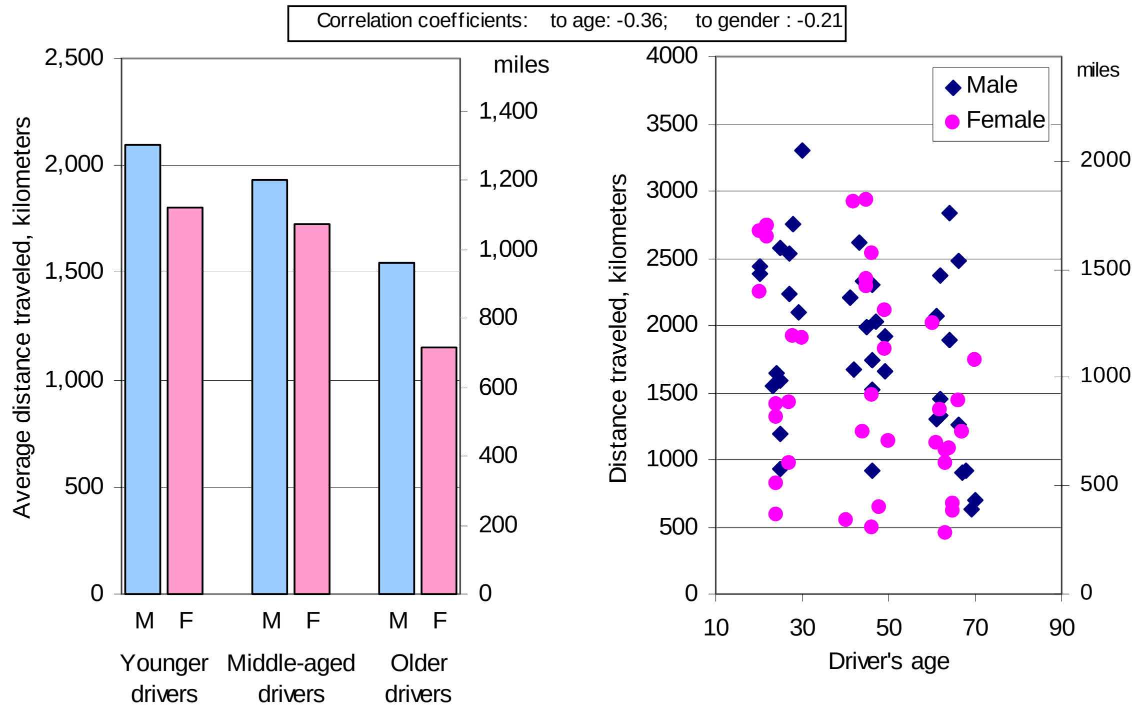
6.3.5 Age and gender influences

Several of the exposure measures discussed in this section were tested for correlations with age or gender of the drivers. Table 6.3 indicates that weak, but appreciable, correlations exist: both age and gender correlated to total distance travel by the driver; age correlated to the percent of that travel on freeways and to the percent of travel on single-pass road segments.

Table 6.3 Correlation coefficients for age and gender with exposure measures

	Total distance	*% freeways*	*% single-pass*
Age	**-0.36**	**-0.23**	**0.38**
Gender	**-0.21**	-0.02	-0.03

Figure 6.18 on the next page uses the correlations of age and gender with total distance as examples to provide insight into these statistics.



a. Average distance traveled by group **b. Distance traveled by individuals**

Figure 6.18 Distance traveled as functions of age and gender

The bar graph on the left of this figure presents the average of the distances traveled by individuals grouped by gender and age group. The relationships are clear: distance traveled tends to be greater for males (M) than for females (F) and also tends to decline as the age of the group increases. The scatter graph on the right is a similar presentation, but it presents distance traveled for each individual plotted against age with gender distinguished by the data-point symbol. Looking closely, the same trends are discernable: the "cloud" of data points tends to descend (less distance) as age increases; and the pink circles (female) generally tend to lie lower (less distance) than the blue diamonds (male). In clear contrast, however, it is apparent the range of the individual measures is much larger than the trends of influence of age or gender.[6] That is to say, the performance of the individual dominates over the influence of age or gender.

[6] This was implied, of course, by the relatively low magnitude of the correlation coefficients: 0.36 and 0.21. Were the variance between the individual data points in each grouping to be smaller, then the magnitude of the correlation coefficients would be larger, approaching unity.

Figure 6.19 presents similar bar graphs showing the relationships of age and gender to the averages of the individual measures of percent of distance on freeways and percent of distance on single-pass segments. As implied by the values in table 6.3, the trends with age are apparent and the relationships with gender are mixed. Although not shown, the scatter among individual measures for these data are similar to that of figure 6.17.

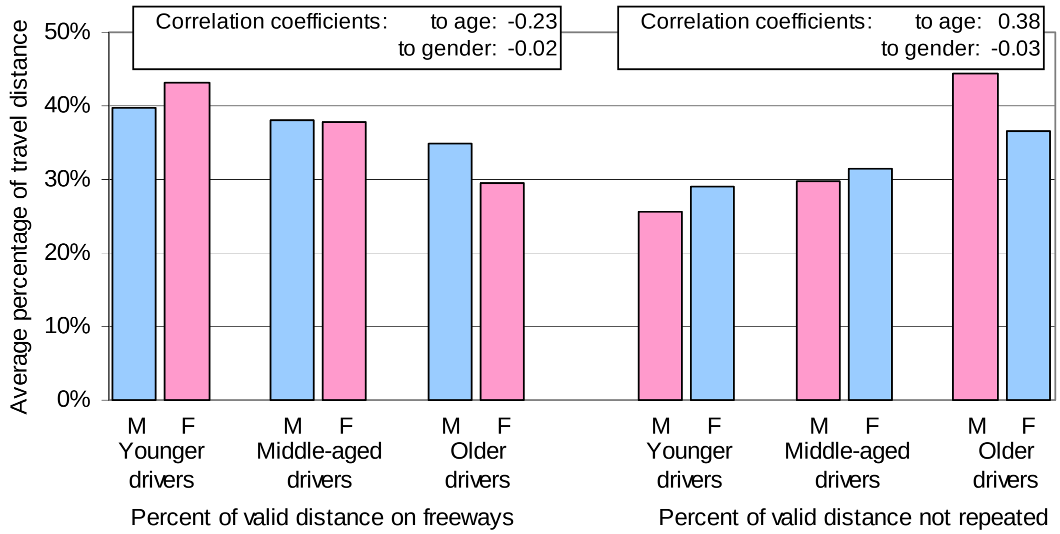


Figure 6.19 Average percentages of valid distance traveled (a) on freeways and (b) on non-repeated road segments, both by age group

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7 RDCW System Events

This section summarizes the performance of the RDCW system from the drivers' perspective. This includes presentation of data addressing the availability of the warning functionalities to provide alerts, as well as characterization of the alerts that drivers received. Therefore this section provides the foundation for analyses in sections 8 and 9 that study changes in driving performance and subjective responses to the events described in this section.

Section 7.1 addresses the availability of the systems and section 7.2 discusses the drivers' selections of sensitivity. Sections 7.3 and 7.4 address the frequency and characteristics of lateral drift warning and curve speed warning alerts, respectively. In general, this section focuses on alerts that the drivers actually received, i.e., those alerts that occurred while RDCW displays to the driver were enabled.

7.1 Availability of the RDCW systems

Availability of the lateral drift warning (LDW) and the curve speed warning (CSW) systems are important factors influencing the safety benefits and acceptance of these two systems and of road-departure warning in general. In the case of LDW, maintaining high availability may represent the greatest technical challenge to the system. For CSW, maintaining high availability was not a difficult challenge.

7.1.1 Introduction to LDW availability

Availability is an important issue —perhaps the most important issue— influencing the usefulness and acceptance of LDW.

Adequate identification of the lane edge by the LDW video system is a difficult task and is the primary impediment to LDW availability. Lane identification is influenced by a variety of factors beyond the control of the system. For example:

- *Quality of the lane markings*. Freshly painted, white lines are optimum. Yellow and older, worn lines provide less contrast and are more difficult to locate.
- *Continuity of markings*. Especially in the urban environment, markings can come and go quickly as the vehicle moves through intersections and as the number and function of traffic lanes change.
- *Obstruction of the camera's view*. At lower speeds and in higher densities of traffic, the LDW camera's view of lane markings can often be obstructed.

- *Surface contamination*. Snow cover can completely block out lane markings; water on the road can obscure lane markings especially at night and in the presence of street lights and other vehicle's headlights. Residue from road salt can sharply reduce the contrast between painted lines and the road surface.
- *Ambient lighting conditions*. The quality of ambient lighting influences the LDW system's ability to identify lane markings. For example, driving in and out of shadows or driving directly into the sun can have very adverse affects on the camera's ability to "see" lane markings.

While lane-edge identification is the primary challenge, other secondary conditions must be met in order for the LDW to be available to the driver: (1) the vehicle must be traveling at a speed of 40 kph (25 mph) or faster; (2) if either the turn signal or the brake is in use or has been in use during the preceding 5 seconds, LDW availability is suppressed; and (3) LDW is generally suppressed when the vehicle is known (via real-time map matching) to be operating on roads of functional class 5 (local roads).

When all necessary conditions have been met, availability of LDW to provide lateral-drift warnings is indicated to the driver by a pair of green/gray, half-circle icons on the RDCW display (as discussed in section 3.3). Availability of LDW is determined on a per-side basis. For example, if the system believes it has identified the lane edge to the left of the vehicle, and other necessary conditions are met, LDW may be available for left-side warnings and this state would be indicated to the driver by green illumination of the left-hand icon. This would be so regardless of system's understanding of the lane edge to the right.

In accordance with the above, this section will report on availability of LDW only for travel above 25 mph and will distinguish between availability on the left side, on the right side, and on both sides simultaneously. Moreover, we will report both full availability, as indicated by the green/gray icons, and the additional *potential* availability when lane identification was established but the system was suppressed by the driver's use of turn signals or brakes. Sensitivities of LDW availability to a variety of operating conditions and variables will be examined.

7.1.2 Overall availability of LDW and availability among individuals

Figure 7.1 shows the percentage of time the various LDW functions were available for all travel above 40 kph (25 mph) during the valid trips of the FOT. The LDW warning function to the left was available about 52 percent of the time, to the right about 51 percent of the time, and to the right and left simultaneously, about 47 percent of the time. LDW suppression due to turn-signal or brake use accounted for from 7 to 10 percent of the travel time.

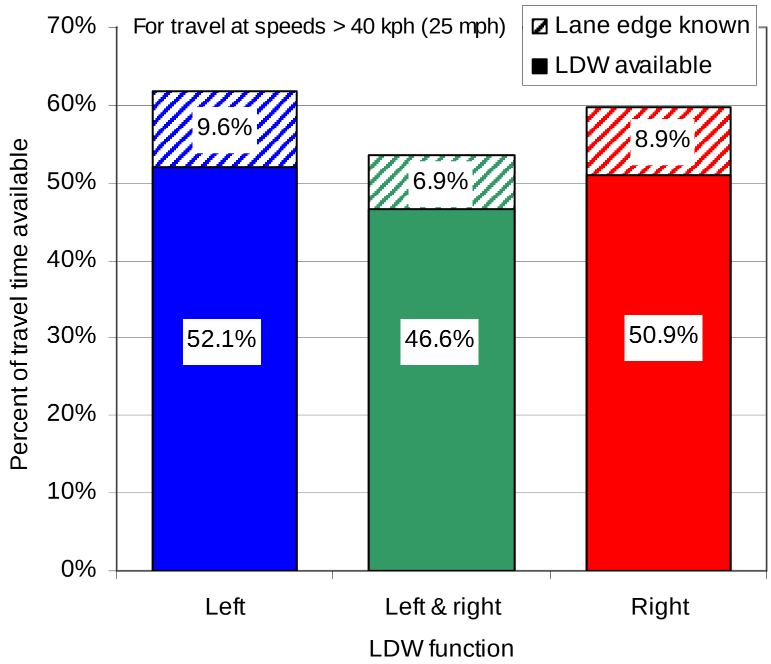

Figure 7.1 Availability of LDW during all valid trips

The availabilities shown in figure 7.1 are for the average performance across the entire fleet. However, the experience of individual drivers varied substantially from these fleet averages. As shown in the histograms of figure 7.2, numerous drivers had LDW functions available less than 30 percent of the time while LDW functions were available nearly 70 percent of the time for other drivers.

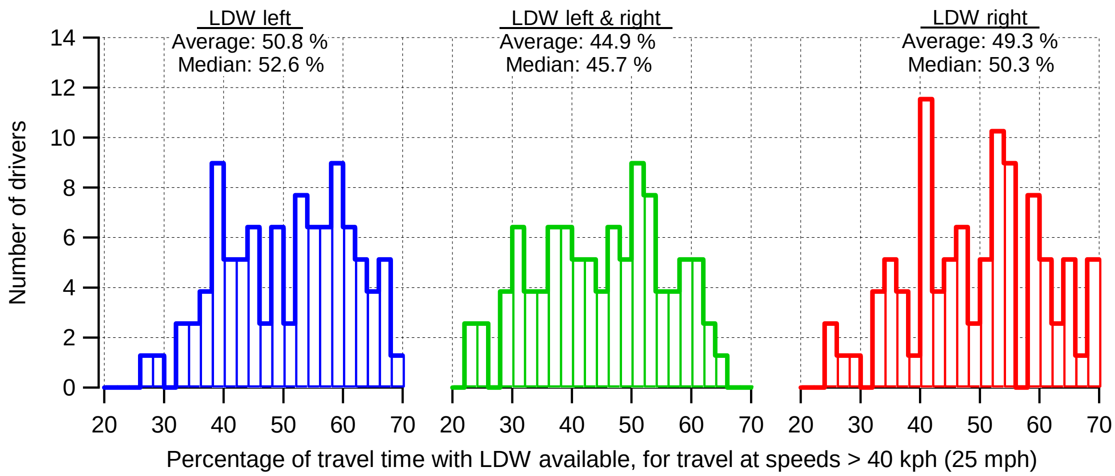

Figure 7.2 Histograms showing the distributions of LDW availability by driver

Across drivers, the average rates of LDW availability on the right side, left side, and with both sides available, were 49, 51, and 45 percent, respectively. The median rates across drivers were 50, 53, and 46 percent for the right side, left side, and with both sides available, respectively. Therefore, it can be said that LDW was available approximately half the time that the vehicle was traveling over the minimum speed for that warning subsystem, 25 mph (40 kph).

Of course, the range of availabilities displayed in figure 7.2 is not attributable to the drivers themselves, but rather to the range of driving conditions under which they drove their LDW vehicles. Many of the more relevant conditions will be investigated in the following sections.

7.1.3 The influence of operating conditions on the availability of LDW

In section 7.1.1, numerous driving-environment factors that influence LDW availability were listed. Some of these factors can be examined rather directly, while the influence of others must be inferred. For example, it can be reasonably presumed that the quality and continuity of lane markings as well as the closeness of vehicles in the camera's view are all correlated to road type. And, as then expected, figure 7.3 shows that road type has a strong influence on the availability of LDW.

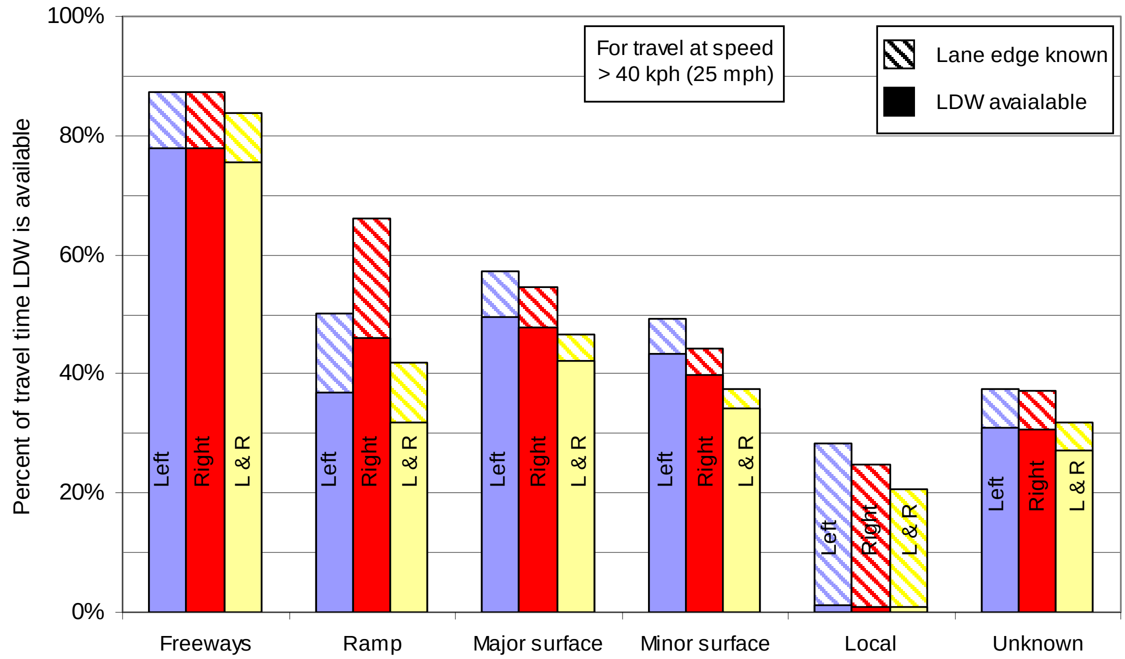

Figure 7.3 LDW availability by road type

This figure shows that on freeways, where lane markings are usually of good quality with relatively few discontinuities and where vehicles ahead are less likely to be very close, LDW functions are available more than 75 percent of the time. However, on any other type of road, availability of LDW never exceeds 50 percent.

Figure 7.4 shows LDW availability as observed in driving on rural versus urban roads. The figure shows that LDW was generally available some 10 to 15 percent more on rural roads than on urban roads. For example, LDW was available on both the left and right side 61 percent of travel time over 25 mph on rural roads, but only 46 percent of the time on urban roads.[1] This result is largely due to the fact that the availability of LDW is much greater on rural surface roads than on urban surface roads.

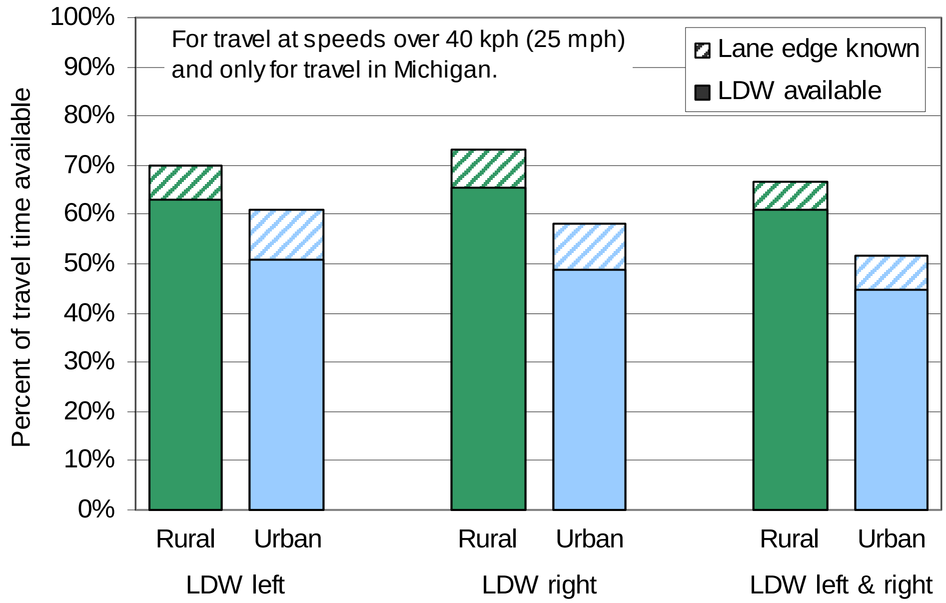

Figure 7.4 LDW availability for rural and urban driving

Figure 7.5 on the next page compares LDW availability on the two classes (major and minor) of rural and urban surface roads. The figure shows that on major, rural surface roads LDW is available simultaneously on both left and right sides 70 percent of travel time over 25 mph (an availability nearly as high as on freeways), but only 38 percent of the time on major urban surface roads. On minor surface roads, simultaneous left-right availability is 51 percent in rural environs and 32 percent in urban settings. Clearly, availability is a greater challenge in urban environments that it is in rural settings.

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[1] Note that, as shown in figure 6.4, about 80 percent of FOT driving was on urban roads. Consequently, he availabilities for urban roads shown in figure 7.4 are nearly the same as those shown for the entire FOT in figure 7.1.

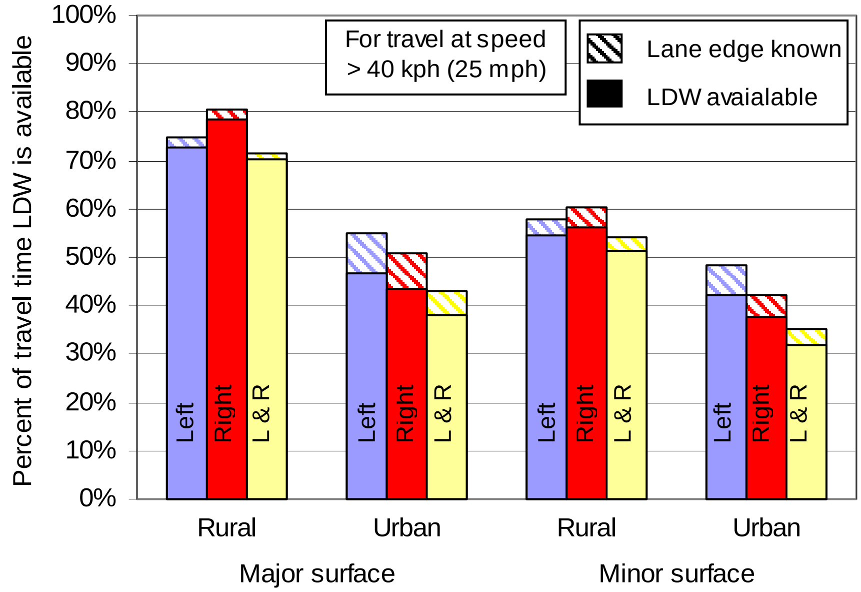

Figure 7.5 LDW availability on rural and urban surface roads

LDW availability changed substantially over the ten months of the field test, largely due to presence or absence of snow cover and road-salt residue on the roads of southeast Michigan. Figure 7.6 presents a chronological comparison of availability (both sides simultaneously) with outside temperatures. The upper graph shows weekly averages of availability while the lower graph shows daily averages of driving temperature.[2] The graph shows that just at the time when average daily temperature drops below freezing (about December 1, 2004) availability quickly drops off about 10 to 15 percent.

Figure 7.7 compares availability in the *warm season* to availability in the *cold season* using December 1, 2004 as the boundary between seasons. This figure shows an 11 to 12 percent drop in availability measures in the cold season relative to the warm season.

[2] Daily average driving temperatures are time-based averages of the temperatures as measured by the RDCW vehicles' outside-temperature sensors and derive from data from all the RDCW vehicles in use on the particular day.

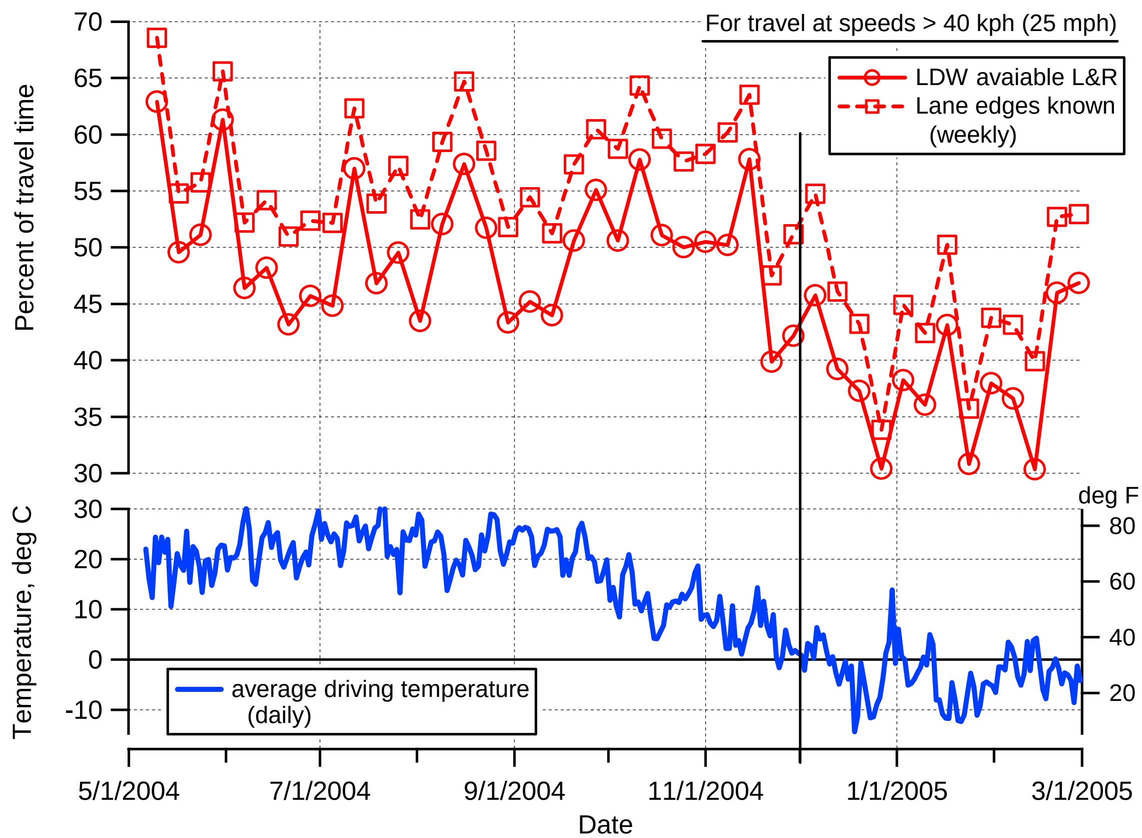

Figure 7.6 LDW availability (both side simultaneously) compared with outside temperature

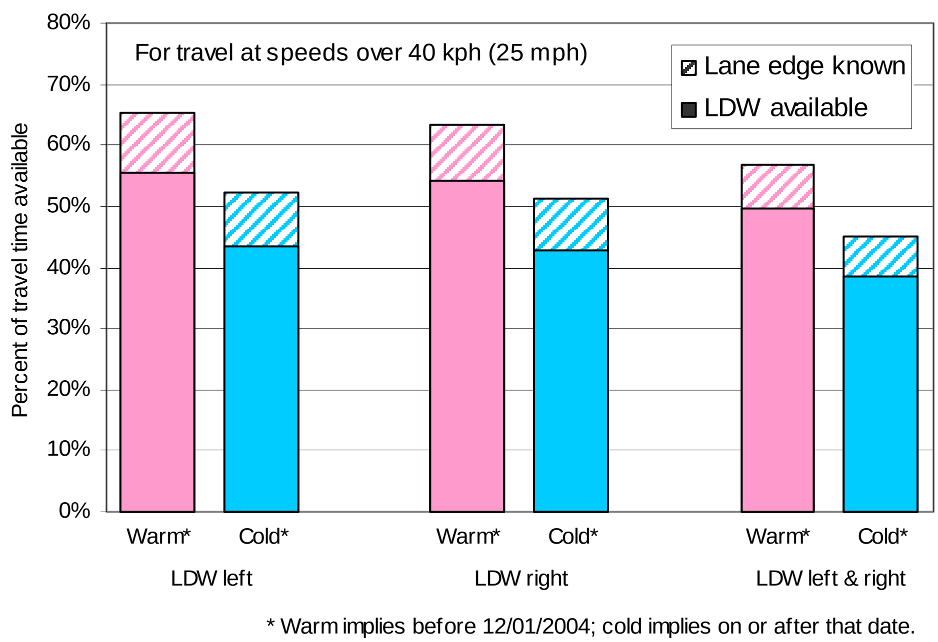

Figure 7.7 LDW availability by season

In as much as LDW determines lane edges by processing video images, it can be presumed that ambient lighting would influence LDW availability. Perhaps surprisingly, however, figure 7.8 shows that there was very little difference between LDW availability during daytime as compared with nighttime.[3] Indeed, availability was seen to be slightly better during nighttime, e.g., LDW was available on both sides during 48 percent of nighttime travel but just 46 percent of daytime travel. The very strong contrast between a dark, poorly lit background and highly reflective lane-marking paints may largely account for this.

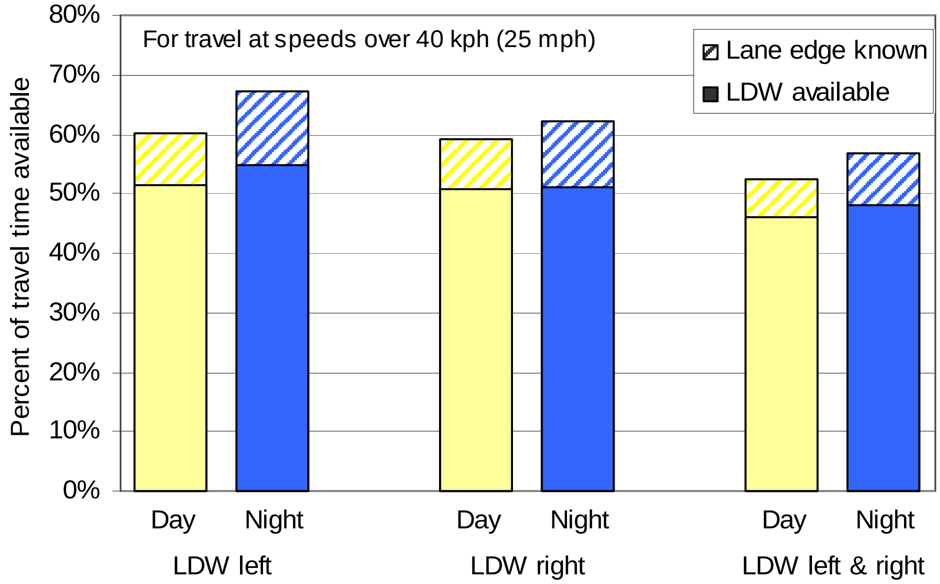

Figure 7.8 Comparison of LDW availability in daytime versus nighttime

Another factor could be the degrading influence of sun glare that occurs during some daytime driving. Figure 7.9 illustrates the problem LDW can have with sun glare.

Face-camera image

Forward-camera image

Figure 7.9 Simultaneous images from the cameras of an RDCW vehicle heading into the sun

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[3] The boundary between daytime and nighttime used in this analysis was standard civil twilight, i.e., when the solar zenith angle is 96 degrees (6 degrees below the horizon). Solar zenith angles were calculated using the position of the vehicle and time of day as determined by the on-board GPS.

The figure shows images from the face camera and the road camera taking simultaneously at 7:35 PM on May 30, 2004. The vehicle is headed nearly directly into a setting sun. The photo on the left clearly shows the difficulty the driver is having with the glare of the sun; similarly, the photo on the right shows the that the LDW camera has much the same problem.

Figure 7.10 presents LDW availability (left and right) as a function of two solar angles: (1) solar elevation or the angle of the sun above the horizon; and (2) the absolute value of the azimuth angle of the sun relative to the car. The figure is limited to times when (1) travel speed exceeds 40 kph (25 mph), (2) the solar elevation is between 0 and 45 degrees, (3) the car-to-sun azimuth angle lies between ± 45 degrees; and (4) to times prior to December 1, 2004 (and, hence, snow cover is not a substantial influence). Note that there is no filtering of data for cloud conditions or other sources of sun shading.

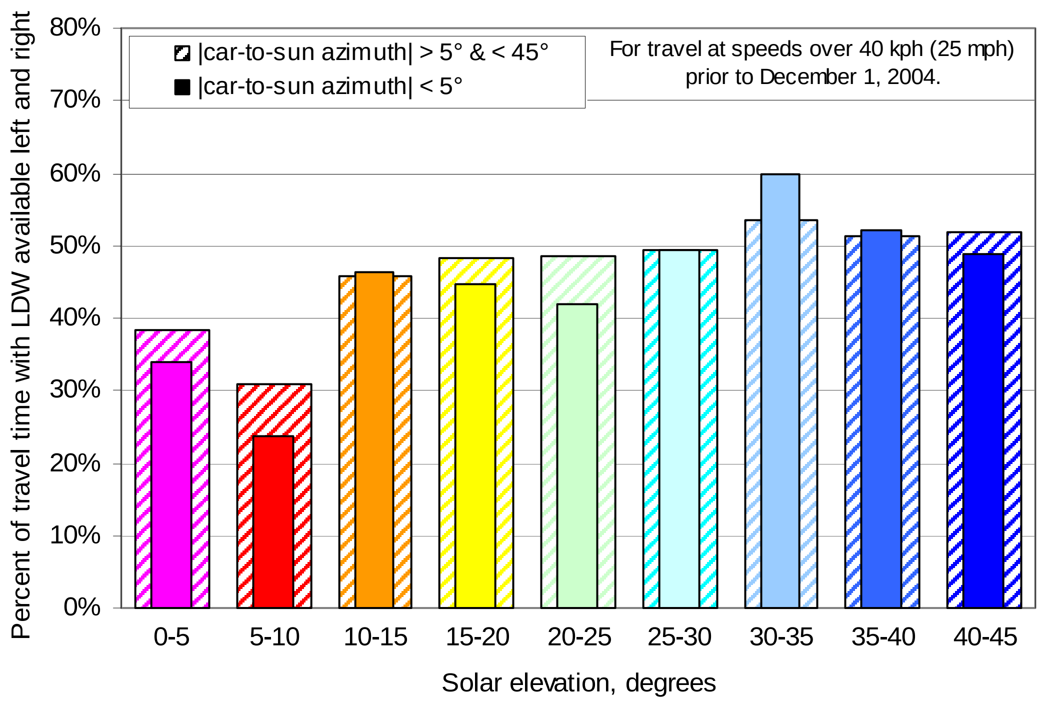

Figure 7.10 LDW availability (left and right) versus solar elevation angle

The data show that, when the vehicle is generally headed toward the sun (azimuth between ± 45 degrees), LDW availability drops sharply when solar elevation drops below 10 degrees and is especially affected when elevation is between 5 and 10 degrees. (Below 5 degrees, shading from buildings, trees and ground elevation may be reducing the problem.) This influence is amplified when car-to-sun azimuth angle is between ±5 degrees. With the combination of this azimuth condition and elevation between 5 and 10 degrees, availability drops to just 24 percent.

7.1.4 Introduction to CSW availability

Section 3.4 discussed how CSW warnings are based on the system alerting the driver that deceleration would be required in the near future in order to keep cornering acceleration below a threshold. To make such estimates, the system must (1) know the vehicle's latitude/longitude position with sufficient accuracy to (2) identify the road segment on which the vehicle is operating, (3) know the vehicles forward speed and (4) determine the geometry of the path of the vehicle in the near future. This in turn means that for warnings to be available the system must be receiving GPS and forward speed data of acceptable quality[4] and the vehicle must be operating on a road segment included, and located with adequate accuracy, within one or the other of the systems two map databases (APS1 and SDAL; see section 6.1.4). Additionally, the vehicle must be traveling at or above a speed of 18 mph (29 kph) as CSW is suppressed when traveling at slower speeds.

GPS reception and accuracy —and, hence, CSW availability— can be influenced by the weather as well as by surrounding buildings, tree cover, etc. The type of road can also have some influence in the sense that private roads, parking lots, and newly-constructed roads will not be identified within the map databases. Despite these factors, maintaining a high level of availability did not prove so great a challenge for the CSW system as it did for the LDW system, nor did CSW availability vary so substantially across the range of driving environments to which the systems were exposed during the FOT.

Like LDW, CSW availability is signaled to the driver via a green/gray circular icon (see section 3.4). In the following sections CSW availability is reported as the percentage of travel time at speeds above 29 kph (18 mph) during which the green icon was illuminated.

7.1.5 Overall availability of CSW and availability among individuals

Overall during the FOT, CSW was available 94.5 percent of the time during which the vehicle was traveling at or above 29 kph (18 mph). Moreover, CSW availability was relatively constant across drivers, ranging from a minimum of 86.3 percent to a

[4] In the case of GPS data, the system can bridge brief outages by projecting path using speed and yaw rate data.

maximum of 97.7 percent. Figure 7.11 presents a histogram of CSW availability for the RDCW drivers.

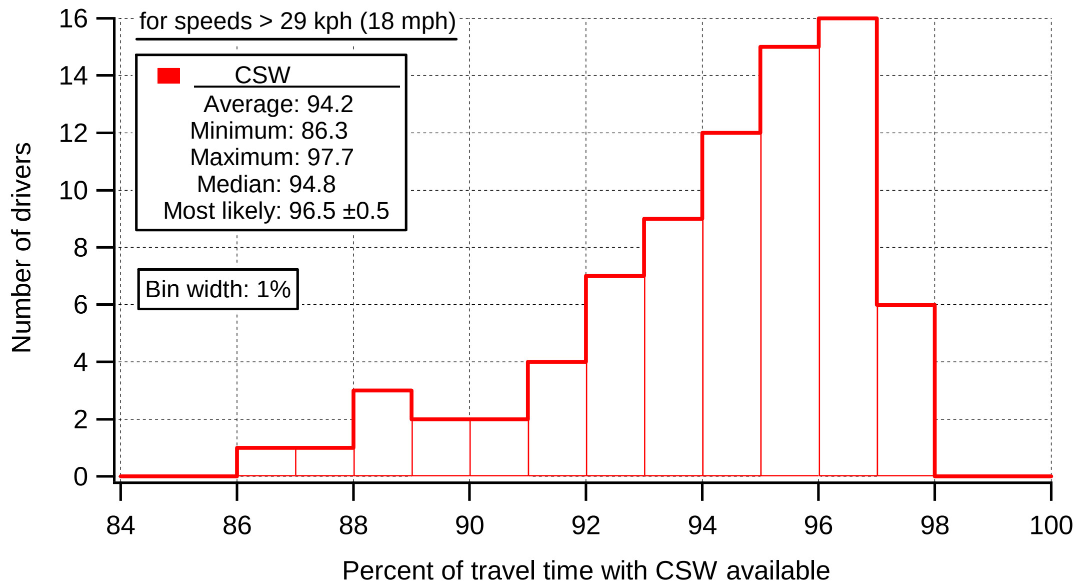

Figure 7.11 Distribution of CSW availability by driver

7.1.6 The influence of operating conditions on the availability of CSW

The availability of CSW was rather insensitive to operating conditions. Indeed, the only operating variable that appeared to have a substantial influence of the availability of CSW was road type. Figure 7.12 shows CSW availability by road type and the trend is as one might expect.

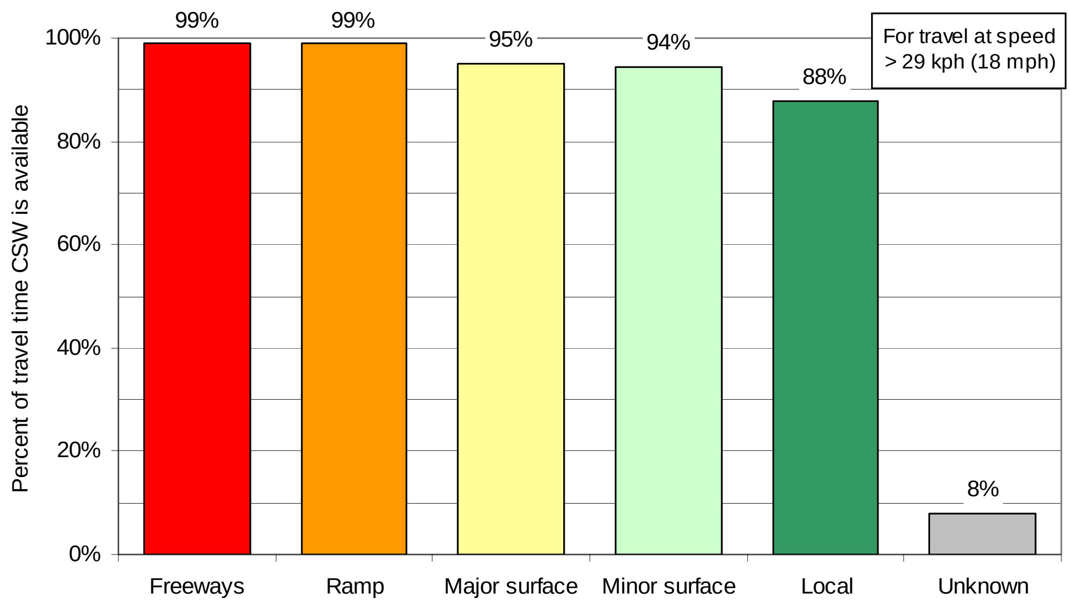

Figure 7.12 CSW availability by road type

That is availability is high —as high as 99 percent— on the more major, and presumably well-mapped, roads but degrades to as low as 88 percent on the less significant, local roads. (The 8-percent availability when the road is unknown, and availability should therefore be zero, is presumably the result of time lags in the updating of road-type designations or the availability flags.)

Figure 7.13 illustrates the sensitivity, or rather, the insensitivity, of CSW availability to three other dichotomous operating variables.

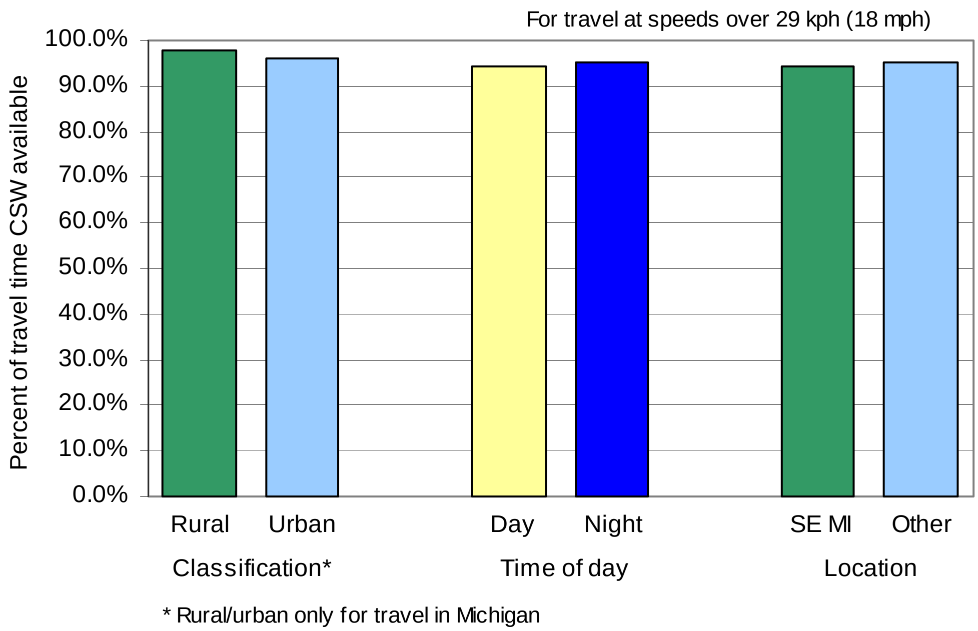

Figure 7.13 CSW availability by road classification, time of day, and by location

7.2 Sensitivity selection by drivers

An important characteristic in the design of the RDCW technology was the separate driver-adjustable sensitivity controls for the LDW and CSW systems. Both the LDW and the CSW systems had five levels of sensitivity adjustment that could be selected using the two toggle buttons mounted in the dash to the left of the steering wheel. These buttons are highlighted in the left-side picture of figure 7.14 which shows the instrumentation cluster of the FOT vehicle.

Figure 7.14 Picture of the RDCW sensitivity-adjustment buttons and sensitivity level via the DVI

Also shown in figure 7.14 is the RDCW DVI-display which provides the visual indication to the driver of the current sensitivity setting for each system. In this case, the figure shows a setting level of “3” (the middle level) for the LDW system and level of “1” (least sensitive) for the CSW system. Also, shown in the figure for both systems is the terminology used to communicate to the driver that broadly speaking the most sensitive setting (i.e., “5”) will result in alerts being issued *sooner* rather than *later* for a sensitivity setting of “1.” For each driver’s first week, when RDCW was disabled, both systems were set to the level “3.” Further details of the influence of sensitivity on the alert decision algorithms are provided in sections 3.3 and 3.4. In brief, a lower sensitivity setting for LDW can be expected to reduce the number of LDW alerts received, while a lower setting for CSW will have a more modest influence on the number of CSW alerts.

For the three weeks during which RDCW was enabled, the drivers were free to adjust the sensitivity level of each system any time the vehicle was running. Figure 7.15 shows the distribution of the drivers’ sensitivity selections as a function of travel time with RDCW enabled and the vehicle speed above the minimum system thresholds. The middle setting of “3” was the most popular selection (43 percent of

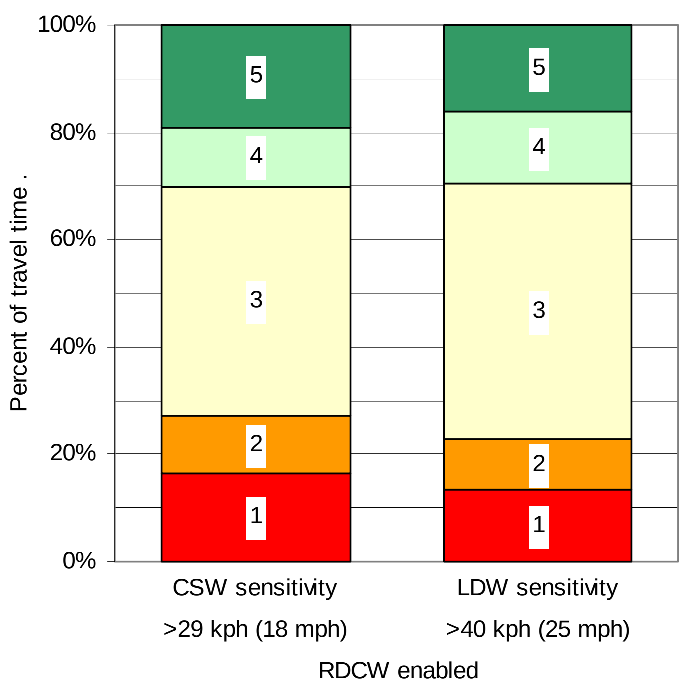

Figure 7.15 Selection of CSW and LDW sensitivity settings as a function of travel time

travel time for CSW and 47 percent for LDW, based on the entire RDCW-enabled period). Drivers chose the more sensitive settings (“4” and “5”) for both systems about 30 percent of the time. The less sensitive settings (“1” or “2”) were chosen 27 and 23 percent of the time, respectively, for CSW and LDW.

Figure 7.16 shows the mean LDW and CSW sensitivity setting for all drivers by week. All three enabled weeks show a mean value very close to “3” for both systems. There was, however, a small but consistent trend from a higher mean sensitivity in week 2 to a lower mean sensitivity setting in week 4. Furthermore, the mean value of the drivers’ selections of the sensitivities for the CSW system and the LDW system remained very similar throughout the testing period.

Figure 7.16 Mean LDW and CSW sensitivity setting for all drivers by week

Figure 7.17 presents the number of drivers who each week selected particular values of sensitivity as their most-used sensitivities. The figure shows these histograms for the CSW (top) and LDW (bottom). . Week 1, of course, is dominated by the default setting of “3” in both systems (with the exception of a few drivers in which their first trips mistakenly had a setting of “5” for both systems). For weeks 2, 3, and 4, the sensitivity setting of “3” continued to be the most favored for both systems, with marginally higher driver counts for the LDW as compared to the CSW system.

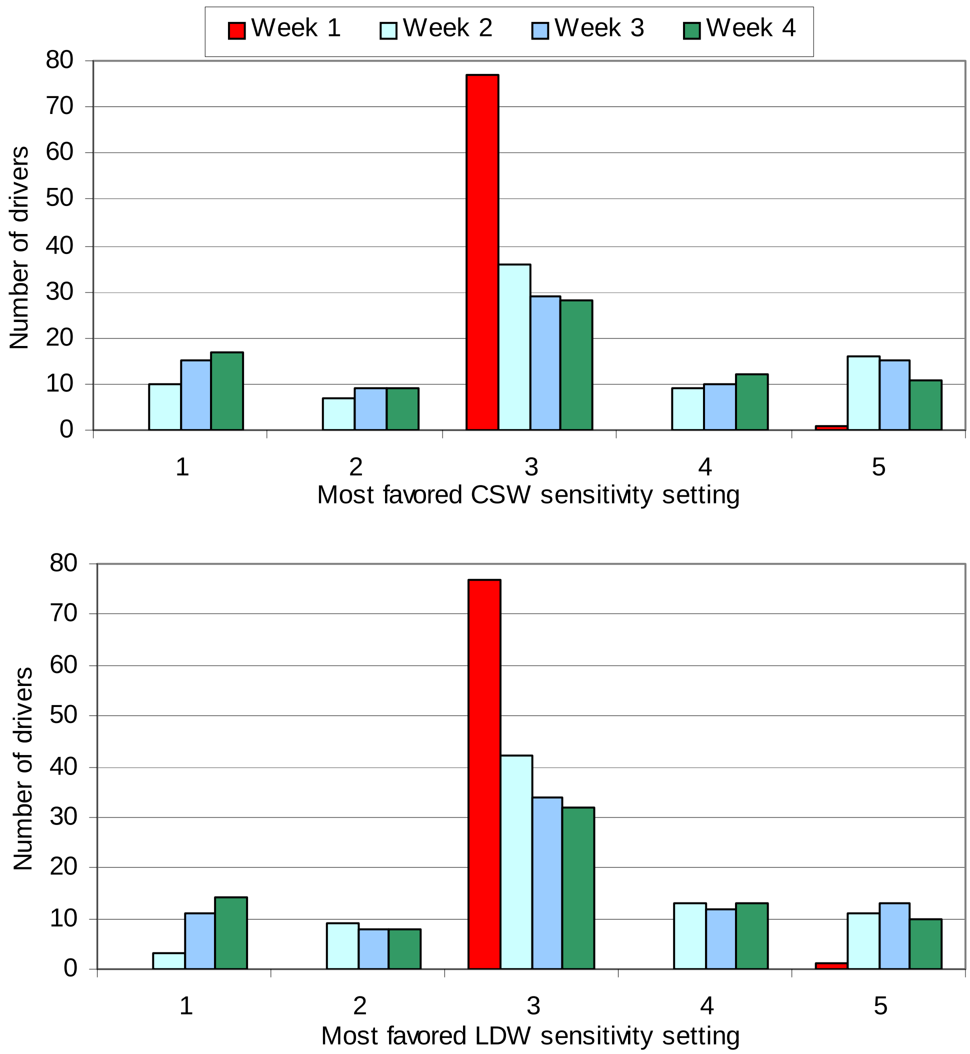

Figure 7.17 Most-favored LDW and CSW sensitivity setting by week

The number of drivers choosing a setting of "3" decreased steadily for both systems from week 2 to week 4, with the number of drivers choosing a CSW setting of "3" decreasing from 36 to 28 drivers, and the number of drivers choosing a LDW setting of "3" decreasing from 41 to 32 drivers. For CSW, the number of drivers who tended to select the higher sensitivity settings ("4" and "5") decreased very slightly from 25 drivers in weeks 2 and 3 (or 32 percent of the 78 drivers) to 21 drivers in week 4 (27 percent). More sensitive CSW settings of "1" and "2" were most favored by 16 drivers (21 percent) in week 2, increasing to 26 drivers (33 percent) in week 4. Between these results and those in figure 7.16, a migration by a minority of drivers over the three weeks of RDCW-enabled driving toward less sensitive settings of the CSW system is apparent. Still, the mean setting remained at 3.0.

For LDW, the number of drivers who tended to select the higher sensitivity settings ("4" and "5") remained constant for the LDW system throughout weeks 2, 3, and 4, at 23 or 24 drivers (30 percent of the 78 drivers). As stated above, the number of drivers choosing the middle setting for LDW decreased over time from 41 to 32 drivers (53 to 41 percent), and the same magnitude of change was seen as an increase in the number of drivers moving toward the less sensitive settings of LDW ("1" and "2"). In the final week, the lower sensitivity settings were most used by 22 drivers (28 percent). Thus, again, the average value of the most-used sensitivity across drivers remained very close to 3.0 throughout the test, with the distribution being slightly skewed toward less sensitive settings.

One possible conclusion from these results is that drivers took some advantage of the ability to select sensitivity for both systems. It may be possible to simplify the design by using only three settings.

Figure 7.18 addresses the inter-dependency of the sensitivity adjustment for both LDW and CSW, specifically, how often drivers selected the same value for both the LDW and CSW sensitivity setting.

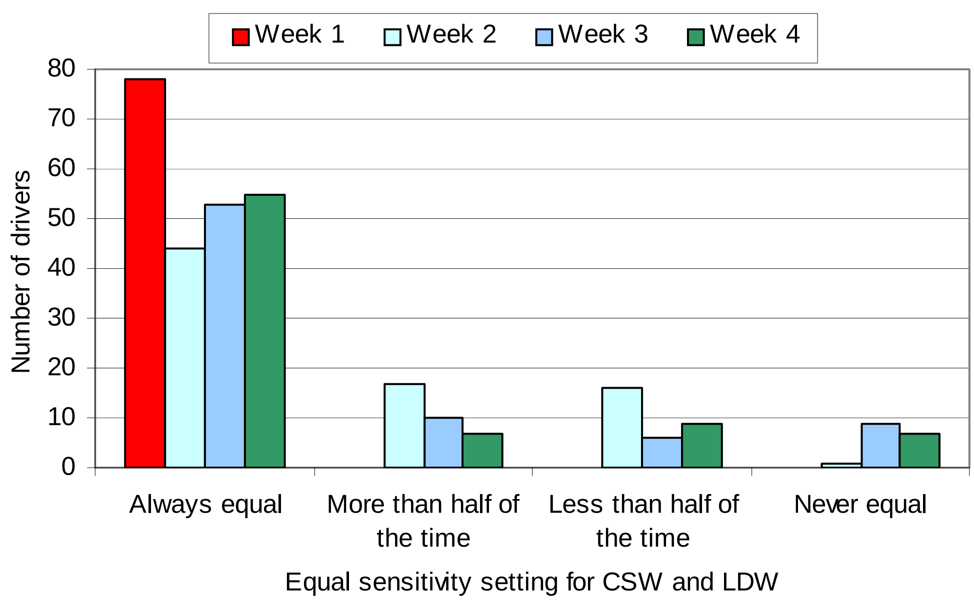

Figure 7.18 Independence of CSW and LDW sensitivity setting by week

To do this, for each week, the fraction of travel time that each driver used the same setting for LDW and CSW was computed. These are categorized as follows:

- Sensitivity settings always equal—same setting over 95 percent of the travel time above 18 mph.

- Sensitivity settings the same more than half of the time—same setting between 50 and 95 percent of the travel time above 18 mph.
- Sensitivity settings the same less than half of the time—same setting between 5 and 50 percent of the travel time above 18 mph.
- Sensitivity settings never equal—same setting less than 5 percent of the travel time above 18 mph.

As mentioned earlier, drivers had the option to set the sensitivity level of each system independently. However, as figure 7.18 shows, by week 4—55 of the 78 drivers (or 70 percent) used the same sensitivity setting for both LDW and CSW. This was an increase from 44 drivers (56 percent) that used the same setting during week 2 and there was only one driver that never had equal settings during week 2. If the driver population is divided into those that had the same setting more than 50 percent of the travel time, then the change in driver count is virtually constant as function of week. That is, for weeks 2, 3, and 4, there were 61, 63, and 62 drivers, respectively, (approximately 80 percent) that kept both systems at the same sensitivity value for more than half of the travel time and conversely, 20 percent of the drivers used different sensitivity levels for each system for more than half of the travel time.

That 70 percent of the drivers use the same sensitivity settings for the CSW and LDW for at least 95 percent of travel time in the final week is striking, considering that the two systems address different driver behaviors, that is, lane-keeping and approach speeds to curves. This question will be addressed further later in section 7.4.2, after the relationship of sensitivity and alert rates is computed from the data.

A related question is how often drivers changed sensitivity levels for the LDW and CSW systems. This was done by computing for each driver the number of distinct sensitivity selections per trip. For example, if during a trip, a driver selected the LDW sensitivity to be “2,” then “4,” then “2,” it is said that the trip included three distinct sensitivity selections. Due to the nature of the adjustment toggle buttons, if a driver went from a sensitivity level of “1” to “4,” they had to briefly pass through levels “2” and “3.” Hence, when counting distinct selections, a minimum dwell time of two seconds was required to remove transient intermediate settings. The total travel time in trips of one setting, of two settings, etc., was then determined per FOT week.

Figure 7.19 presents the results by showing the fraction of travel time for the FOT week that was accumulated in trips with different numbers of distinct sensitivity selections. Results are shown separately for LDW and CSW sensitivity settings. As could be expected, due to the inclination of drivers to experiment with the systems, the figure shows that week 2 had the highest number of distinct selections for both systems. Even so, for trips that accounted for 87 percent of the travel time in week 2, drivers did not change the CSW or the LDW sensitivity in those trips. Furthermore, for trips that accounted for approximately 11 percent of the time, drivers made only one adjustment (using two distinct sensitivity levels) to the sensitivity setting in both systems during week 2 and there were virtually no trips in which drivers used three or more distinct sensitivity selections in a given trip in any of the enabled weeks.

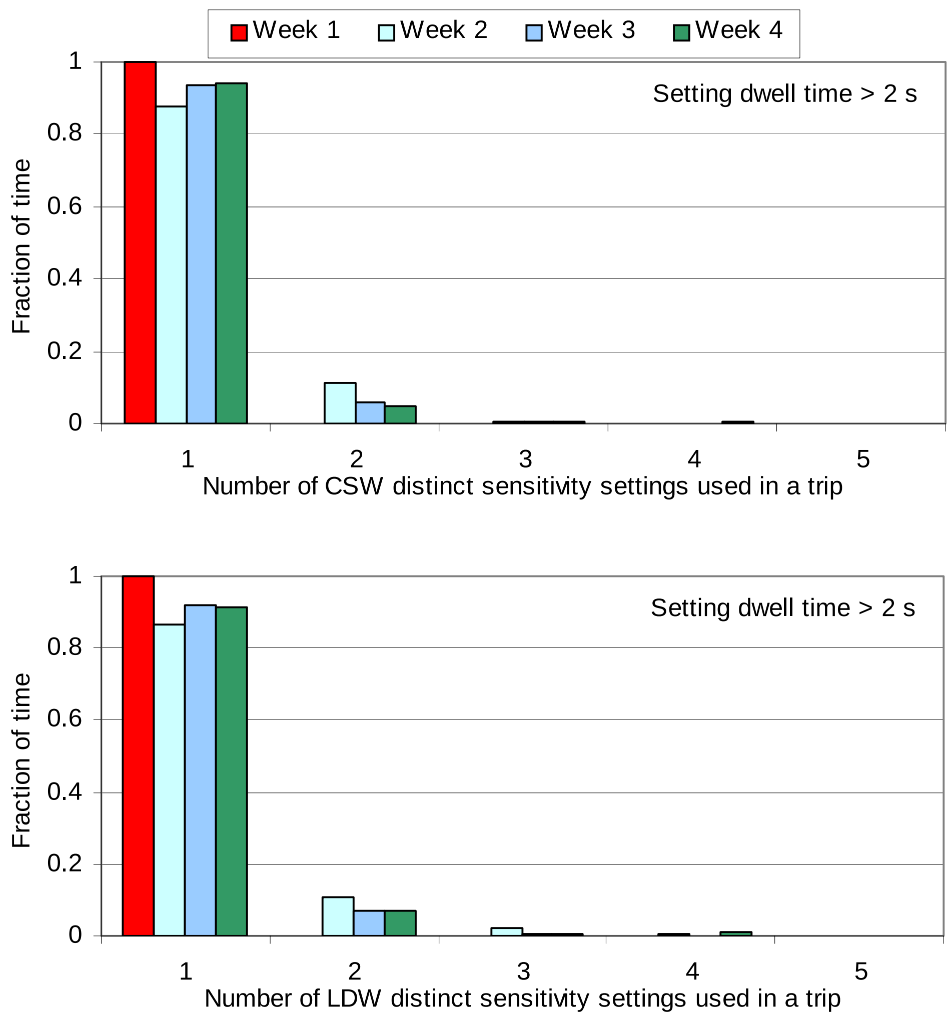

Figure 7.19 Number of distinct LDW and CSW sensitivity settings used in a trip by week

In short, drivers did not change sensitivity settings often. During those trips in which a driver changed sensitivity, it was almost always once per trip. Data from weeks 3 and 4 revealed even less tendency for the drivers to adjust sensitivities. During these two weeks, the number of trips in which drivers adjusted sensitivity of either system accounted for only about 6 percent of travel time.

7.3 LDW Alert events

The issuance of each individual alert by the LDW system, be it a cautionary or an imminent alert, constitutes an LDW alert event.[5] During the first week of driving, when the RDCW system is disabled (from the driver's point of view), an alert-event does not result in an actual alert to the driver, but it is recorded in the data, just as if the system were enabled. During the latter three weeks of driving, when RDCW is enabled, the driver does receives an alert, either haptic or audible, for each LDW alert event. (See section 3.3 for details on LDW alert logic and the alert modalities.)

The LDW sensitivity setting, of course, influences whether or not a given driving event actually evokes an LDW warning and, therefore, an LDW alert event. During the first week of driving, the LDW sensitivity was fixed at the median level, level 3.[6] During the three latter weeks, sensitivity setting was under control of the driver and could be at any of the five settings. (Section 7.2 reported on driver selections of LDW sensitivity.)

7.3.1 LDW Alert rates for the fleet and for individuals

Overall counts and rates of LDW alerts are presented on the next page in table 7.1.[7] There were 8532 LDW alerts during the valid trips of the FOT, 2790 during the first week with RDCW disabled and 5742 during the latter three weeks with RDCW enabled. On average, the alert rate was 11.25 alerts per 100 miles (161 kilometers). The rates with the system disabled and enabled were 13.02 and 10.56 alerts per 100 miles, respectively. Imminent alert counts and rates were consistently greater than cautionary counts and rates.

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[5] This may seem an obvious definition of an alert event. However, it stands in contrast with the definition of a CSW alert event for which one event may contain more than one warning. See section 7.4.

[6] This is not precisely true. By some means not well understood, LDW sensitivity was apparently set to 5 during some drivers' first or second trip. This resulted in LDW sensitivity set to 5 rather than 3 during about 2 percent of week-1 travel time over 40 kph (25 mph).

[7] Alert rates in this table are computed by dividing the total number of alerts for all drivers by the total distance traveled by all drivers at speeds over the minimum speed threshold for LDW of 25 mph (40 kph).

Table 7.1 Counts and rates of LDW alerts

Counts of LDW alerts

	Cautionary	*Imminent*	*Total*
RDCW disabled (1 week)	1148	1642	2790
RDCW enabled (3 weeks)	2163	3579	5742
FOT (4 weeks)	3311	5221	8532

Rates of LDW alerts	*Alerts per 100 miles (161 km)*		
	Cautionary	*Imminent*	*Total*
RDCW disabled (1 week)	5.36	7.66	13.02
RDCW enabled (3 weeks)	3.98	6.58	10.56
FOT (4 weeks)	4.37	6.89	11.25

Figure 7.20 examines the rates of LDW alerts in more detail. The figure presents means of the rates for the 78 individual drivers (as apposed to overall rates presented in table 7.1); only valid trips are considered.

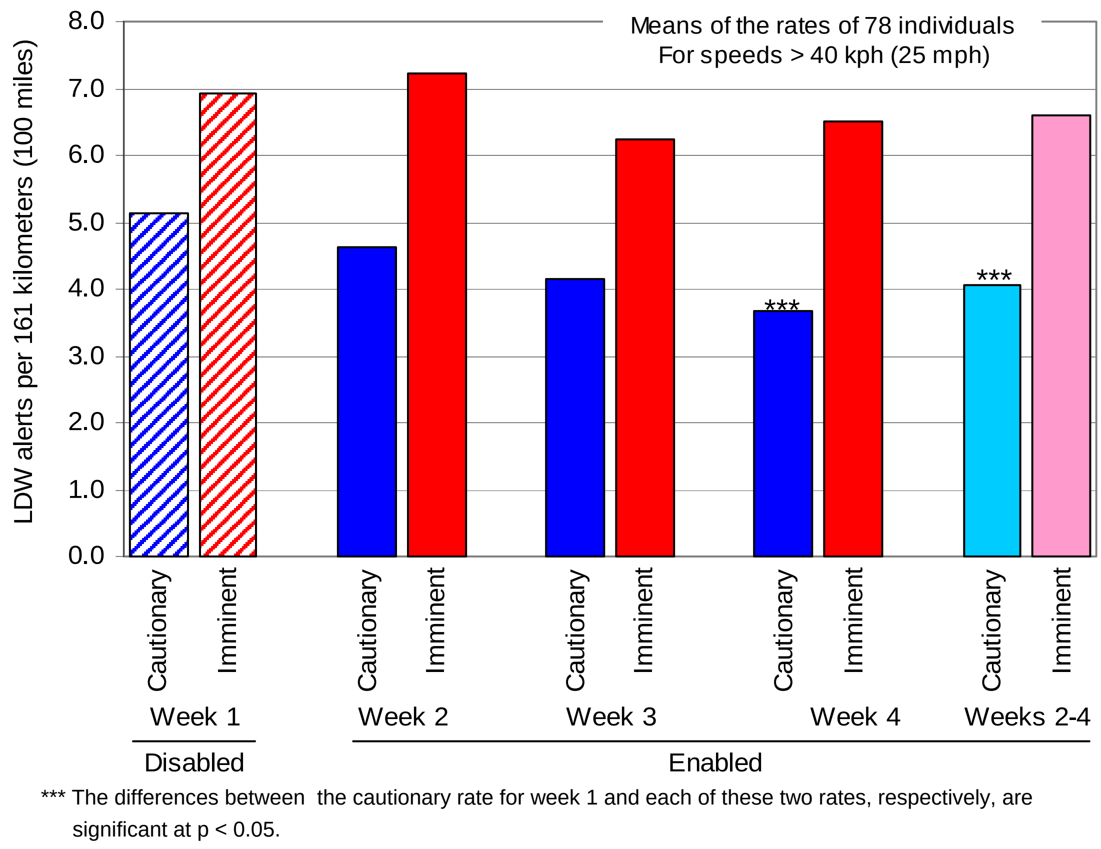

Figure 7.20 Mean LDW alert rates by level and week

The figure shows rates for cautionary and imminent alerts by week and, on the far right, for the entire enabled period (i.e., pooled data for weeks 2, 3 and 4). The mean rates of LDW alerts during the three weeks that RDCW alerts were displayed are 4.0 cautionary alerts and 6.6 imminent alerts per 100 miles (161 kilometers).

The most interesting point of the figure is that it reveals a regular decline in the rate of cautionary alerts over the four weeks of driving, from 4.5 alerts per 100 miles in week 2 to 3.8 alerts per 100 miles in week 4. Moreover, applying Student's t test to the 78 sets of data reveal that the difference between the means of the cautionary rates in the first and fourth weeks is significant (t=0.003) as is the difference in mean cautionary rates between the first week and the pooled second, third and fourth weeks (t=0.046). No other comparison of any mean rate with the system enabled to the corresponding mean rate of week 1 yields a difference significant at $p < 0.05$. In particular, although there is an apparent trend toward a lower rate of imminent alerts in the third and fourth weeks, there is not a statistically significant change in the rate of these alerts when the system is enabled, or between weeks 2, 3, or 4. Some of the decrease observed in both rates may be due to better lane keeping with RDCW enabled. However, in section 8.1.2, it is shown that the stronger decrease in the rate of cautionary LDW alerts is primarily due to an increase in the use of turn signals.

A second point evident in the figure 7.20 is that the means of the imminent alert rates are consistently higher than the means of the cautionary rates. Indeed, for every pair of cautionary and imminent rates, i.e., for every week, the difference shown is statistically significant (t values for the four weeks respectively: 0.011, 0.002, 0.001, <0.001). This is necessarily a reflection of the behavior of drivers, in which there are more lane excursions, without the use of turn signals, in conditions that trigger imminent alerts than there are in conditions that trigger cautionary alerts.

Figure 7.21 on the next page shows the range of alert rates experienced by individual drivers by presenting histograms of those rates by driver. Histograms for week 1, when the RDCW system was disabled, appear in the upper section of the graph; the lower section present histograms for the rates with the RDCW system enabled in weeks 2 through 4. Histograms for cautionary-alert rates appear on the left and for imminent-alter rates on the right.

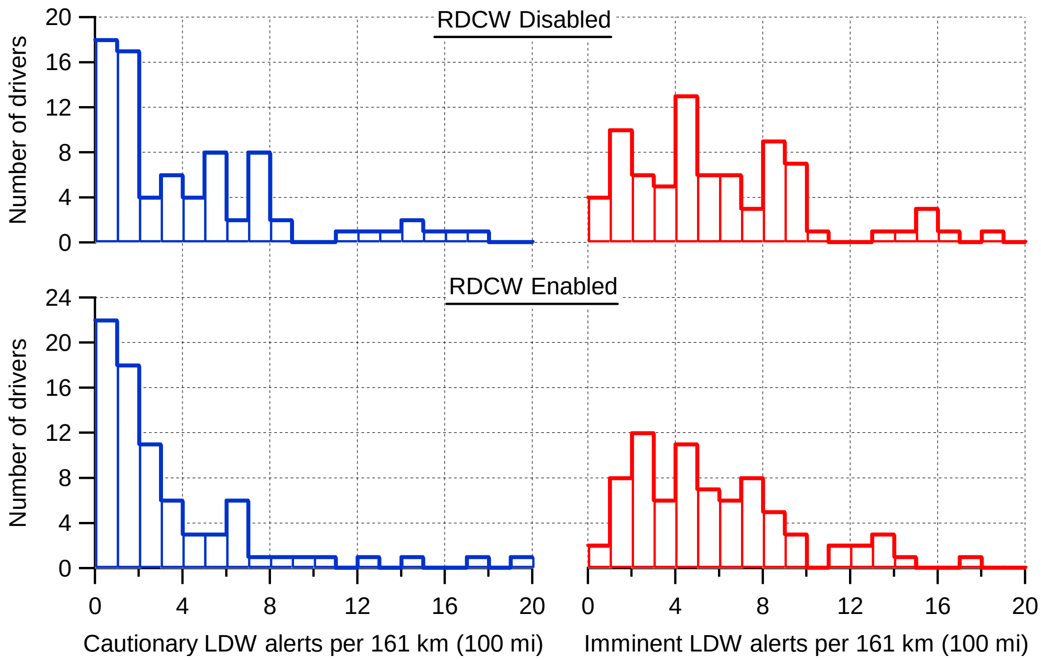

Figure 7.21 Distributions of LDW alert rates by driver

Comparing cautionary- to imminent-alert rates, the graph shows that many drivers experienced a rather low rate of cautionary alerts; indeed the most likely cautionary-alert rate was less than 1 alert per 100 miles (161 km). For imminent alerts, however, the most likely rate was between 4 and 5 alerts per 100 miles with the system disabled and between 3 and 4 alerts per 100 miles with the system enabled. Comparing disabled to enabled rates, the distribution of both cautionary and imminent rates skew to the left when the system is enabled. That is, with the system enabled, more drivers generate lower alert rates.

7.3.2 Influences of operating variables on LDW alert events

<u>LDW sensitivity setting.</u> . The LDW sensitivity setting allowed the driver to adjust the system such that LDW alerts would occur at lane positions that were farther inside the lane (higher sensitivity settings) or farther outside the lane edge (lower sensitivity settings). This section examines whether drivers who selected higher sensitivity settings had different alert rates than drivers who selected lower sensitivity settings.

Figure 7.22 shows LDW alert rates (from the pooled fleet data) as a function of sensitivity setting. The relationships shown are clearly quite orderly. The rates of both cautionary and imminent alerts increase with increasing sensitivity setting. As the LDW sensitivity increases from 1 to 5, the cautionary alert rate increases from 2.0 to

7.2 alerts per 100 miles (161 km) and the rate of imminent LDW alerts increases from 4.0 to 13.3 alerts per 100 miles (161 km). This relationship may be due to the influence of the sensitivity setting, per se, a correlation between drivers' choice of sensitivity and their lane-keeping behavior, or, most likely, some combination of the two. In any case, presuming that drivers used the LDW sensitivity setting to establish an acceptable rate of alerts, then it is clear that what constitutes such an acceptable rate varies substantially among individuals.

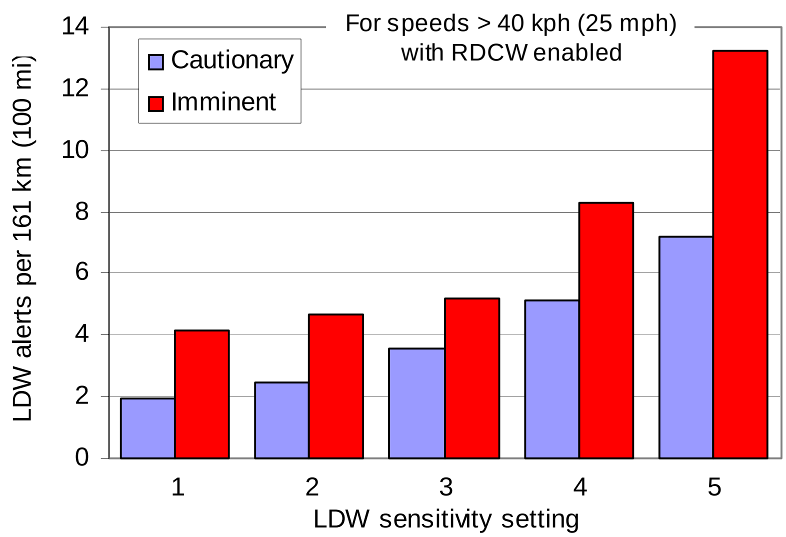

Figure 7.22 LDW alert rates by alert level and LDW sensitivity setting

Road type. Figure 7.23 on the next page presents both the distribution of the total number of LDW alerts (upper graph) and rates of LDW alerts (lower graph) by alert level and by road type. Largely because so much of FOT travel took place on freeways, freeway travel resulted in the greatest number of alerts. Conversely, because so little travel is on ramps, travel on ramps contributed a relatively small number of LDW alerts. (LDW is intended to be disabled on *local* roads. The small number of alerts that took place on local roads are probably due to lags in road-type identification and/or the disabling function.)

In the lower graph, however, it is seen that the *rate* of cautionary alerts is relatively constant across the four road types where LDW is active, and that the rate of imminent alerts is actually highest on ramps. Also, the rate of alerts on freeways is about midway between the rates for major and minor surface roads. Earlier it was shown that LDW availability is much higher on freeways than surface roads. Consequently, it can be concluded that the rate of LDW alerts per distance traveled *with LDW available* is substantially greater on surfaces roads than on freeways.

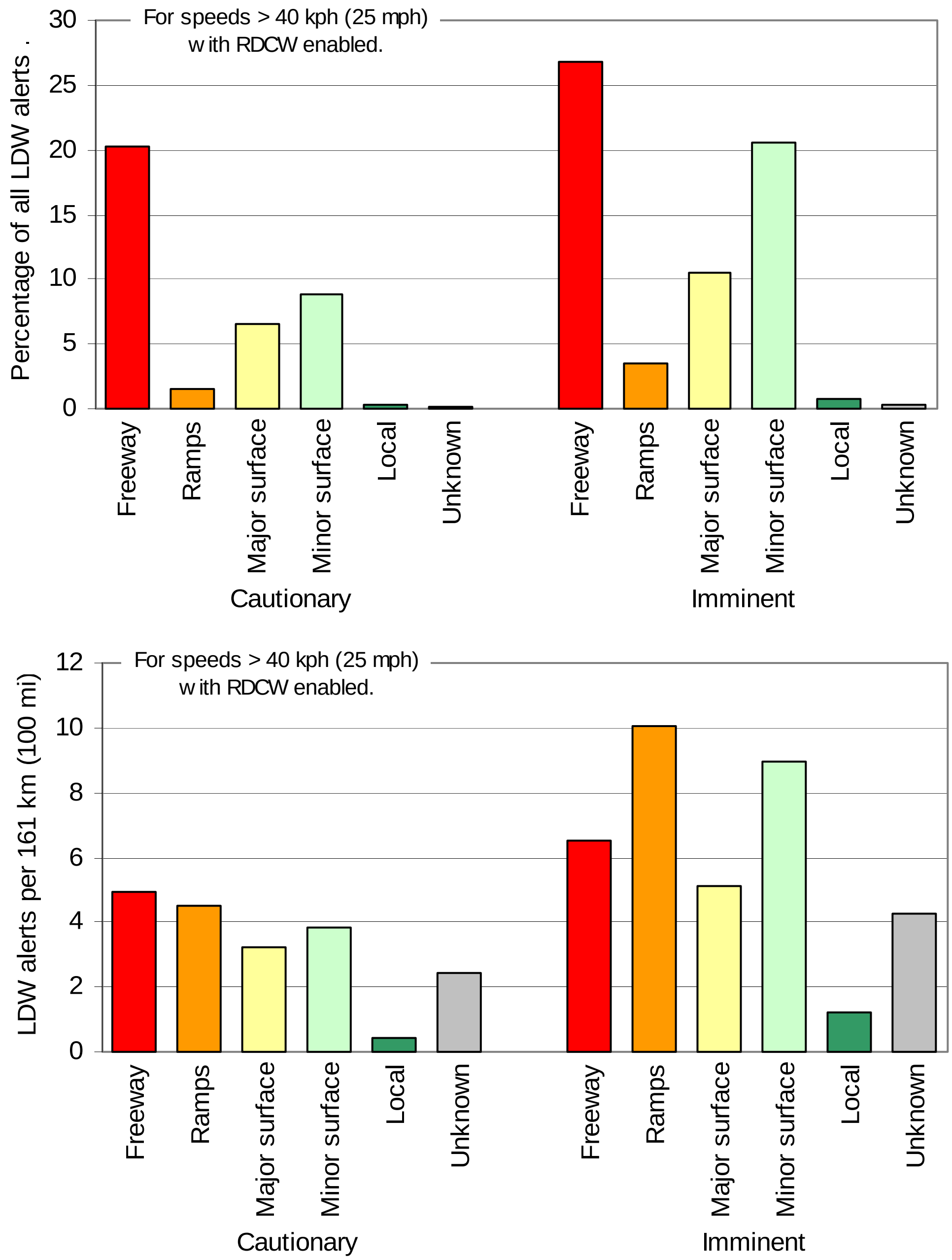

Figure 7.23 The distribution and the rates of LDW alerts by alert level and road type

Left- and right-side alerts. Figure 7.24 presents the distribution of LDW alerts by alert level and by side. It is apparent that while cautionary alerts are fairly evenly distributed left and right, imminent alerts are not and that a substantially great number are associated with approaching or crossing the lane boundary to the left than the lane boundary to the right.

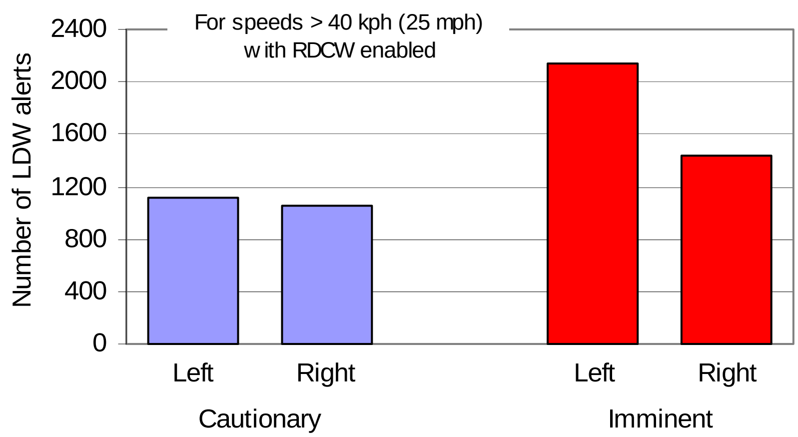

Figure 7.24 Distribution of LDW alerts by alert level and alert side

Figure 7.25 reveals that this directional bias in imminent alerts derives virtually exclusively from travel on freeways and ramps as apposed to travel on surface roads (where, as implied by figure 7.23, pooled measures for freeways and ramps are dominated by travel on freeways). This figure shows *rates* of LDW alerts by level, side, and this dichotomy of road types. Except for the case of imminent alerts on freeways and ramps, left-to-right differences of alert rates are relatively small.

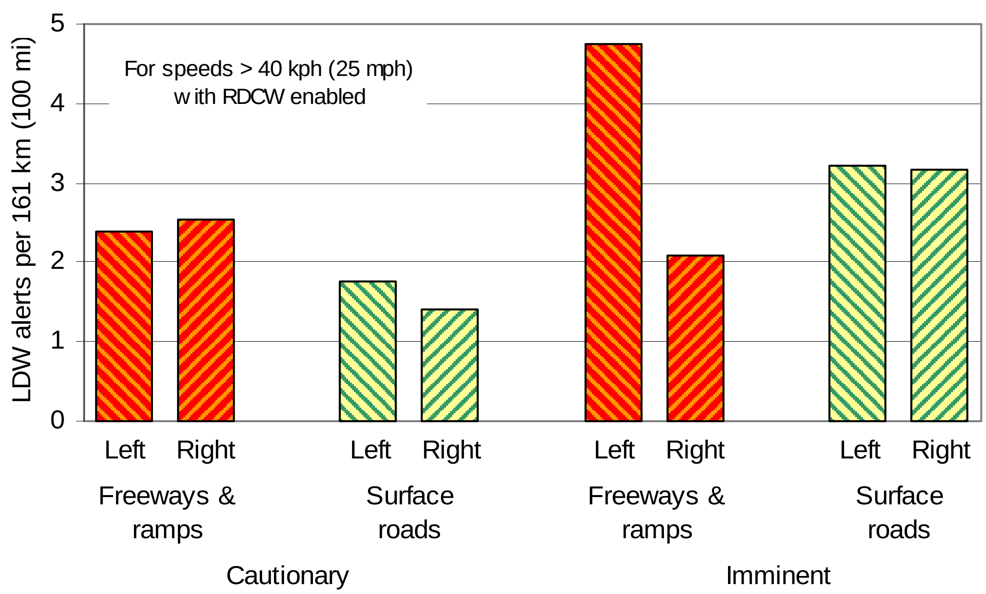

Figure 7.25 LDW alert rates by alert level, alert side and freeways versus surface roads

The strong left-to-right bias of the LDW imminent alert rate on freeways and ramps displayed in figure 7.25 is driven primarily by the fact that, when traveling on freeways, a great number of imminent alerts are generated by the left-side radar. (See section 3.3 for details about the influence of radars and the look-aside database on LDW alerts.)

Figure 7.26 presents the counts of LDW alerts by the same factors considered in figure 7.25, but with the addition of the critical source of the alert. In the figure, the four sources that can generate the critical value of available maneuvering room (AMR, see section 3.3) that generates the LDW alert are:

- Default: a default value of AMR is assigned based on the current functional road class and sensitivity setting.
- Forward radar: the AMR is adjusted (reduced) as a result of targets seen in the forward radar.
- Side radar: the AMR is adjusted (reduced) as a result of targets seen in the side radar. Cautionary alerts are usually upgraded to imminent alerts.
- Look-aside data base (LADB): Side radar targets that have appeared repeatedly at the same GPS location and heading are “remembered” and used similarly to actual side-radar targets. Therefore, in interrupting figure 7.26, it is appropriate to consider the LADB alerts as “more of” the side-radar alerts.

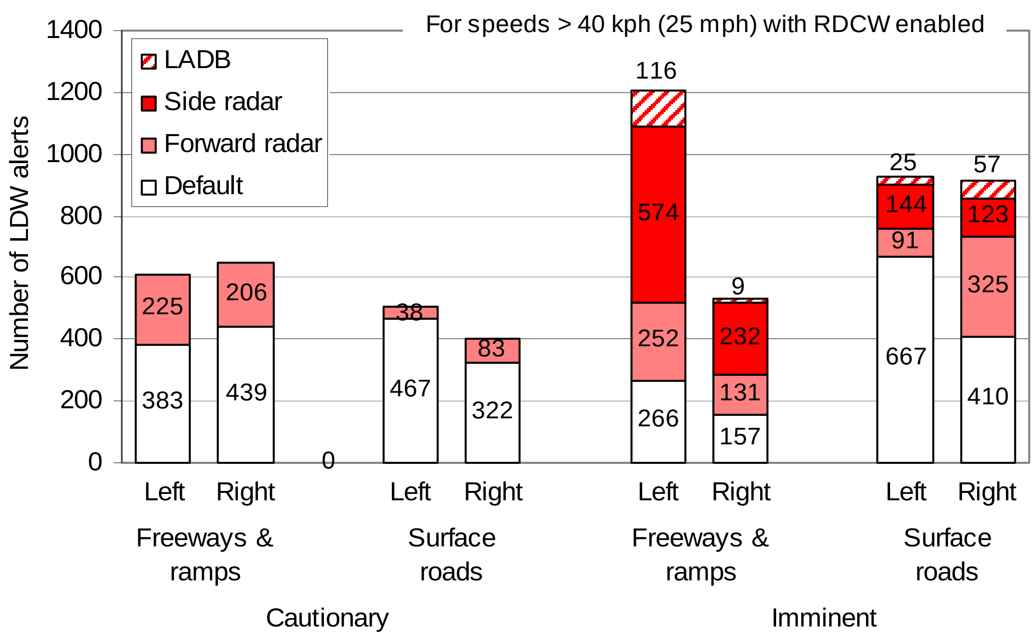

Figure 7.26 Distributions of the critical LDW alert source by alert level

Figure 7.26 shows that most cautionary LDW alerts are driven by the default AMR; that is, cautionary alerts are usually not associated with a radar-driven threshold. Only 552 of the 2163 cautionary alerts that took place while RDCW was enabled (26 percent) were driven by radar-based influences (and only by forward radar, as side-radar alerts are always imminent alerts). That is likely because cautionary alerts are, by definition, given for crossings of dashed lines without side-radar-based targets appearing to be significant. For imminent alerts, however, radar-driven alerts account for three of four alerts on freeways and ramps, and a slight majority of right-side, surface-road alerts as well. Only one in four left-side imminent alerts on surface roads are caused by radar, however. Specifically, the figure shows that 1314 of 1737 imminent alerts that occur on freeways or ramps (76 percent) are driven by radar. For imminent alerts that occur on surface roads, 505 of 915 imminent alerts occurring on the right-side (55 percent) and 260 of 927 imminent alerts that occur on the left-side (28 percent) are driven by radar.

The figure also shows that, for imminent alerts on freeways and ramps, each of the four AMR sources generate more alerts on the left than on the right. The counts of events are apparent from the figure; the ratio of counts, left-over-right, by category are: default, 1.7; forward radar 1.9 ; side radar and LADB combined, 2.9. Hence, by both count and ratio, the left-side bias of side-radar alerts is the largest and is the primary source of the asymmetry. Indeed, default and forward radar categories combined produce 230 more left-side than right-side imminent alerts, but the combination of side radar and the LADB produce an excess of 449 left-side, imminent alerts.

This large bias for side-radar alerts on the left is related to three types of radar targets. Table 7.2 presents an accounting of the various types of targets that produced side-radar, imminent alters on freeways (as determined by review of the forward-camera video of all 762 alerts of this type).

Table 7.2 Target sources for side-radar, imminent alerts on freeways

	Number of alerts		*Difference (left – right)*	
Target	*Left*	*Right*	*Count*	*Percent*
Barrier	175	6	169	50.3
Vehicle	248	167	81	24.1
False	119	38	81	24.1
Other	7	2	5	1.5
Total	549	213	336	100

As the table shows, road-side barriers are the largest source of the left-side bias, accounting for 50 percent of the “excess” left-side radar alerts. This is easy to understand as jersey barriers and guard rails are found very close to the far left lane on freeways that have little space for the median, but barriers and guard rails are rarely located close to the far right-hand lane on freeways. Harder to understand are the data showing that side-radar alerts from vehicles passing, or being passed, close in the adjacent lane and false alerts are both more prevalent to the left than on the right. Each of these categories, respectively, account for about one quarter of the excess left-side alerts.

Distance to lane edge. Figure 7.27 presents the distribution of the RDCW vehicle's distance-to-lane edge at the moment of an LDW alert for each of the four types of AMR critical sources. Cautionary and imminent, and both left- and right-side alerts are included. (Separate examinations showed no particular side-to-side bias.) Polarities are adjusted so that distance-to-lane-edge is always positive when the vehicle is fully in the lane and is negative when the edge of the vehicle has crossed outside the lane. The data are limited to alerts that took place when LDW sensitivity was set to the median value of 3. (Note that for a standard U.S. lane width of 12 feet (3.66 m) and a vehicle width of 6.2 ft (1.9 m), a perfectly centered vehicle has tire edges about 35 inches (0.9 m) from the lane edge.)

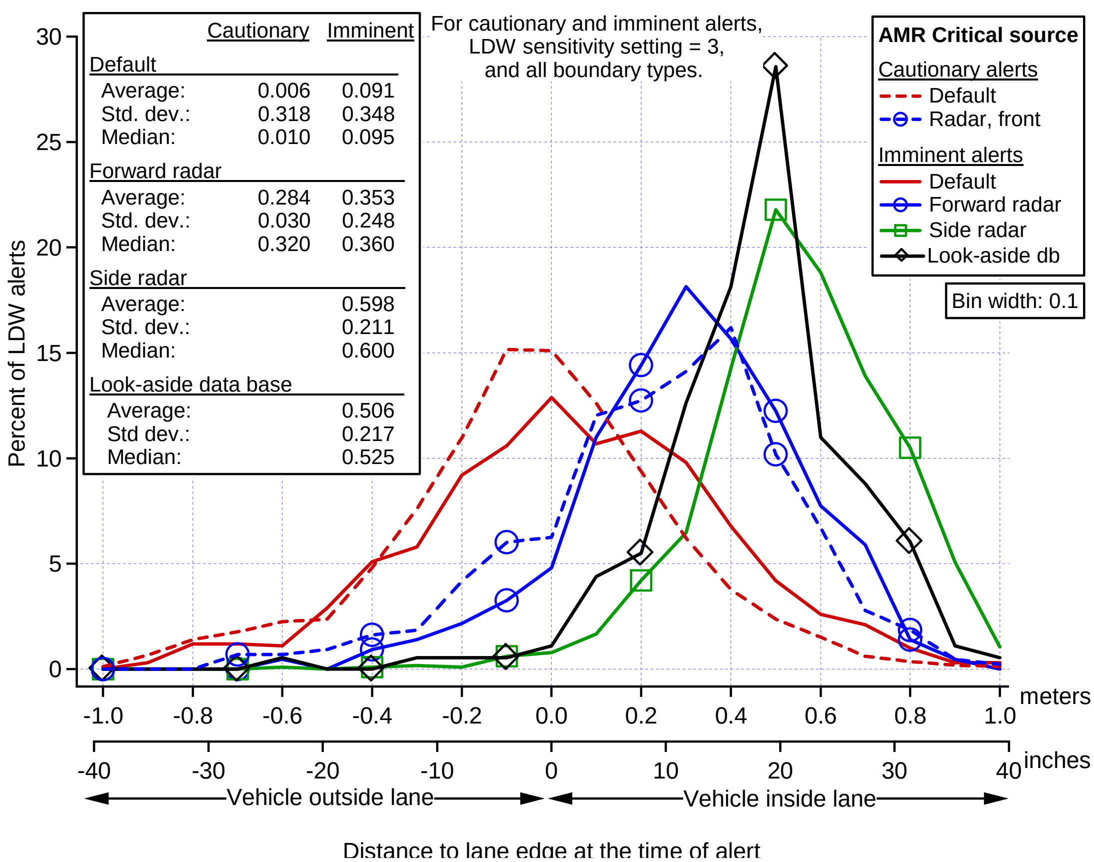

Figure 7.27 Distributions of distance-to-lane-edge by AMR critical source

The figure shows that, for alerts triggered by the default AMR (and, therefore not influenced by real-time or historical radar data), the distribution of the distance-to-edge measure is rather well centered on, and relatively symmetric about, zero. That is, the mostly likely position of the vehicle at the time of an imminent alter of this type is with the tire essentially at the lane edge. The relatively large spread of this distribution, as characterized by a standard deviation of 0.348 meters, is, presumably, largely the result of the predictive algorithm that triggers alerts and which includes lateral velocity of the vehicle relative to the lane edge. Also, cautionary alerts triggered by default AMR take place slightly farther out of lane than do imminent alerts so triggered.

As would be expected, the distribution for the distance-to-edge measure for alerts triggered by either type of radar shifts inwardly in the lane. After all, it is the purpose of the radar to locate objects within the default AMR and reduce AMR accordingly. The most likely values for forward- and side-radar-driven alerts is 0.3 m and 0.5 m inside the lane, respectively. Additionally, the similarity between the distribution for LADB-alerts and side-radar alerts is expected, as the LADB is constructed from repeated side-radar targets. And, as was the case for default alerts, cautionary alerts triggered by forward radar take place a bit farther out of lane than similar imminent alerts. (Similar comparisons can not be made for side radar and LADB, as alerts triggered by these sources are always imminent.)

One may ask whether the use of radar increases or decreases the alert rate. The answer is not simple and can not be obtained directly from the FOT data because (1) only one system was fielded, and (2) the use of radar has two opposing influences on alert rate. That is, on the one hand, radar was included in the system to provide additional protection for drivers who are inadvertently moving toward a lane edge that has an observed, potential crash threat within a modest distance of the edge. This function moves the alert threshold inboard in specific circumstances, tending to increase the rate of alerts. On the other hand, however, the use of radar to identify such specific crash threats allowed the *default* thresholds to be placed further outboard than they would otherwise have been, had radar not been used. This more general, outboard shift of the alert thresholds clearly tends to reduce the rate of alerts. Precisely how these two influences actually combined to increase or decrease LDW alert rates in this FOT cannot be determined. Potentially, however, it would seem that the use of radar in a mature, fully developed system would necessarily serve to reduce the number of nuisance alerts by allowing less conservative default conditions.

7.4 CSW Alert events

The curve speed warning system was intended to provide alerts to help drivers avoid traveling into and through curves at speeds that may be unsafe. Section 3 described the CSW system and stated that the CSW system has two levels of alerts, cautionary and imminent. Unlike the LDW system, the CSW system may provide both a cautionary and imminent alert during the approach to a single curve. In fact, for extended curves, such as on interstate transition ramps in which the vehicle's heading changes by 270 degrees, several imminent alerts may occur on the same curve. This is because the vehicle speed and the curvature may vary within the curve, so that, despite the hysteresis built into the alert thresholds, the imminent alert may be triggered more than once. Therefore, in describing and analyzing driver's experience and interactions with the CSW system, the term, *CSW alert event*, is used. A CSW alert event is intended to group alerts of all levels that occur within a single curve into one alert event. The alert events have been defined in post processing by grouping together alerts that occur without the CSW threat level dropping to zero for more than one second.   Examining the outcome of this algorithm shows that it is effective in approximating the intention of grouping alerts on a single curve approximately 95 percent of the time.

7.4.1 Numbers of CSW alert events

Table 7.3 shows that for the 78 drivers in the FOT data set, there were 6,880 CSW alerts triggered during valid trips throughout the FOT, including those that were not presented to the driver in the first week (baseline driving). Those alerts were grouped to identify 4819 CSW alert events.

Table 7.3 Number of CSW alerts and CSW alert events

	All data	Valid trips data	Percent during valid trips
Trips	*11,072*	*9,582*	*86.5*
CSW alerts	*7,256*	*6,880*	*94.8*
CSW alert events	*5,085*	*4,819*	*94.8*

Figure 7.28 shows the relative frequency of different types of CSW alert events according to the level of alerts provided. Sixty-nine percent of the alert events consisted of only cautionary alerts, and almost all of these involved only a single cautionary alert. Thirty percent of the events involved one or more cautionary alerts that escalated into one or more imminent alerts. One percent of the events involved only a single imminent alert; these were mostly false alerts due to a system operational issue that will be discussed later. Not shown in the chart is the fact that

four percent of the alert events included more than two alerts; the most common scenario for this was the 270 degree transition ramp scenario described earlier.

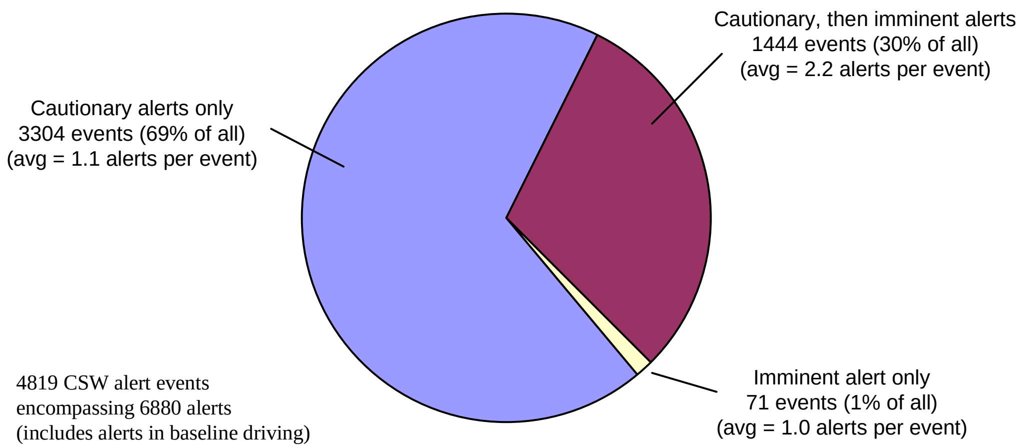

Figure 7.28 CSW alert events – makeup of events according to the alerts provided

For this analysis, CSW alert events were classified as either cautionary-level events (those with only cautionary alerts) or imminent-level events (events involving at least one imminent alert, but possibly with one or more cautionary alerts as well). For events in which both cautionary and imminent alerts occur, the system was designed so that the time delay between the cautionary and the imminent alert was no less than 1.3 seconds, but was sometimes greater than 1.3 seconds, depending on the escalation of the potential threat that the CSW system computes. Figure 7.29 shows that there was variation in this time delay, as expected. The most common delay between the alert levels was approximately 1.4 or 1.5 seconds.

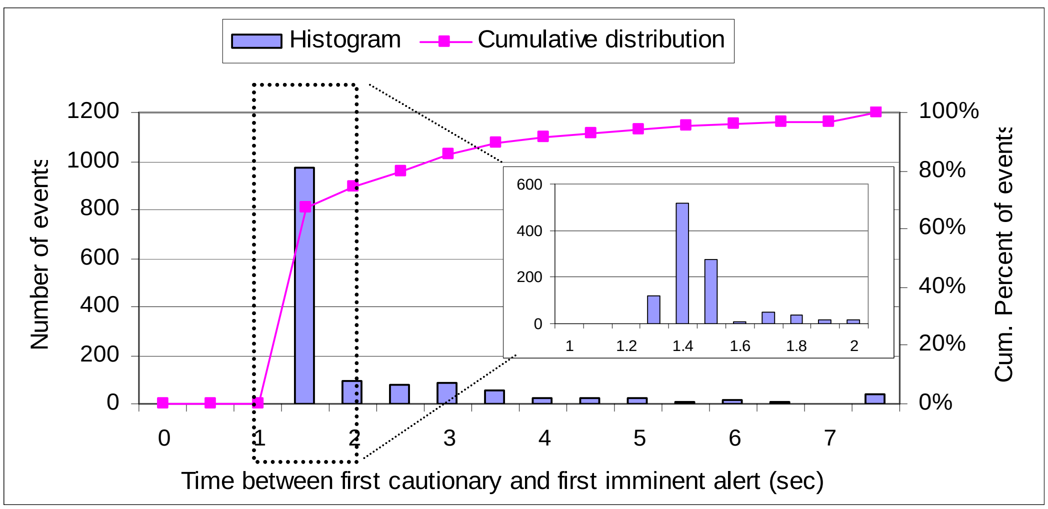

Figure 7.29 Time between first cautionary alert and first imminent alert for the imminent-level CSW alert events (all driving)

Approximately 70 percent of the imminent-level CSW alert events involved a time delay between the cautionary and imminent of 1.75 seconds or less. Longer delays did occur and include cases where drivers are responding shortly after the initial cautionary alert. Very long delays between the cautionary and imminent alerts are sometimes an artifact of the post-processing that grouped alerts into alert events.

Figure 7.30 addresses the breakdown of alert events in terms of whether they occurred during the baseline period (without the alert being presented to the driver) or during RDCW-enabled driving. The figure shows the number of each type of alert event with and without RDCW enabled. There were 1234 of the alert events (26 percent) in the baseline period and 74 percent of the alert events after RDCW was enabled, which is consistent with the approximately one-to-three ratio of distance traveled during the baseline (RDCW disabled) and RDCW enabled periods. More detailed comparisons of these numbers will be presented later in this section. Approximately two of three alert events are cautionary level events in both the baseline and RDCW-enabled periods.

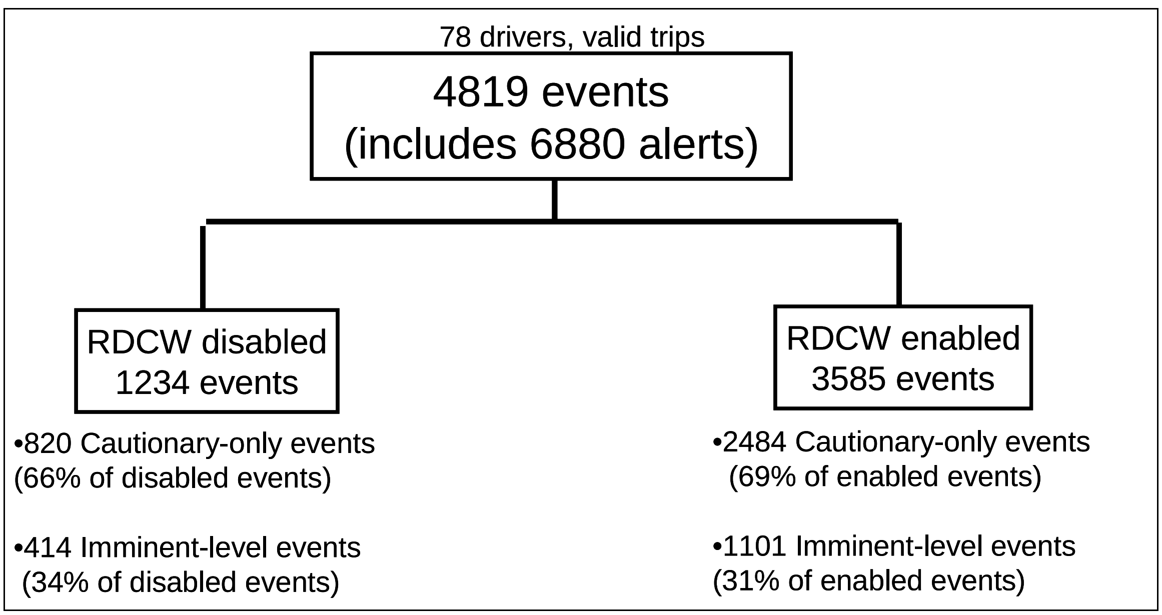

Figure 7.30 Number of CSW alert events – breakdown by alert type and whether RDCW was enabled

Note that 5742 LDW alert events were provided during the RDCW-enabled periods of driving and 3585 CSW alert events during this same period. Thus, there were 38 percent fewer CSW alerts experienced by drivers than there were LDW alerts experienced by those same drivers. Recall also that while CSW was available over 94 percent of the distance that the vehicle traveled over the minimum threshold speed for CSW alerts of 18 mph (29 kph), the average availability of LDW across drivers was 46 percent of the travel distance over 25 mph (40 kph). Thus it is clear that even though CSW was available over twice as often as LDW, the number of alerts provided by the CSW was 38 percent fewer. This is due in part to the fact that CSW intends to only warn drivers at curves, which typically comprise 9 to 14 percent of travel distance, based on previous FOT tests. It is also due to the tendency of drivers to drift or intentionally move toward the lane edges.

As with the LDW system, there was a substantial variation between drivers in the number of CSW alert events received, as well as between the relative frequency at which the alerts occurred in different drivers' experiences. Two metrics are used to express the driver's exposure to alert events – the number of alert events, and the rate of alert events expressed as events per 100 miles (161 km). Figure 7.31 shows a histogram of the number of RDCW-enabled alerts received by individual drivers. Some additional statistics are also shown in figure 7.31, including the median, minimum, and maximum number of CSW alert events received by a driver.

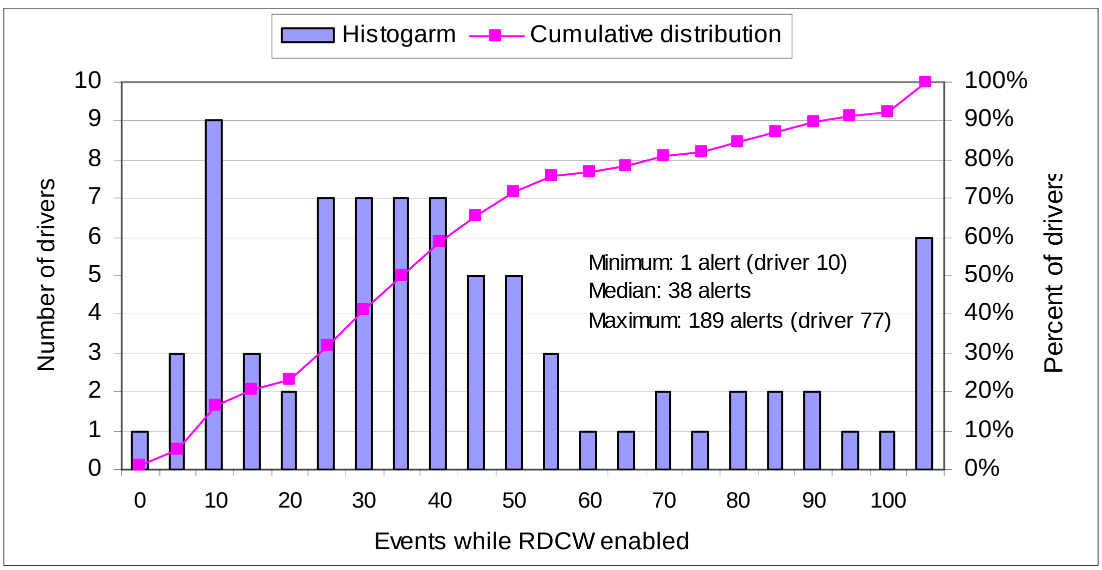

Figure 7.31 Histogram and cumulative histogram of CSW alert events experienced, by driver, with RDCW enabled.

The median number of CSW alert events experienced by drivers was 38 alert events, with the median number of cautionary alert events being 28 and the median number of imminent alert events being 12. Furthermore, the following observations were made from the data:

- One driver experienced only one CSW alert event – a cautionary-level alert event during week 4. All other drivers experienced at least 5 CSW alert events.
- Nine drivers experienced fewer than 10 CSW alert events (this includes the one driver with only one alert event).
- Seven drivers experienced over 100 CSW alert events.

7.4.2 Rate of CSW alert events

The number of alert events shown above varies among drivers in part because of the wide variation in distance traveled by individuals (see section 6 for charts on distance traveled by individuals). Figure 7.32 shows the variation in the total alert rate (number of CSW alert events divided by the distance traveled by that driver at speeds over the minimum speed for CSW alerts (18 mph or 29 kph)). The median rate is 5.5 alert events per 100 miles, with 71 of 78 drivers having rates between 1.0 and 11.0 alerts per 100 miles. The average rate is 6.1, which is composed of 4.3 cautionary alert events and 1.8 imminent alert events per 100 miles.

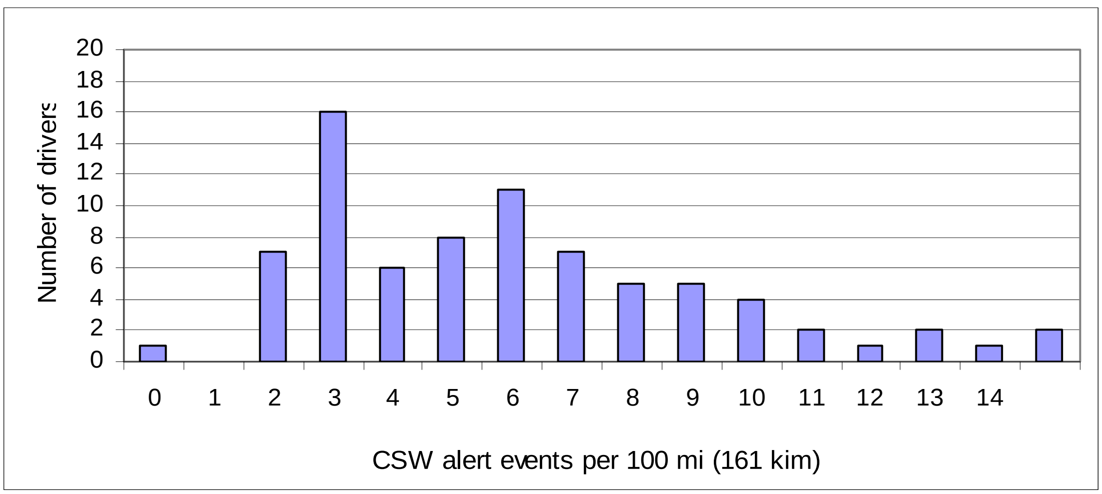

Figure 7.32 Histogram showing number of drivers with various alert rates for all levels of CSW alert events (RDCW-enabled driving)

Figure 7.33 shows each driver's rate of cautionary alert events, as well as their rate of imminent alert events. This shows that for all but four drivers, the rate of cautionary alert events is greater than or equal to the rate of imminent alert events, with a typical ratio of two or three cautionary events for every imminent level event.

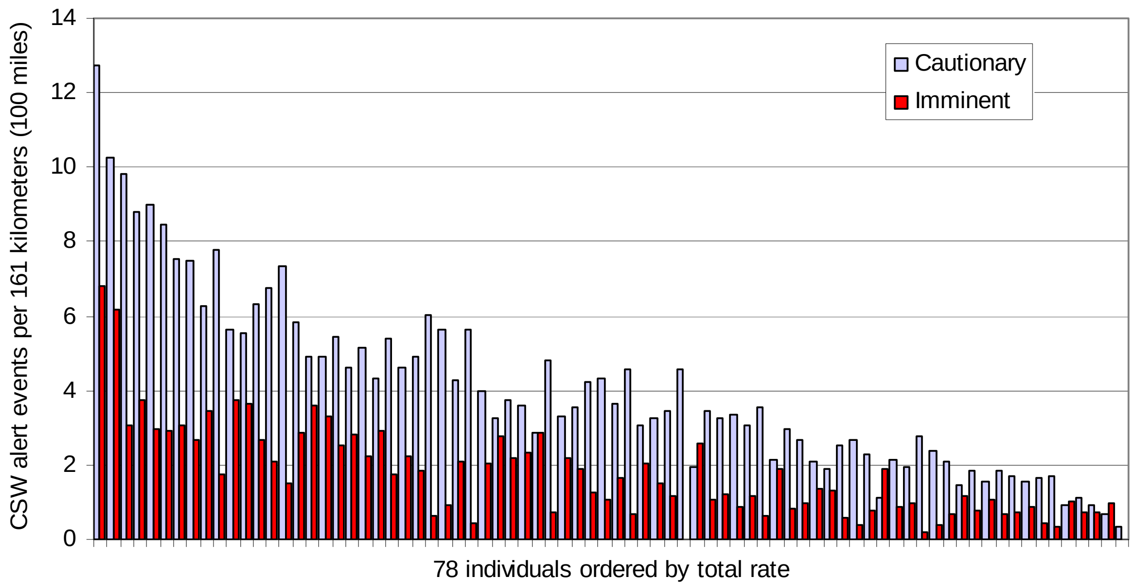

Figure 7.33 CSW alert event rate for individual drivers during RDCW-enabled driving

The average rate among drivers of CSW alert events per unit distance traveled is less than that for LDW alert events. For LDW, the rates were 4.0 cautionary and 6.6 imminent alerts during RDCW-enabled driving, which summed to 10.6 alerts per 100 miles. Thus the alert rate for CSW alert events is 42 percent less than that for LDW.

7.4.2.1 Rate by sensitivity selection

The driver-adjustable sensitivity setting influences the threat level that the CSW computes in each curve-approach situation, as described in section 3.4. While the rate of imminent LDW alerts was shown to vary substantially with the LDW setting, Figure 7.34 shows that there is no clear trend in the rate of CSW alerts at different CSW sensitivity settings. (The figure shows the number of alert events produced at that sensitivity setting across all drivers, divided by the total distance traveled above the minimum

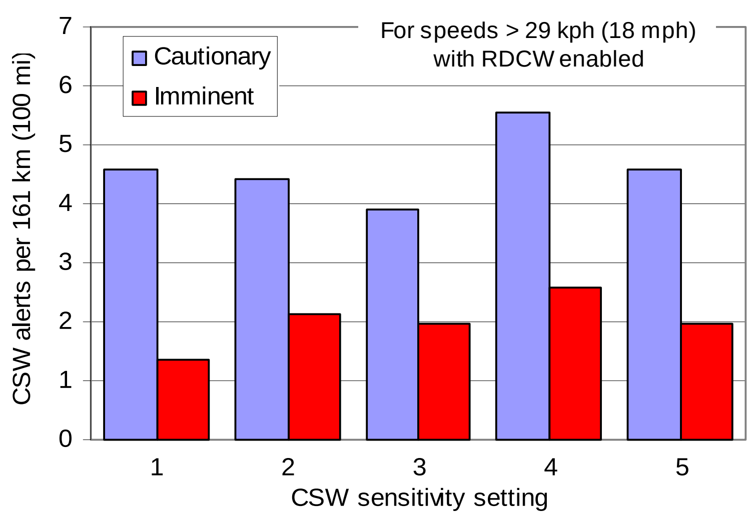

Figure 7.34 CSW alert event rate for travel at different sensitivity settings

CSW speed at that sensitivity setting.) The rate of cautionary alert events does not consistently increase or decrease at higher sensitivity settings in the figure. The rate of imminent alert events may show a slight increase with higher sensitivity settings, but this may also be a result of random chance.

It was expected that there might have been a more pronounced trend of higher alert event rates at higher sensitivities. The expectation was based on two hypotheses: (1) since a higher setting would assign higher threat levels to each curve approach situation, then there would be more alerts at a higher sensitivity setting for the same set of events, and (2) drivers who desire more CSW alert events would increase the sensitivity. The actual data does not clearly bear out this expectation, and this outcome may be due to one or more causes. The second hypothesis may well be incorrect – it is not possible to determine whether drivers select sensitivity to produce a desired set of alerts and suppress unwanted alerts. For some drivers, the sensitivity settings may reflect that driver's general desire for safety, and for others, the sensitivity setting may be selected to remove all nuisances. One unique characteristic about setting sensitivity with the CSW system is that since curves that trigger alerts are encountered infrequently, the driver who adjusts sensitivity may be unlikely to experience another alert soon after the adjustment, so that there is no immediate feedback about the alert timing with the new sensitivity value.

7.4.2.2 Frequency of CSW alert events on different road types

Figure 7.35 shows the location of CSW alert events during RDCW-enabled driving, with cautionary-level and imminent-level alert events shown on the left and right side, respectively of the figure. Consider three groups of road types – freeways, ramps, and surface roads. The number of CSW alert events is roughly spread equally among these three types, however, when the rate of alert events per unit distance is considered, as in Figure 7.36, then ramps are clearly the setting in which CSW alerts are most likely to occur, with an alert rate of 37.3 alerts per 100 miles, or six times the overall rate. Rates on freeways and surface roads are approximately the same, in order of magnitude. Ramps – especially exit ramps – often involve curves and decreases in speed, which together make CSW events more likely as the system must attempt to anticipate whether the driver is aware of the curve and the need for slowing. Later, a detailed study of a subsample of the CSW alert events will provide further insight into the differences in the occurrence of CSW alert events in different roadway settings.

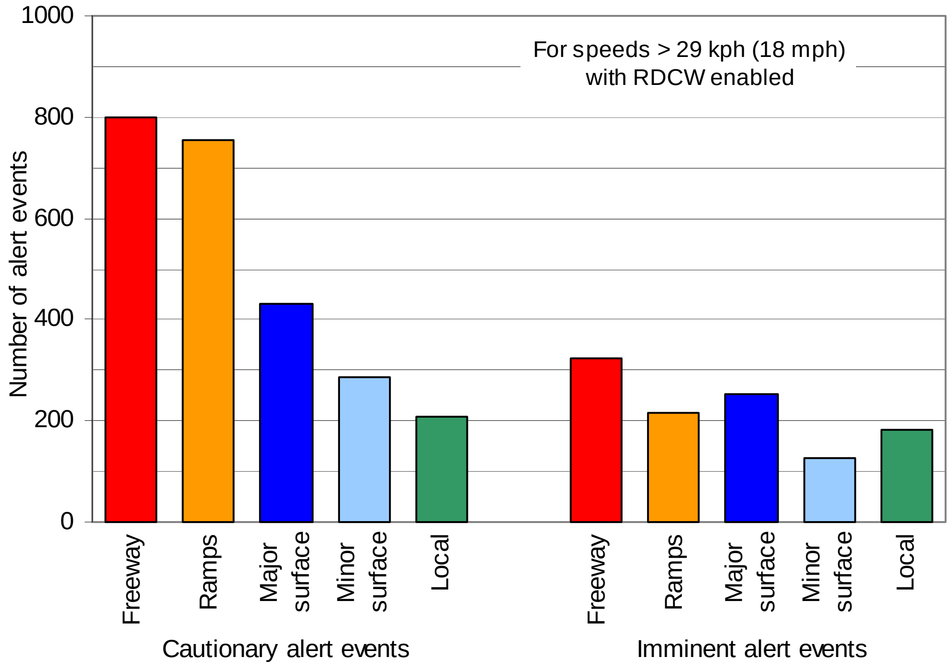

Figure 7.35 Numbers of CSW alert events by alert level, road type, and validity

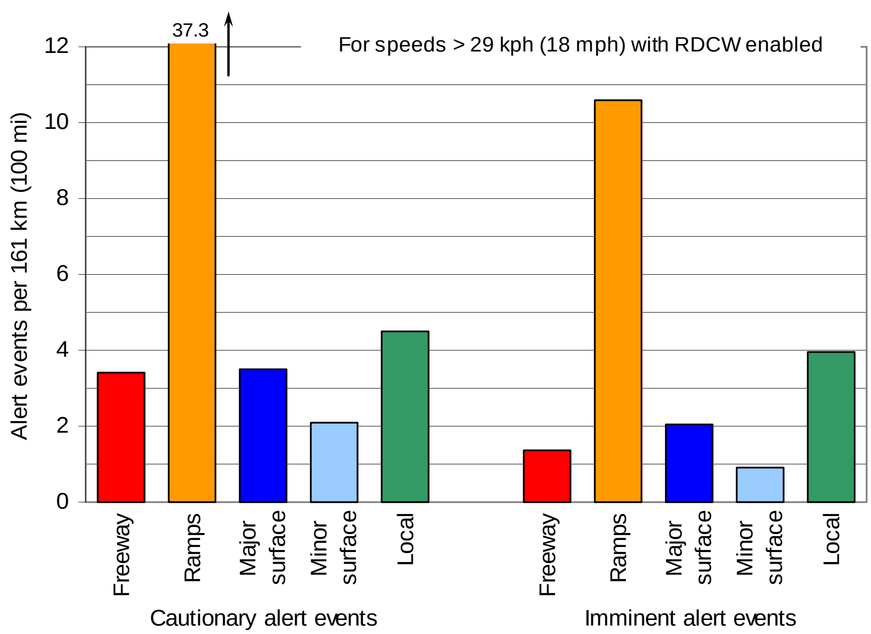

Figure 7.36 Rates of CSW alert events by alert level, road type, and validity

7.4.2.3 Speed at the onset of CSW alert events

Figure 7.37 shows that CSW alert events occur over a wide range of speeds, with significant numbers of events between 35 to 80 mph (55 to 125 kph), and smaller numbers at both lower and higher speeds outside that range.

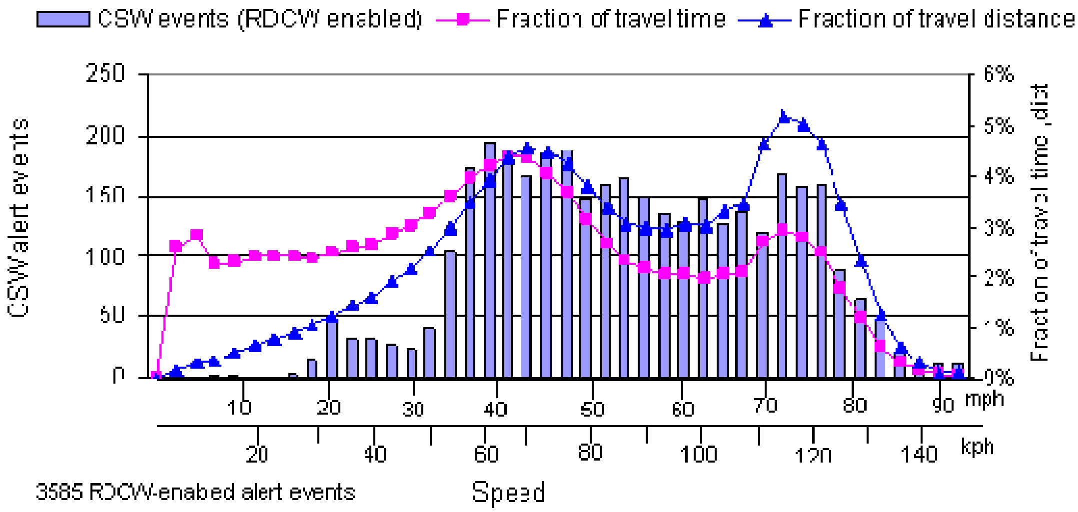

Figure 7.37 Distribution of CSW alert events by speed

Overlaid on this figure is the relative fraction of both time and distance traveled in these same speed ranges. The general trend is that CSW alert events occur at speeds that roughly mirror the overall time (or distance) spent at those speeds, except that the relative frequency of CSW alert events is smaller at speeds below 35 mph (55 kph). Recall from figure 2.1 in section 2 that crashes involving the loss of vehicle control on curves has a distribution over posted speeds that is not unlike that shown in figure 7.37. Thus, when only speed is considered, the occurrence of CSW alert events appears to be reasonably distributed.

7.4.3 Locale and type of digital map

CSW events in the FOT were slightly more common in the urban settings than in the rural settings. While approximately 80 percent of both travel time and distance occurred on urban roads, 89 percent of the RDCW-enabled CSW alert events occurred on these roads. This is shown in figure 7.38. Nine percent of CSW alert events occurred in areas labeled as rural by the Highway Performance Monitoring System (HPMS) database (versus 16 percent of travel distance and 10 percent of travel time); two percent of the alert events occurred outside Michigan.

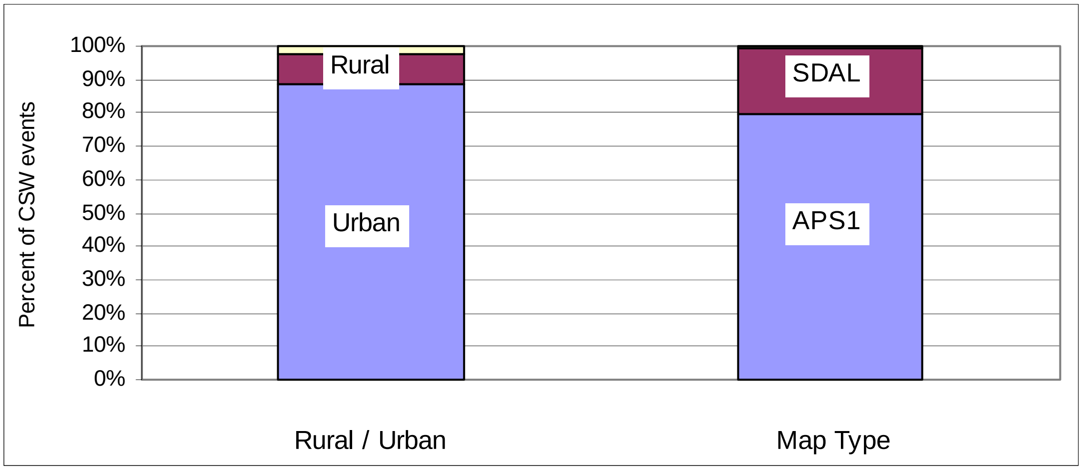

Figure 7.38 The location of CSW alert events including rural/urban designation and digital map type

It is not concluded, however, that the over-representation of CSW alert events on urban roads can be expected in a general deployment across the U.S. FOT travel in rural areas may have included an unusual amount of long-distance travel by urban/suburban drivers traveling across rural areas to arrive at a distant destination. Such travel is usually on freeways, and it is hypothesized that freeways crossing rural areas are likely to trigger many fewer alerts than most road types because the number of ramps per unit distance is likely smaller than that in suburban or urban settings.

A more important observation is that crashes addressed by the CSW are most common in rural settings, and yet 80 percent of FOT travel is concentrated in urban settings. Section 2.1 noted that the USDOT analysis of crashes involving the loss of vehicle control on curves showed that 60 percent and 80 percent of crashes on freeways and non-freeways, respectively, occurred in settings defined as rural. While it is true that the definitions of rural used in the analysis of the FOT data and in the classifications of crashes by US DOT may be different, it is clear that future FOTs might attempt to increase the exposure of the system to rural settings, relative to that collected in this experiment. Regarding the analysis of this CSW data, then, there may fewer than desired CSW alert events that are stereotypical of events in which most curve-speed crashes occur.

CSW events associated with travel on the APS1 map network accounted for about 80 percent of CSW events, with SDAL accounting for the others. This breakdown is consistent with the travel time and distance in areas covered by these two map types, as described earlier in section 6.1.4.

7.4.4 Same-location CSW events

Because many drivers traversed certain curves more than once during their FOT experience, they sometimes experienced CSW alert events more than once at the same location. On the other hand, the data also show that multiple traversals of the same curve did not always result in an alert event at each pass. This section studies the phenomenon of *same-location CSW alert events,* which are defined as CSW alert events that a given driver experiences at the same location and in the same travel direction as the location and heading of a previous CSW alert event experienced by that same driver. This section presents the number of same-location alerts per driver, as well as the fraction of all curve-related alerts that are same-location alerts. Also presented is a summary of how consistently alert events occur on successive passes of the same curve.

Because the motivation is in understanding drivers' experiences, only alerts during the RDCW-enabled period are considered. Also, in these analyses, only those alerts that are associated with the driver passing through a curve shortly after the alert are considered. The reason for discarding events in which a curve is not taken after the alert is that drivers are hypothesized to be less likely to associate those alerts with a location, so that the location per se is not as important a factor in their experience of that alert.

A total of 3585 CSW alert events were experienced by drivers in the FOT, of which 2207 are associated with a driver traveling through a curve shortly thereafter. Twenty-nine percent (643) of these 2207 alert events occurred while a driver is traveling through the same location and in the same direction as s/he was when a previous alert was experienced. Note that the first alert that is heard at any location is not counted as a same-location alert (otherwise the fraction above would be 1246 / 2207 or 56 percent of all alerts).

Same-location alert events are not necessarily undesirable or desirable alert events– it depends on the driver's perspective and the details of the particular set of alerts. Alerts that occur repeatedly on the same curve may lead the driver to have more confidence in the system. On the other hand, for other drivers, or in other circumstances, same-location alerts may be perceived as needless and annoying.

Furthermore, a driver may approach a curve on which a previous traversal let to an alert, and they may or may not experience another alert. This variability could be due to difference in approach speed, the sensitivity they have selected, or even changes in variables that are used as secondary influences in the CSW threat assessment algorithm, such as recent turn signal use, weather, and so on. In addition, normal errors in GPS may contribute to a small number of non-repeated events. Thus there can be no simple assignment of the quality of the alert based only on whether it is a same-direction alert. Nevertheless, it is worth characterizing drivers' experiences with same-direction alerts.

There is wide variation among drivers of the frequency that same-location alerts occur, relative to all alerts associated with curves. For the FOT drivers, the median value of the fraction of curve-related alerts that are same-location alert events is 22 percent, with values falling between 0 percent and 67 percent. Figure 7.39 shows the number of drivers that experience different numbers of same-location alerts. (Labels on the abscissa denote the bin centers of the histograms.)

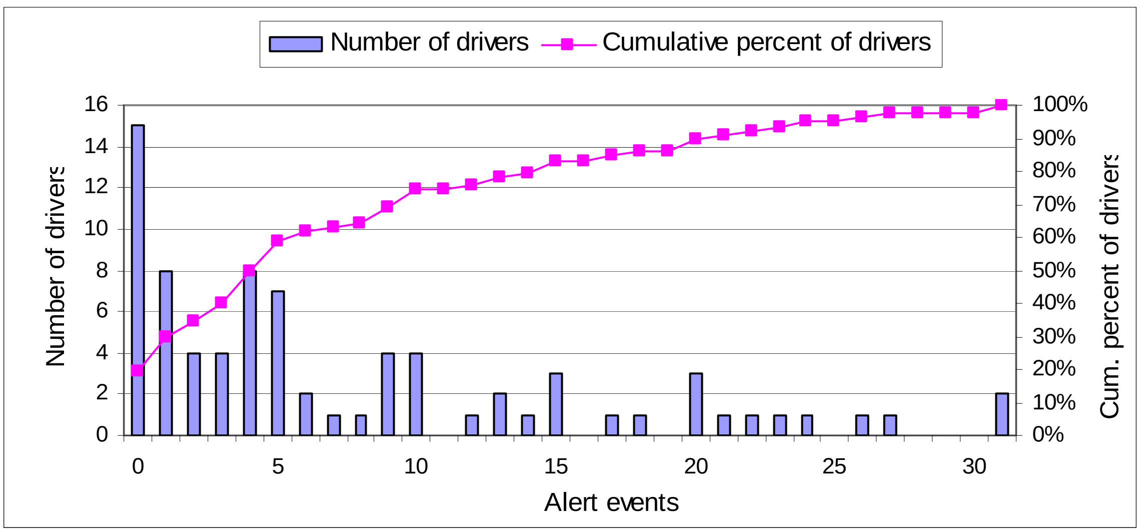

Figure 7.39 Number of drivers who experienced different numbers of same- location CSW alert events associated with curves

Exactly half the drivers experienced fewer than five same-location alerts in curves. On the other hand, twenty-one drivers experienced 16 or more same-location alerts in curves.

Figure 7.40 represents the same data, expressed as the percentage of CSW alert events associated with curves that were same-location alerts. Thirty percent of the drivers had same-location alerts that totaled 10 percent or less of the total number of alerts experienced that were associated with curves. Thirty percent of the drivers, however, had over 30 percent of their alerts as same-location alerts.

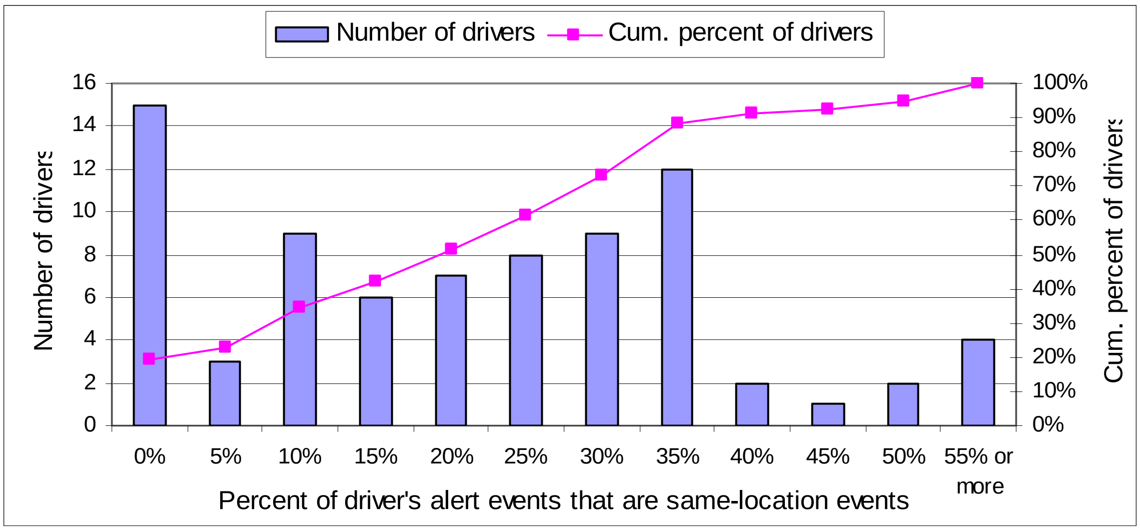

Figure 7.40 Number of drivers who experienced various percentages of same-location CSW alert events associated with curves, as a fraction of all CSW alert events associated with curves

Figure 7.41 shows the percentage of curve-related CSW alert events that are same-location alerts, with each point in the figure representing a driver. The figure does not show a clear trend, so the data do not support hypotheses that link the relative frequency of same-location alert events to the number of events. Later, in Section 9.2, a study of possible influences on an individual driver's acceptance of CSW will fail to show a statistical link across all drivers between same-location alerts experience and acceptance.

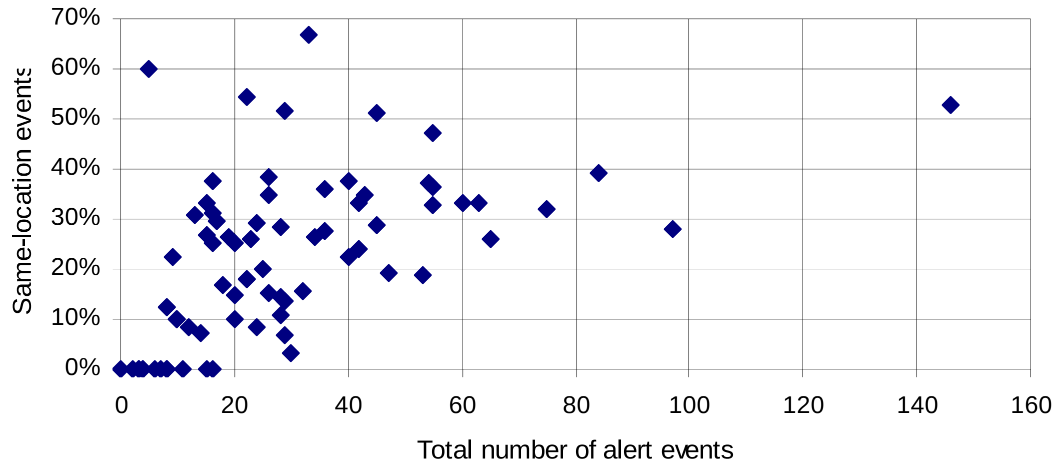

Figure 7.41 Percent of CSW alert events associated with curves that are same-location alert events

The results of this section, of course, are for the FOT and may or may not generalize well to experiences with vehicles that are driven for more than three weeks of RDCW-enabled exposure. If the FOT drivers had had the opportunity to drive the vehicle for longer than the time allowed in this experiment, the percentage of alerts that are same-location alerts may or may not increase over time. This depends in part on whether there is a general increase over time in the fraction of travel that occurs on roads previously traveled by that driver. If this occurs, then the percent of alert events that are same-location events would increase over time, and the issue of same-location alerts would be amplified in an actual deployment in the U.S. fleet.

Drivers who received same-location alerts may not have received an alert for each pass of that road segment. Variations in approach speed and sensitivity setting affect the warning timing, as do secondary influences such as recent driver brake application or turn signal use, and outside temperature and wiper status.

As cited above, there were 2207 CSW alert events that were displayed to the driver that were associated with travel through a curve shortly after the alert. Nine hundred and eighty one of these alerts were associated with locations through which the driver passed only once in that same direction. The remaining 1226 alert events – in which an alert occurred, and the driver made multiple passes over that road segment – can be divided by the total number of passes by that driver over those curves, which is 2893, so that overall, the average rate of alert occurrence per traversal of those curves was 42 percent, or about two alerts in five passes. This is an overall average, however, and examination of these 2893 individual curves that are traversed by an individual driver more than once, and that trigger at least one CSW alert event, shows wide variation in how often the alert occurs for a given driver at a particular curve. The rate differs, for example, from 14 cases of only one alert in 10 or more passes to 115 sets of multiple passes over a road segment during which an alert occurs every time, which together account for 311 alerts.

If a CSW system had a memory feature which attempted to suppress alerts that had occurred previously in a location, the upper bound on the number of alerts that could be suppressed would be 643 alerts of 2207 alerts, or 29 percent of those alerts associated with travel through a curve.   These calculations are not meant to suggest that such a feature is necessarily desirable.   An advantage of such suppression logic could be to reduce the potential nuisance of same-location alerts, at the cost of additional system complexity and cost. However, again, it is not known that all same-location alerts are considered nuisances by the drivers, and indeed it seems reasonable to expect that some drivers may find selected same-location alerts as reassuring.   The tradeoff involves many factors, of course, for example, considering that driving occurs in many weather situations, with different driver states, and even with different drivers using the same system. A more reasonable suggestion is to alter the alert algorithm based on previous traversals; in this case, the number of alerts that would have been suppressed would be somewhere between 0 and 29 percent, depending on the algorithm and the circumstances of the same-direction alerts.

7.4.5 Scenario analysis of CSW alert events

Two subsets of CSW alert events were studied in more detail to better understand drivers' experiences and perceptions of the CSW system. For these event sets, the driving scenarios in which CSW alert events occurred were identified using expert review of video and data using a set of customized computer review tools and a protocol for coding data for each event. The results lend additional insight into the design challenges associated with CSW systems. Later, in section 9, these results will also be correlated with driver subjective data to study the relationship between driving scenarios associated with the alert events and the drivers' post-drive ratings of alert utility.

The following elements are presented in the sections that follow: the sample populations that were examined; descriptions of the new data that was created during the review process; the development of curve-approach scenarios as well as groups of scenarios; and results of the scenario study.

7.4.5.1 Sample sets

Two subsets of CSW alerts were studied: a randomly-sampled event set that included 884 alerts and a driver-debriefing event set that included 411 alerts that were reviewed by drivers and discussed during post-drive debriefing sessions. The debrief event set addresses the drivers' review of those alert events and subsequent ratings of utility, and will be described in detail in section 9.2. The 884 randomly-sampled events are those that are studied in this section, and they are split evenly between cautionary alert events and imminent alert events. They are randomly selected from all CSW alert events that occurred during valid trips, and not stratified for driver, week, or other variables. Therefore, there is some overlap between the two sampled sets that occurs because each set drew from all alerts. The randomly-sampled set includes different numbers of events from each driver's experience. The distribution of the random alert set across the four weeks of driving is 246, 221, 199, 218 alerts during weeks 1, 2, 3, and 4, respectively.

7.4.5.2 Video review protocol

For those CSW alerts that were selected for review, analysts assigned values to 24 different variables based on review of video and the objective data from those alerts. Twelve of the variables are associated with the circumstances of the CSW alert event and 12 variables address driver activities before, during, and after the alert. These events were coded by two reviewers with extensive experience with both crash warning systems and event coding. Initially, an overlapping set of events was coded by both reviewers and the results compared in order to improve inter-reviewer reliability before the remaining events were coded.

Table 7.4 on the next page lists the variables that address the driving circumstances associated with the reviewed CSW alert events. This list was developed in an iterative manner by studying different sets of alert events and working with the Visteon CSW system designer. A more detailed description of each variable can be found in appendix R.

Table 7.4 CSW scenario variables coded during video-assisted review

CSW scenario variables	
Road type (from video).	Rain, snow, or no active precipitation.
Is the curve that triggered the CSW alert on the current road or is it on a branch ahead? .	Actual post-alert path of the vehicle, relative to RDCW's prediction of road branching.
Presence of a nearby curve.	Presence of nearby overpass or underpass.
Type of branch that triggers the alert, e.g., ramp, turn lane.	Direction of any recent lane change.
Reviewer's confidence in identifying the curve that triggered the alert.	Number of through travel lanes in travel direction, as well as any nearby change in the number of lanes.
Wetness of road.	Reviewer notes regarding the scenario.
Driver behavior variables	
Eyes on/off driving task at alert onset.	Obscuration of driver's vision or video images at alert time.
Glance direction at alert onset.	Possible driver startle response to alert.
Glance direction in transition at moment of alert onset.	Possible driver steering response to alert or situation.
Glance direction: last non-forward glance before alert.	Hand location at alert onset (e.g., on steering wheel).
Time from non-forward glance before alert to the alert onset.	Driver involvement in secondary, non-driving tasks.
Glance change from non-forward to forward direction within 1 sec of alert onset.	Reviewer notes regarding driver behavior.

7.4.5.3 Definition of scenarios and scenario groups

Using the coded values of variables listed in table 7.4, each event in the sample sets was assigned a scenario label. These labels capture a few aspects of the alert event, including:

- Success of the CSW system's prediction of which roadway the vehicle will take at an upcoming branch (e.g., whether the vehicle will move onto an exit ramp or pass by the ramp).
- False alerts that were caused by system issues, such as issues in using map data to compute curvature, map-matching errors, and software issues, and

- Roadway environment parameters, including the type of road on which the vehicle is traveling, as well as the presence of any upcoming branches that triggered the alert.

There are other important attributes of alert events that are not captured by these three factors. These factors were selected, however, to provide data regarding the role of driving scenario on the relative frequency of alerts that drivers describe as useful alerts.

The scenario labels are listed in table 7.5, and are arranged in three groups of rows, which will be called "scenario groups." The first of these groups, Group A, addresses alert events in which the alerts are triggered by significant curves that are in fact traversed by the vehicle. The term "significant" is intended to represent curves that could conceivably warrant an alert, per the intended design of the system.

Table 7.5 CSW alert event scenarios

Scenario index	*Scenario (including road setting)*	
Group A	**Alerts triggered by significant curves that are traversed by the vehicle.**	
A1	Traveling on ramp;	alert triggered by curve on same ramp
A2	Traveling on freeway;	alert triggered by exit ramp taken
A3	Traveling on surface road;	alert triggered by exit ramp taken
A4	Traveling on ramp;	alert triggered by merge onto main roadway
A5	Traveling on ramp;	alert triggered by branch taken
A6	Traveling on freeway;	alert triggered by curve ahead on same road
A7	Traveling on surface road;	alert triggered by curve ahead on same road
A8	Traveling on surface road;	alert triggered by Michigan left taken
A9	Traveling on surface road;	alert triggered by branch taken
Group B	**Alerts triggered by curves located on road branches that are not traversed by the vehicle.**	
B1	Traveling on freeway;	alert triggered by ramp not taken
B2	Traveling on surface road;	alert triggered by ramp not taken
B3	Traveling on ramp;	alert triggered by branch not taken
B4	Traveling on surface road;	alert triggered by Michigan left not taken
B5	Traveling on surface road;	alert triggered by branch not taken
B6	Branching from surface road;	alert triggered by curve on original road not taken
Group C	**Alerts due to system issues and unclassified alert events** ▪ Alerts due to exaggerated curvature estimates, navigation system reboot, and map-matching errors ▪ Alerts that reviewers could not confidently classify	

An example of an insignificant curve is a typical freeway curve without a special posted speed advisory and without any apparent hazard even when traveled at 20 mph (32 kph) over the posted speed. This scenario group is likely to contain many alerts that drivers can be presumed to comprehend and perhaps appreciate, since there is indeed a curve that follows the alert. The second group of scenarios in the table is Group B. These are alert events that are triggered by roadway branches that are never traveled by the vehicle. An example of this is a CSW alert event that occurs as the host travels on a freeway and approaches – but does not take – an exit ramp that has substantial curvature. This set of alerts is due to the inherent difficulty of predicting the path of the vehicle several seconds into the future, and studying this set highlights this basic challenge. Another cause of this type of alert is an error in the CSW system's placement of the vehicle on a roadway in the digital map, the so-called map-matching problem. The third scenario group is group C, which consists of those alert events that the reviewers could not place in the first two categories. The great majority of these are false alerts due to technical issues including generic challenges to CSW systems as well as a small number of system-specific alert events. The different types of alerts in this group are described in detail below. This final group also includes a smaller set of alert events that would ideally have been categorized in the other scenario groups, but in the first two groups, but was not because the reviewer had limited time and tools at their disposal. The false alert portion of this third scenario group represents a set of alerts that drivers are unlikely to comprehend, and may be less likely to value.

Another dimension of scenario characterization is the roadway setting at the time of alert onset. . Three roadway settings are used, as indicated in table 7.5: surface road, freeway, and ramps. The term *ramps* is used here to also include any portion of an interchange between two highways, including transition roadways that may be several hundred meters long. It does not include turn lanes or U-turns on surface roads, which fall under surface roads.

Each of the sixteen scenario labels in Table 7.5 is now described. Several scenarios in Table 7.5 address cases in which the vehicle is approaching a ramp or traveling on a ramp, and a CSW alert event is triggered by estimates of curvature on the ramp. Figure 7.42 shows these scenarios, including scenario A1, in which the vehicle is on the ramp. Scenarios A2 and A3 represent approaches to an eventual traversal of the ramp from freeways and surface roads, respectively. CSW alerts may be triggered by a ramp, even though the vehicle is passing by – or will pass by – the ramp. Scenario labels B1 and B2 are used to identify these situations, and they are shown in figure 7.42, also.

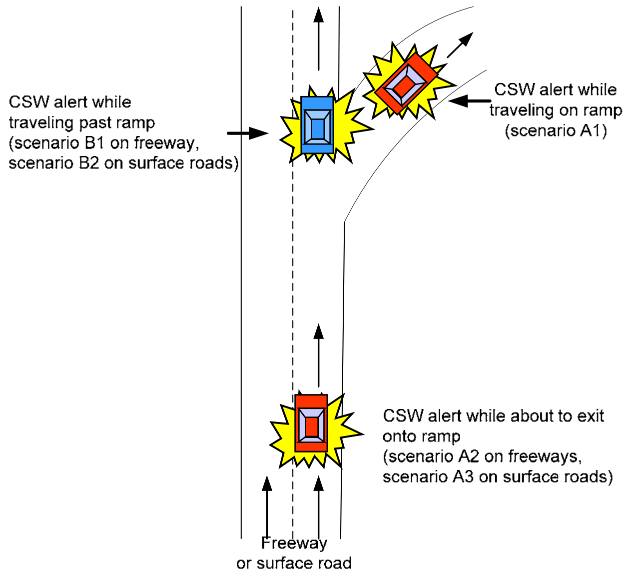

Figure 7.42 CSW alert event scenarios involving curvature on a nearby ramp

Scenario A4 addresses a special case of a ramp-related scenario in which the vehicle is traveling on a ramp and is within several seconds of merging onto another roadway. (This is not illustrated in a figure.) This scenario is kept separate from others because the root cause of these alerts is usually different than that of the previous scenarios. The common cause of these scenarios is that the driver often increases speed when approaching the merge point. There are also occasional unwanted alerts that can result from using digital map points near merge points; again, this is due in part to using a map constructed for navigation, which requires less precision than CSW. (This is described later, under scenario group C). Scenario A5 addresses the approach from a ramp or other transition roadway to a secondary ramp, with the CSW alert event triggered by curvature on the secondary ramp. This has a counterpart scenario B3, which is used when the vehicle does not branch onto the secondary ramp.

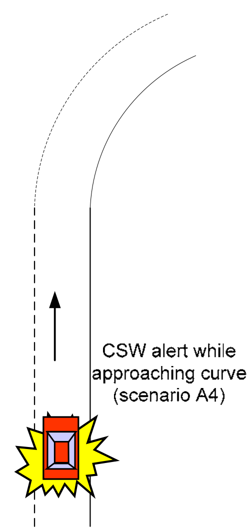

Figure 7.43 CSW alert event scenarios in which the alert is triggered by the freeway or surface road curvature ahead

The two scenarios labeled A6 and A7 in Table 7.5 describe situations in which the CSW alert event occurs while the vehicle is traveling toward a curve on the road ahead, with scenarios A6 and A7 associated with freeway curves and surface road curves, respectively. These are perhaps the simplest scenarios, since the curve ahead is the source of the alert, and there is no relevant branching of the vehicle onto other roadways. These scenarios are illustrated in Figure 7.43.

Two more scenarios are A8 and B4, which both address alert events that are triggered by curves within U-turns or short left turn lanes that are part of the so-called *Michigan left turn*. Michigan left turns are a regional highway design practice that seeks to improve intersection capacity and reduce crash harm by utilizing a combination of a U-turn and a right-hand turn as a replacement for a left turn. These are found on surface roads, primarily arterials in urban areas. On these roads, the CSW system constantly needs to predict whether the driver may be deciding to branch onto the approach lane leading to the small-radius U-turns. When this is combined with a multiple-lane arterial and lane-changing activity, consistently predicting the path is a difficult challenge. These events are separated in part because the Michigan left is not a common feature on U.S. roadways, and therefore would be an issue only a small fraction of drivers nationwide. Figure 7.44 shows two scenarios involving Michigan lefts. The first is scenario A8, in which the vehicle eventually travels through the curve. The second scenario is scenario B4, which is assigned to events in which the alert is triggered by the curve within the Michigan left but the vehicle continues on the original roadway.

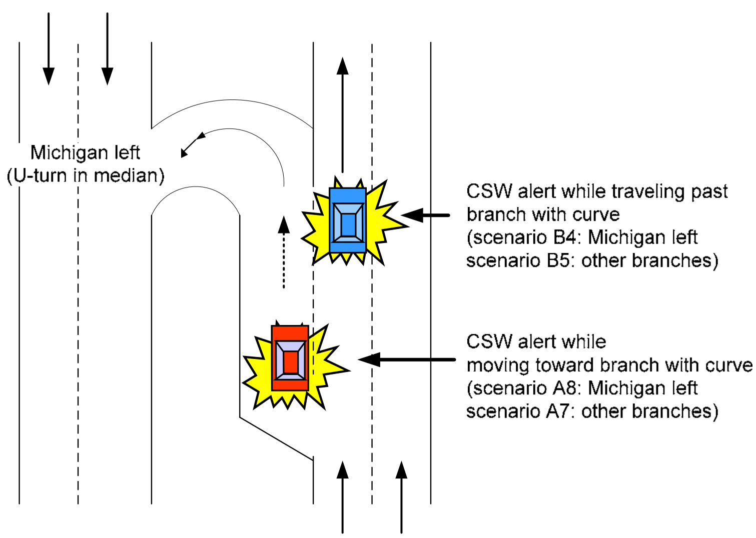

Figure 7.44 CSW alert event scenarios involving Michigan left turns

Two other scenarios are similar in nature to the Michigan-left scenarios, except that the estimated curvature that triggers the alert event is associated with a turn lane or another type of branch from a surface road. The labels for these are A9 and B5 which address, respectively, alert events in which the vehicle either branches onto the transition segment (A9) or passes by the segment (B5).

The final scenario in group B is B6, and is associated with a rare situation in which the vehicle is branching from a surface road onto a new roadway segment, yet a CSW alert event is triggered by a curve on the original roadway segment.

Finally, scenario group C addresses the set of events which the reviewer could not sort into either of the first two groups. This group is comprised mostly of false alerts that occurred due to system issues, although a minority are simply events in which the reviewer was not able to confirm the source of the alert. System-issues events include at least four types of alerts, as listed in Table 7.5, which are described further in the subsections that follow.

7.4.5.4 Alerts due to incorrect curvature estimates that in turn are derived from digital map shape points that are laterally offset.

There are at least three situations in which the combination of digital map information and the use of that information within the CSW system led to false perception of curvatures ahead. These situations were identified during the development phase by the CSW development team led by Visteon, and are reported here with examples from the FOT data. It should be stressed again that the maps used in this project were developed over recent decades to support applications including navigation – but not originally meant to support precise curvature calculations that are required for autonomous, onboard CSW systems.

(a) Lateral misplacement of roadway geometry shape points within the digital map database can lead to exaggerated estimates of curvature.

The digital map consists of discrete points called shape points that are intended to be centered within the roadway. Waypoints are occasionally offset laterally from the actual road geometry, especially near overpasses or underpasses, where points are added to indicate the grade level of each roadway. Applications such as CSW systems use sequences of shape points to generate curvature estimates for the upcoming roadway and are currently not aware which points are lower-accuracy, grade-level points.

Although the latest NAVTEQ digital map (APS1) has improved accuracy and additional attributes specifically added for driver support systems such as CSW, the maps were historically built for navigation purposes. For navigation, of course, the precise lateral location of consecutive waypoints is not a concern. Furthermore, occasionally during the process of constructing the map database, there are hand input points (which are more common in complex roadway configurations, such as overpasses, U-turns, and others). A misplacement of even a few meters can lead to a noticeable change in curvature if not filtered out.

Figure 7.45 shows the concept of an offset waypoint leading to an error in estimating curvature. There are two common situations in which false CSW alerts occur due to the offset waypoints: curvature that is estimated where none exists (on straight roadways), and exaggerated curvatures at actual curves. These are illustrated in figure 7.45. Both situations occur most often on freeways, since underpasses and overpasses are more common on freeways than on other road types.

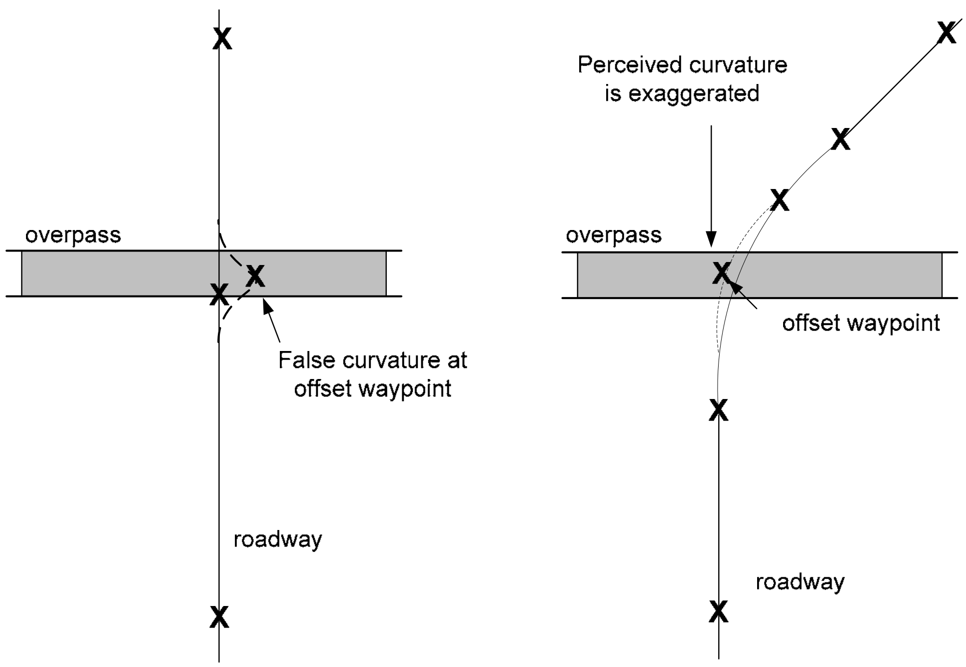

Figure 7.45 Misperceptions of upcoming curvature associated with laterally offset map waypoints

For CSW, the knowledge of occasional misplaced points presents a design dilemma. If the points suggest a sudden change in curvature, should the system assume that it is a false artifact, and suppress the alert? Or should the CSW be more conservative and alert drivers for an actual sudden change in curvature that may be associated with a particularly dangerous geometry? The design of the CSW under study has emphasized responsiveness to possible curve-overspeed situations, so that the system is not heavily filtering the computations of curvature.

(b) Misrepresentation of merging road geometries.

There are occasional misrepresentations of the geometry of a merging ramp, so that the angle at which the merging ramp intersects the main throughway becomes large, as illustrated in Figure 7.46. When processing is not designed to look for this phenomenon, this can lead to a false estimate of a sudden significant curvature, which was seen to occur in this project and lead to false CSW alert events.

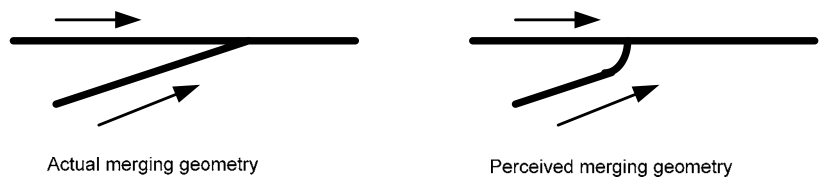

Figure 7.46 Error in map-based perception of road geometry at a merge point

(c) False perception of road curvature at locations where the number of through-lanes changes.

The map database represents road geometry through points along the center of the roadway. When the number of through lanes changes, there then becomes a lateral shifting of the waypoints, as shown in the top part of Figure 7.47.

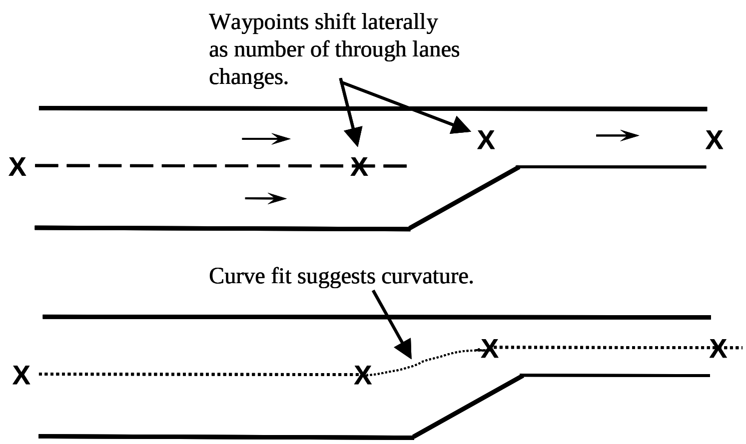

Figure 7.47 Change in number of through lanes can lead to false perception of road curvature

Depending on the relative displacement between waypoints and the host vehicle speed, the apparent curvature that would result from some curve-fitting algorithms can trigger a CSW alert event based on the perceived curvature. This only applies to changes in through lanes, not to the endpoints of dedicated turn lanes.

7.4.5.5 False alerts due to rebooting of the CSW navigation system

Occasional self-induced reboots of the navigation portion of the CSW system were known to lead to temporary errors in the GPS location of the vehicle. While the system design suppressed CSW alerts for several seconds following such an event, there were occasional remaining episodes in which incorrect GPS locations were processed. This sometimes led to false CSW alert events that would occur regardless of the actual position of the vehicle. Based on some follow-up review of the data, it is estimated that approximately 10 percent of the system-issues alerts (3 percent of all alert events reviewed) could be due to this error.

7.4.5.6 Map matching errors (vehicle placed on wrong roadway).

A necessary step in most map database applications is a computation that selects the roadway on which the vehicle is currently traveling. Another error is thus the occasional misplacement of the vehicle on the wrong road, usually a nearby road. This CSW system used a non-differential GPS system because that is considered the commercially viable type of system. The RMS of the horizontal positioning error was roughly 10 m. Examples of map-matching errors were observed on both freeways as well as surface roads. A particular challenge occurs when a vehicle approaches an exit ramp and does not branch off onto the ramp. The map-matching occasionally places the vehicle on the ramp, resulting in an alert for a curve on the ramp. This particular case is categorized in group B. Other cases, such as the mis-placement of a vehicle on a nearby road, are categorized here in group C. While this latter case is a contributor to false alerts, it is not thought to be a major factor. It is noted that even a differential GPS unit would still not prevent map-matching errors.

7.4.5.7 Other events that reviewers could not categorize

Some alert events occurred in complex situations, so that the reviewers could not be confident in their determination of the source of the CSW alert. An example is a case in which an alert occurred on a freeway just before a gentle freeway curve, but also near an overpass as well as related ramps that are part of a complex interchange between two major freeways. The reviewer could not determine which roadway the map-matching system had located itself on, whether the curvature leading to the alert was on the ramp or an exaggerated perception of the curve ahead, or whether an overpass waypoint issue was relevant. Events such as this constitute a minority of the events that were labeled “system issues,” and an engineering estimate based on a limited study is that this may account for one in four or five of the system issues events.

7.4.5.8 Outlook for reducing Group C alert events

The large majority of Group C events result from artifacts of the implementation of a CSW system, including digital map characteristics and prototype system stability. Events due to the system instability (navigation subsystem rebooting) are clearly events that can be eliminated in a second experiment or in commercial release. The digital map issues are more challenging, however, there are approaches to mitigate those effects, so that the fraction of alerts within Group C can be expected to decrease as second and third generation CSW systems are created. Some solutions include making additional map database attributes available to the CSW system to enable better decision-making capability in the presence of complex geometries. In addition, improvements to the real-time filtering of curvature estimates can eliminate more false curvatures. While substantial work would be needed to develop these improvements, a preliminary estimate of the approximate impact is that it may be possible to reduce the fraction of events associated with the systems issues Group C by an estimated factor of three to five in the near term.

7.4.6 Results of scenario coding

Results from assigning scenario labels to the randomly sampled set of CSW alert events are presented in this section. The purposes of showing these results are:

1. to characterize drivers' experience in this experiment, in order to interpret subsequent sections on driver behavioral changes and driver acceptance, and
2. to provide insights into the design challenges of CSW systems, no matter where they may be deployed.

Results will be shown for cautionary alert events, imminent alert events, and a weighted average of those two alert event types. Recall that during the FOT, 68.6 percent of the alert events were cautionary alert events and 31.4 percent were imminent alert events. Since the randomly sampled set was split evenly between cautionary alerts and imminent alerts, the weighted average is computed as:

Weighted average =

0.686 x (Cautionary event set result) + (1 – 0.686) x (Imminent event set result)

The reader is reminded that because CSW system performance is strongly influenced by the roadway environment, the results that are reported here should not be taken as quantitatively applicable to different regions across the country or, indeed, the entire country. The relative frequency of scenarios found in these data is influenced by the geographical location of the FOT experiment. Important regional differences include the prevalence of curved road geometry, as well as the characteristics of the curves. These are clearly quite different in southeast Michigan than they are, for example, in the mountainous regions of the Appalachian or Rocky Mountain states.

Figure 7.48 compares the distribution of all CSW alert events across roadway types with the distribution of CSW alert events within the randomly-sampled alert set. In the figure, the randomly-sampled set is characterized by the weighted average of the cautionary and imminent alert events within the set. The distribution of all RDCW-enabled events across road types was shown earlier in Figure 7.35.

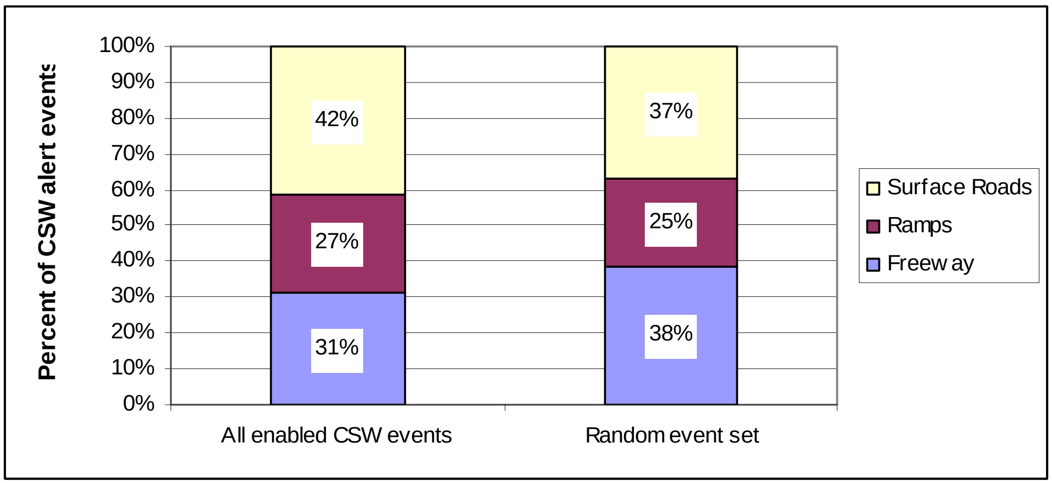

Figure 7.48 Distribution of CSW alert events across road types based on analysts' review of 884 randomly sampled events

The comparison in Figure 7.48 shows that when comparing the randomly sampled set with the entire set of enabled CSW events, the randomly-sampled set has a higher percentage of freeway events (38 percent vs. 31 percent), a lower percentage of surface road events (37 percent vs. 42 percent), and approximately the same percentage of ramp events (25 percent vs. 27 percent). The differences in the freeway and surface road contributions will be considered in the following discussions of results of studying the randomly-sampled set.

Table 7.6 presents details of the scenario results, including the relative frequency of cautionary and imminent alert events for each scenario. Consider first the fractions of cautionary events associated with scenario groups A, B, and C, discussed

Table 7.6 Relative frequency of occurrence of CSW alert event scenarios using randomly sampled alert event set

884 CSW alert events coded (442 each for cautionary and imminent level events)
Roadway setting: R = ramp-related, S = surface road, F = freeway

Scenario index	Scenarios	% of Cautionary Events	% of Imminent Events	Weighted average
Group A	**Alerts triggered by significant curves that are traversed by the vehicle.**	**43.9%**	**40.5%**	**42.7%**
A1	Traveling on ramp (R); alert triggered by curve on same ramp	16.3	10.6	14.5
A2	Traveling on freeway (F); alert triggered by exit ramp taken	3.2	2.7	3.0
A3	Traveling on surface road (S); alert triggered by exit ramp taken	1.1	0.7	1.0
A4	Traveling on ramp (R); alert triggered by merge onto main roadway	2.0	0.7	1.6
A5	Traveling on ramp (R); alert triggered by branch taken	3.2	0.5	2.3
A6	Traveling on freeway (F); alert triggered by curve ahead on same road	1.4	0.7	1.1
A7	Traveling on surface road (S); alert triggered by curve ahead on same road	12.0	16.3	13.3
A8	Traveling on surface road (S); alert triggered by Michigan left taken	2.9	7.0	4.2
A9	Traveling on surface road (S); alert triggered by branch taken	1.8	1.4	1.7
Group B	**Alerts triggered by curves located on road branches that are not traversed by host**	**26.9%**	**21.9%**	**25.2%**
B1	Traveling on freeway (F); alert triggered by ramp not taken	17.2	5.9	13.6
B2	Traveling on surface road (S); alert triggered by ramp not taken	2.0	2.5	2.2
B3	Traveling on ramp (R); alert triggered by branch not taken	2.9	1.8	2.6
B4	Traveling on surface road (S); alert triggered by Michigan left not taken	2.9	8.8	4.8
B5	Traveling on surface road (S); alert triggered by branch not taken	1.8	2.5	2.0
B6	Branching from surface road (S); alert triggered by curve on original road	0.0	0.5	0.1
Group C	**Alerts due to system issues and unclassified alert events** ▪ Alerts due to exaggerated curvature estimates, navigation system reboot; and map-matching errors ▪ Alerts that reviewers could not confidently classify	**29.2%**	**37.6%**	**31.8%**
	Traveling on ramp (R)	4.1	3.8	4.0
	Traveling on freeway (F)	18.6	24.9	20.5
	Traveling on surface road (S)	6.6	8.8	7.3
ALL	**ALL SCENARIOS**	**100%**	**100%**	**100%**

previously; cautionary events are considered first because they constitute about two of three CSW alert events. The table shows that the scenarios that belong to Group A, in which the vehicle traverses the curve that has triggered the alert, account for 43.9 percent of all cautionary alert events in the randomly sampled alert set.

It is hypothesized that Group A alert events may be more likely to be valued or acceptable to drivers than events associated with Groups B and C. This hypothesis is based on the notion that drivers may be more likely to link Group A alerts with a curve than events associated with the other groups. Thus, these alerts are more likely to make sense to them, whether or not they agree with the judgments of risk. Section 9 presents drivers' ratings of utility of alerts by scenario group, and one outcome of that study is that drivers rate events in Group A as having more utility than events in either Group B or C.

The second group of scenarios, Group B, accounts for 26.9 percent of cautionary alert events in the randomly sampled set. These scenarios are associated with alerts triggered by curves that are not traversed by the driver, as explained earlier. The relatively high frequency of events associated with Group B highlights central design issues of CSW. These alert events occur because the system considers the possibility of branching whenever the vehicle approaches a branch. This philosophy is one that maximizes safety benefits as long as the system predicts the correct path. The prediction is quite challenging because it involves:

- uncertainty in the placing the vehicle on the correct roadway with a non-differential GPS and a digital map that is not built to identify precise branching locations (e.g., is the vehicle already on a ramp?)
- uncertainty of predicting whether a driver approaching a ramp will take the ramp.

The system attempts to address these challenges in part through complex rules that consider driver control actions, lane boundary information, and the relative confidence in the hypothesis of branching. In fact, the system was usually successful in predicting the most likely path, i.e., whether the vehicle will branch or not. This can be illustrated by the fact that the rate of CSW alert events on freeways is less than 5 alerts per 100 miles (161 km), and yet drivers pass by ramps at a rate that is at least an order of magnitude higher. Thus since travel simply has a high exposure to possible branches in the road, a system that considers branches may tend toward an accumulation of events that leads to a significant number of Group B alerts unless its accuracy in predicting branching is extremely high.

One solution to this is using a different set of thresholds when computing CSW threat levels in transition road segments, such as ramps or turn lanes. By definition, these often involve braking and direction changes, and elsewhere this report shows that drivers tolerate higher lateral acceleration levels during transitions. Thus, the current system design (which, to first order, assumes the same lateral-acceleration threshold on all road types) could be revised to reduce Group B alerts by increasing the lateral-acceleration thresholds on transitional road segments. Furthermore, drivers are often intending to take significant braking action on a transition segment, and the system is assuming that the driver may be inattentive or unaware of the curve severity. Thus, another approach is to increase the assumed braking response of a driver to an alert on a transitional road segment. Yet another solution is to not consider some road branches when computing the risk of curve-overspeed. Turn lanes and Michigan lefts could be omitted from consideration when computing CSW alerts through logic that exempts surface roadways with very small radii.

Finally, Group C, which includes events due to system issues, as well as unclassified events, adds the remaining 29.2 percent of the cautionary alert events. The number of events associated with this is unexpectedly high -- almost one in three alerts is a false alert with a root source that the driver is very unlikely to understand. While a hypothesis was posed during the analysis of the data that this fact may constitute a significant impediment to driver acceptance, this hypothesis could not be substantiated in the analyses of Section 9. Many Group C alerts will be reduced by relatively simple means that were mentioned in the previous section.

Taking Groups B and C together, it is seen that a majority of the CSW alert events are either false alerts or are alerts triggered by a curve that the vehicle does not actually travel. Section 9 will present results that study whether this seems to affect drivers' opinions of the CSW system.

The corresponding results for imminent alert events are somewhat different. Table 7.6 shows that the relative fraction of imminent events associated with the system issues group C (37.6 percent of all imminent events) is larger than the fraction of cautionary alert events associated with the same group (29.2 percent). This might be explained by the fact that the mechanisms leading to the bulk of the system issues alerts often include false curvatures that are large enough to eventually trigger an imminent alert event. Furthermore, the CSW system has an intentional design feature whereby alerts that occur near branching points are often not allowed to progress to imminent alert events. Therefore the first two scenario groups would be expected to contribute a higher number of cautionary alert events since branch-related situations comprise a substantial fraction of these groups.

It is informative to divide the events associated with Group A scenarios into two subgroups, based on whether the vehicle changes roadways during the event, or within a short period of time before or after the event. Figure 7.49 shows the fraction of alert events (using the weighted average of cautionary and imminent alert events) associated with each of the scenario groups, where Group A has been partitioned in this manner. The figure shows that 14 percent of all the sampled events involve alerts triggered by a significant curve on a surface road or freeway that the vehicle will travel on in the near future, without branching onto another roadway to do so. These are perhaps the stereotypical curve speed warning scenarios, with no issues of predicting which road branch the vehicle will take. Twice that many events (28 percent) involve situations in which the vehicle is on an exit ramp or other transitional roadway segment, or is about to branch or merge onto such a ramp or segment, and the alert is triggered by that upcoming branch. Thus within Group A, there is a 2:1 ratio of transitional-road scenarios to non-transitional scenarios, which underlines how pervasive the role of ramps, turn lanes, Michigan lefts, and other transitional segments are in the environment that CSW design needs to address.

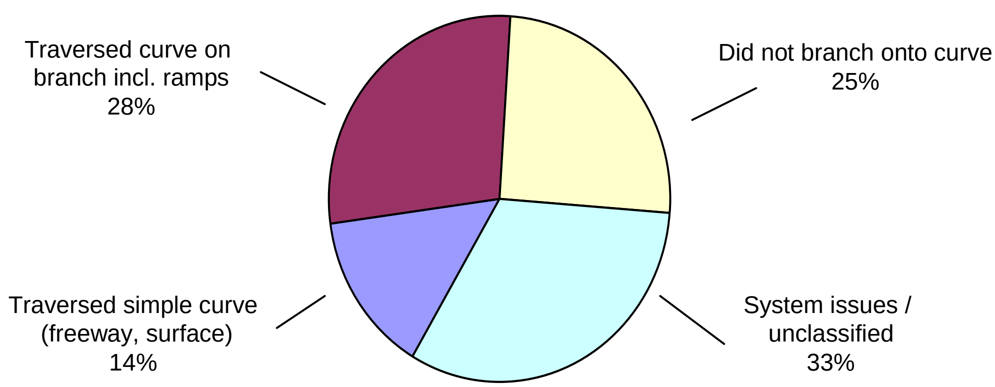

Figure 7.49 Percent of CSW alert events within each of the scenario groups (uses randomly sampled set)

When Group B is considered, the importance of transitional road segments in the CSW alert experience becomes even greater. All events within Group B are related to transitional road segments, since those events are triggered by branches that the vehicle did not take. Adding the total of Group B events in the rightmost column of

Table 7.6 (which is 25.2 percent) to the subtotal of Group A events associated with transitional road segments (28 percent) indicates that a total of 53 percent of all events would be related to transitional road segments. This is almost four times as many as the 14 percent of events in Group A's non-transitional segments subgroup, so that clearly transitional road segments are a major factor in the design and performance of CSW systems.

These ratios were surprising upon first observation, however, upon reflection, the large contribution of transitional road segments to CSW alerts seems quite natural and manageable as well. Transitional road segments are natural sources of curve speed issues. Such segments are, by nature, places where vehicles change direction or speed, and oftentimes both. On the other hand, freeways and most surface roads are designed specifically to avoid speed changes and curves that may pose risk or discomfort. Surface roads, of course, often involve curves with higher design lateral accelerations than freeways. But even surface-road curves are designed in tandem with posted speed limits (or advisory speed signs), so that on most curves, vehicles do not need to reduce speed to safely and comfortably negotiate the turns. If it is assumed that the majority of curves on surface roads allow drivers to continue at posted speed or speeds within reasonable differences from posted speeds, then CSW alert events are only necessary for substantial speeding behavior or unusual curves that do require slowing. Furthermore, it will be observed in Section 8 that the lateral accelerations on surface road and freeway curves are significantly lower than accelerations observed on ramps.

On the other hand, for transitional road segments, drivers often expect to slow down upon curve entry since they are aware that transitional segments often have curves, or they are expecting a decrease in speed on the approach to a different throughway. This leaves the CSW system designer with a tradeoff to manage – warning early enough to provide adequate response time to a driver who is unaware of the risks of the upcoming curve, while accommodating drivers who are aware of the need to slow down soon and are possibly expecting and accepting that the lateral acceleration will be greater than they would choose on a non-transitional road segment.

Earlier, the discussion had presented a series of ratios comparing the frequency of alert events triggered by transitional road segments to events triggered by other curves. To complete this discussion, it is noted that from the perspective of a driver in the FOT, the events within Group C should be considered as well. Table 7.6 shows that Group C represents 31.8 percent of the weighted average of the cautionary and imminent alert events. When this is added to the mix, the percentage of all events involving transitional road segments becomes 57 percent, and the percentage of events that do not involve these segments amounts to 43 percent. Therefore drivers' actual experiences in this FOT may not have such an exaggerated sense of transitional road segments being involved in their CSW alerts because of the "diluting" effect of the Group C events.

The balance of cautionary and imminent alert levels is approximately the same across scenario groups. Figure 7.50 shows the distribution of cautionary and imminent alert events across the groups. The ratio of cautionary to imminent events is roughly 2:1 for the system-issues group C, and closer to 3:1 for the other groups. Thus it is acceptable to study the relative frequency of the groups themselves without undue concern for the level of the alerts.

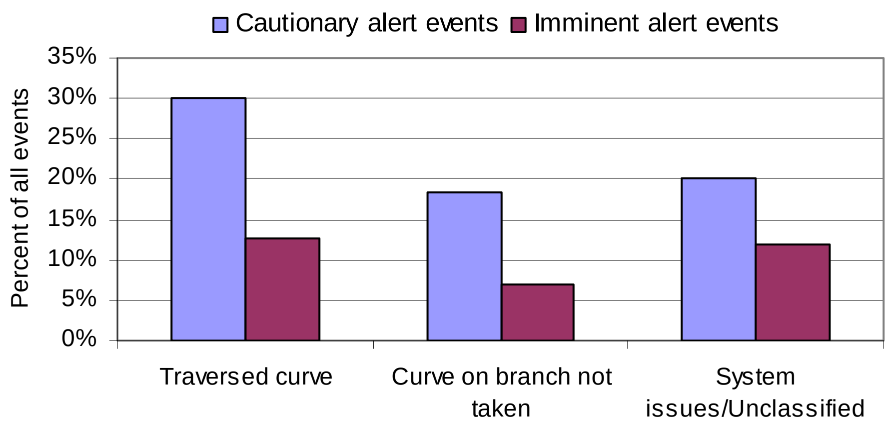

Figure 7.50 Distribution of CSW alerts by alert level and scenario group (randomly sampled alert set)

The role of road type in CSW alert event experience is now discussed. Figure 7.51 shows the distribution of the events across the scenario groups, as a function of the three road settings.

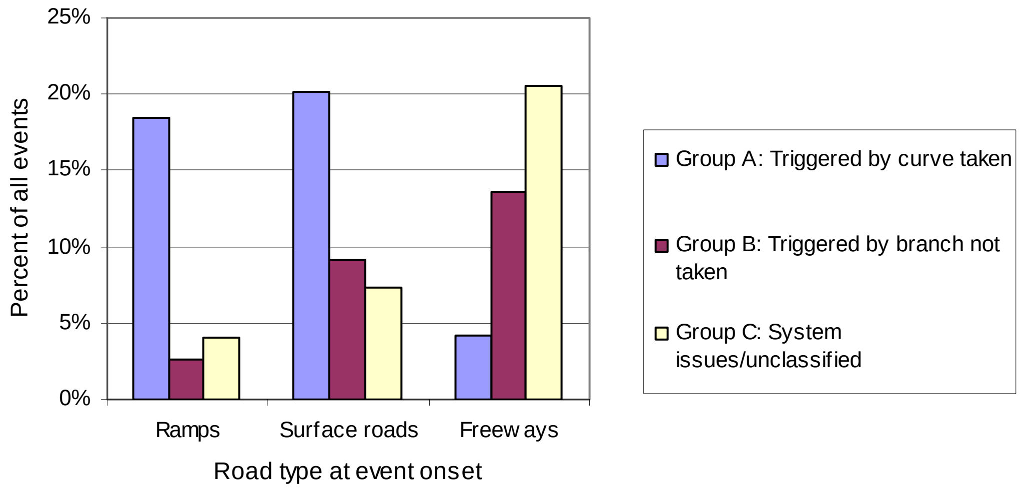

Figure 7.51 Relative frequency of CSW events associated with the three scenario groups and the three roadway settings (weighted average estimate using the randomly sampled set)

This figure shows that the driver's experience with CSW tends to be different while traveling on different road types. First, consider the fraction of events within each road setting that falls within scenario Group A. For ramps, the Group A scenarios account for most of the events. When traveling on surface roads, the most common scenarios are those of Group A, with just over half of events that begin on ramps. On the other hand, Figure 7.51 shows that Group A accounts for only 10 percent of the freeway alerts. That is, while CSW alert events experienced on surface roads and ramps are likely to be related to a curve that the driver will soon travel, the events that occur on freeways per se (and not on freeway ramps) are rarely related to upcoming freeway curves. The "quality" of CSW alert events on freeways could therefore be presumed to be lower than the events on other road types.

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8 Driver Behavior: Analysis of Objective Data

The safety impact of the RDCW system is best studied through observing the changes in driving patterns and driving behavior that occur when drivers move from the first, baseline week of the FOT to the remaining three weeks, during which drivers are presented with the RDCW driver alerts. As noted in earlier sections, the FOT does not capture enough travel time to allow comparison of road-departure crashes or near crashes. Instead, indications of driver responses to alerts and drivers' adjustments of their lane-keeping and curve-speed habits are used to suggest the potential for safety impacts.

This section often discusses the potential effects of the LDW and CSW system as if the effects of those two warning functionalities are separate phenomena and their effects can be decoupled. That is, lane-keeping performance and lane excursions are studied and discussed in association with LDW alerts. Likewise, the speeds that drivers choose to travel through curves is examined and linked to CSW alert events that those drivers received. However, there is no proof that lane-keeping performance is only influenced by the LDW and not by the CSW, and that curve-speed behavior is only related to the CSW alerts. In fact, the driver experiences both systems within the same vehicle, on the same set of trips, and there is little guidance from the data regarding the degree to which any particular driver views the system as either completely integrated -- and related only to preventing road departures -- or, conversely, as two completely independent systems. Thus, in discussing changes in observed driving behavior, the actual causes for changes or lack of changes cannot be attributed with confidence to either LDW or CSW individually, but only to the presence of the integrated RDCW system.

This section includes three major sections. Section 8.1 studies the changes in lane-keeping performance and responses to LDW alerts. Section 8.2 addresses the speeds at which drivers approached curves, both with and without the RDCW system. Finally, in section 8.3, the frequency with which drivers chose to engage in secondary, non-driving essential, tasks with and without the RDCW system engaged is examined.

8.1 Driver behaviors related to LDW

This section will examine the objective data for indications of the drivers' responses to LDW alerts. Both short- and long-term responses will be examined, that is, response to LDW alerts when they take place, as well as more general changes in driving behavior that appear to be related to the LDW function and come about following exposure to the RDCW system.

8.1.1 Responses to LDW alerts

The 78 FOT drivers experienced 5742 LDW alerts during their three weeks of driving when RDCW was enabled. Analysis of the objective data indicates that following 3906 of these alerts, or 68 percent, the drivers remained in the lane they were in when the alert took place (for at least 5 seconds). Figure 8.1 shows this result but also distinguishes between the response following cautionary and imminent alerts, respectively. Interestingly, drivers appear to have continued to change lanes following more than half (60 percent) of the cautionary alerts. Or put another way, more than half of the cautionary alerts appear to have been caused by deliberate lane changing. On the other hand, drivers did stay in their current lane following the great majority (85 percent) of imminent alerts.

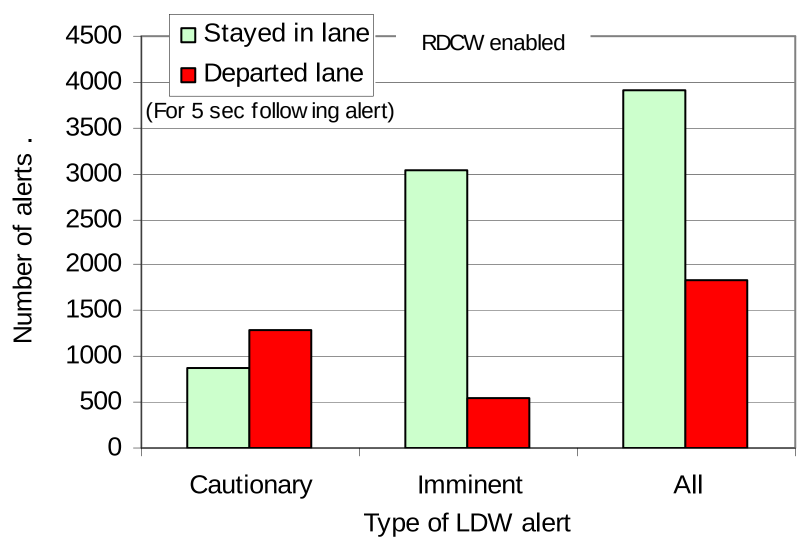


Figure 8.1 Lane-changing patterns following LDW alerts

Figure 8.2 examines responses following those imminent LDW alerts for which the vehicle remained in its lane (i.e., the set making up the taller center bar of figure 8.1). The abscissa of the graph plots the lateral position of the vehicle in the lane relative to its position at the time of the alert (i.e., the change in lateral position since the alert). The polarities are arranged such that a positive value indicates the vehicle *returning to* the original lane and a negative value indicates the vehicle moving farther *out of* the lane. The ordinate axis is the fraction of the sample of responses within the lateral motion bin (0.5-meter bin width).

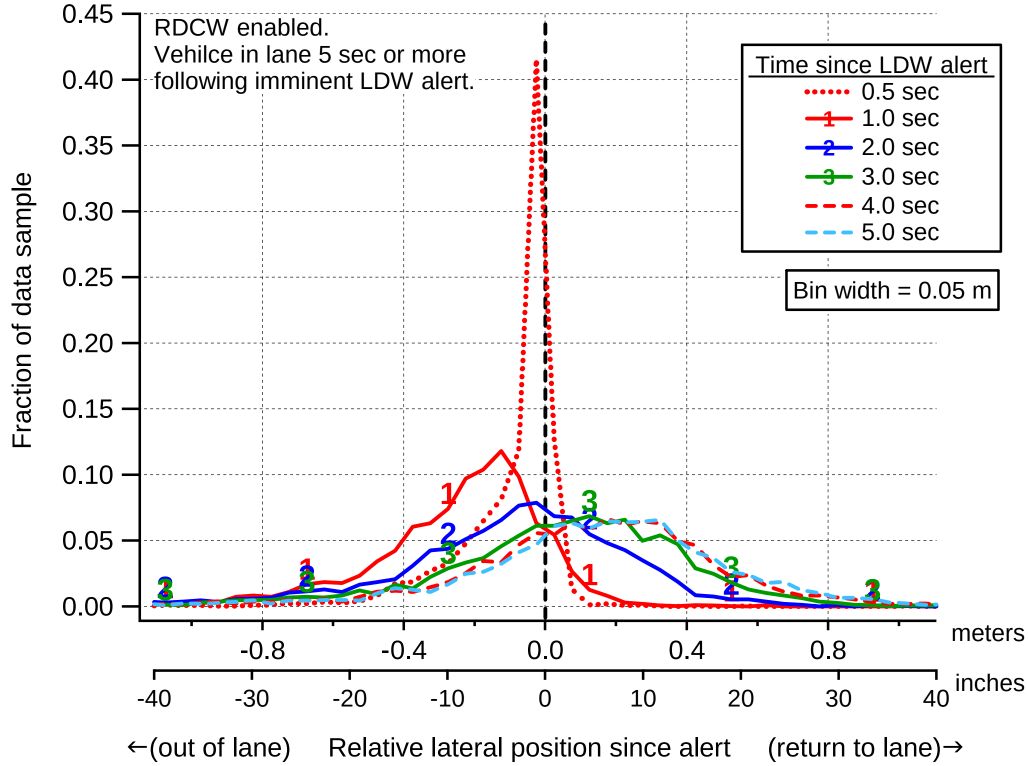


Figure 8.2 Distributions of the change in lateral lane position for vehicles remaining in the lane for 5 seconds following imminent LDW alerts

Six plots of the distribution of relative lateral position are shown in this figure; they vary in the time elapsed since the alert was issued, and range from 0.5 second after the alert to 5.0 seconds after the alert. Half a second after the alert, the distribution is very tight: most people were drifting slowly out of the lane and the short time elapsed has not allowed much variation in response. As time progresses and discretionary responses are possible, the distributions generally become wider. In general, the maximum drift out of lane appears most probable at about 1 second. Thereafter, the responses generally return toward the lane with the most probable response moving from negative to positive between 2 and 3 seconds after the alert. By four seconds, most response actions have apparently been completed as evidenced by the fact that the 4- and 5-second distributions are nearly identical.

Figure 8.3 and 8.4 on the next pages examine lateral position response as influenced by alert level, road type and LDW-sensitivity setting. These graphs are based on distributions similar to those of figure 8.2 (but including distributions at *each* 0.5-second interval over the five seconds following the time of the alert). Rather than showing the entire distribution, however, only the *median* (50 percentile) value of each full distribution is plotted. The relative lateral-position measure is now shown on the ordinate. Time since the alert appears on the abscissa.

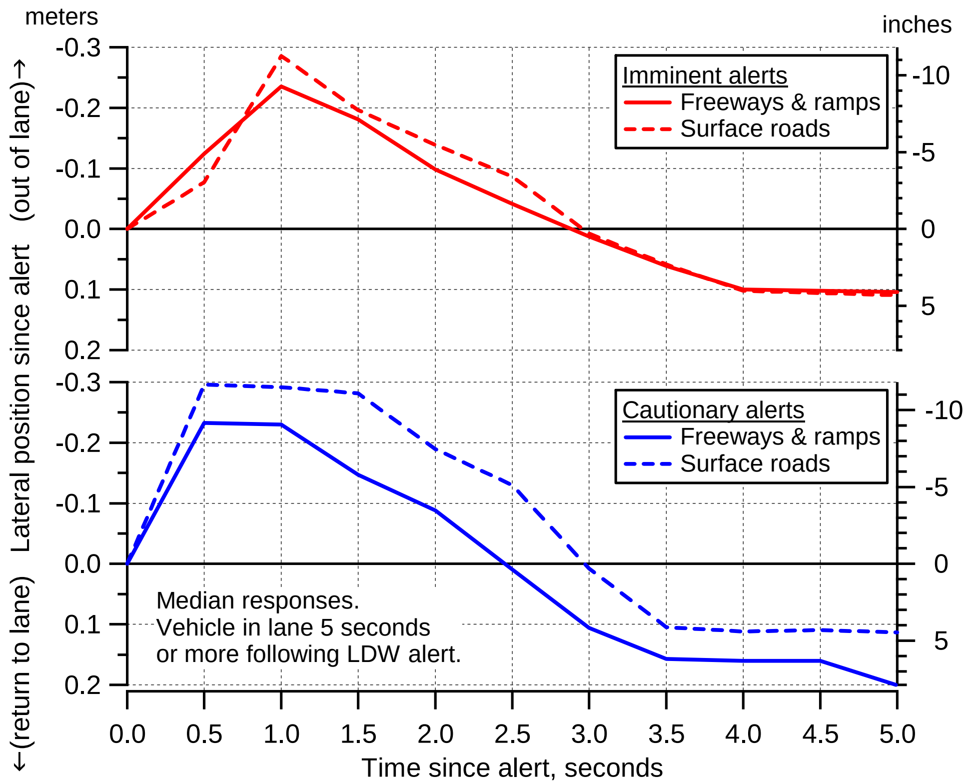


Figure 8.3 Median lateral-position responses for vehicles remaining in the lane for 5 seconds following LDW alerts: by alert level and road type

Figure 8.3 presents these median, lateral-response measures for imminent and cautionary alerts, respectively, showing the data for alerts on freeways and ramps (which account for 53 percent of cautionary alerts and 44 percent of imminent alerts) and on surface roads separately. The graph shows two tendencies: (1) the excursions out of lane tend to be larger on surface roads than on freeways and ramps, and (2) recoveries seem to be a bit faster on freeways and ramps than on surface roads. In general, however, peak excursions remain at about 1 second, the crossover from negative to positive relative position remains in the 2.5- to 3.0-second range, and the maneuvers appear to be completed in about 3.5 to 4 seconds.

Figure 8.4 presents median, lateral-response measures following imminent alerts and distinguishing responses by LDW-sensitivity setting. This figure shows a mild tendency for individuals who have set LDW sensitivity low (1 or 2) to take a bit more time in recovery than do other drivers. On the other hand, the peak median excursion for all sensitivity settings occurs at 1 second and there is little apparent correlation between sensitivity setting and the magnitude of the excursion following the alert.

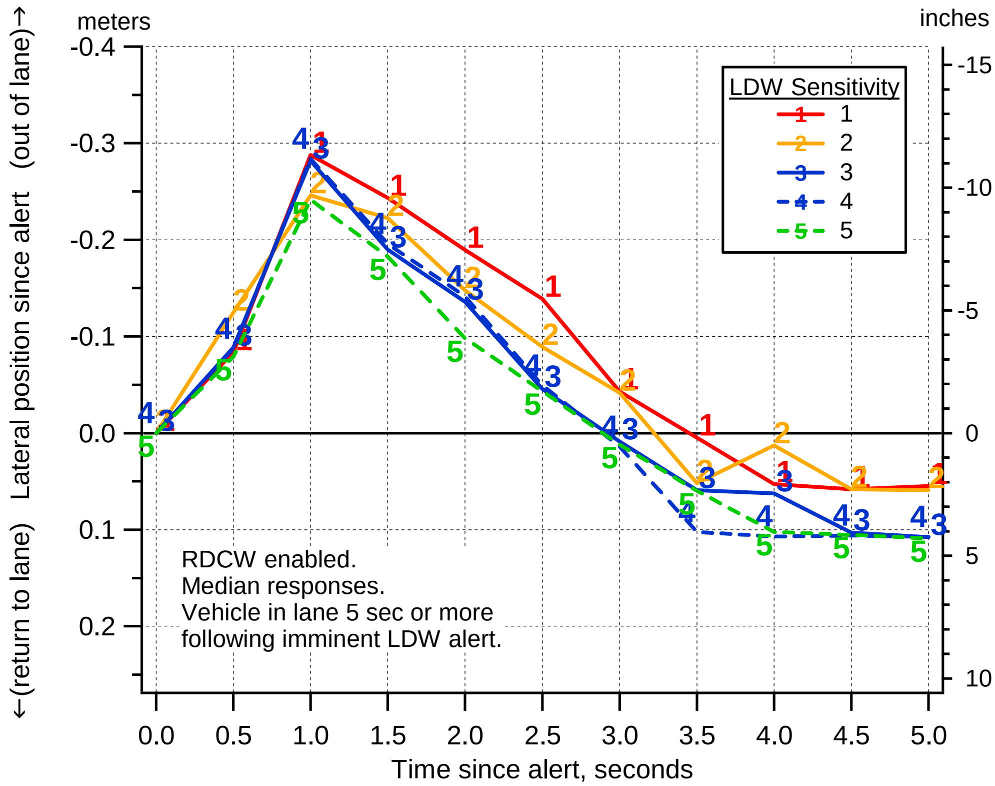


Figure 8.4 Median lateral-position responses for vehicles remaining in the lane for 5 seconds following imminent LDW alerts: by LDW-sensitivity setting

Finally, figure 8.5 compares the same median, lateral-response measures following LDW alerts during the first FOT week when RCCW was disabled, and alerts were therefore "silent," and during the latter three weeks when RDCW was enabled, and drivers actually were given the LDW visual and haptic or audible warnings. The figure also distinguishes between cautionary and imminent alerts. The data in the figure indicate that, for both cautionary and imminent alerts, there was a trend for quicker recovery back into the lane when LDW alerts were actually given — about ½ second quicker on average. Conversely, the presence or absence of LDW warnings did not appear to influence the extent of lateral excursion.

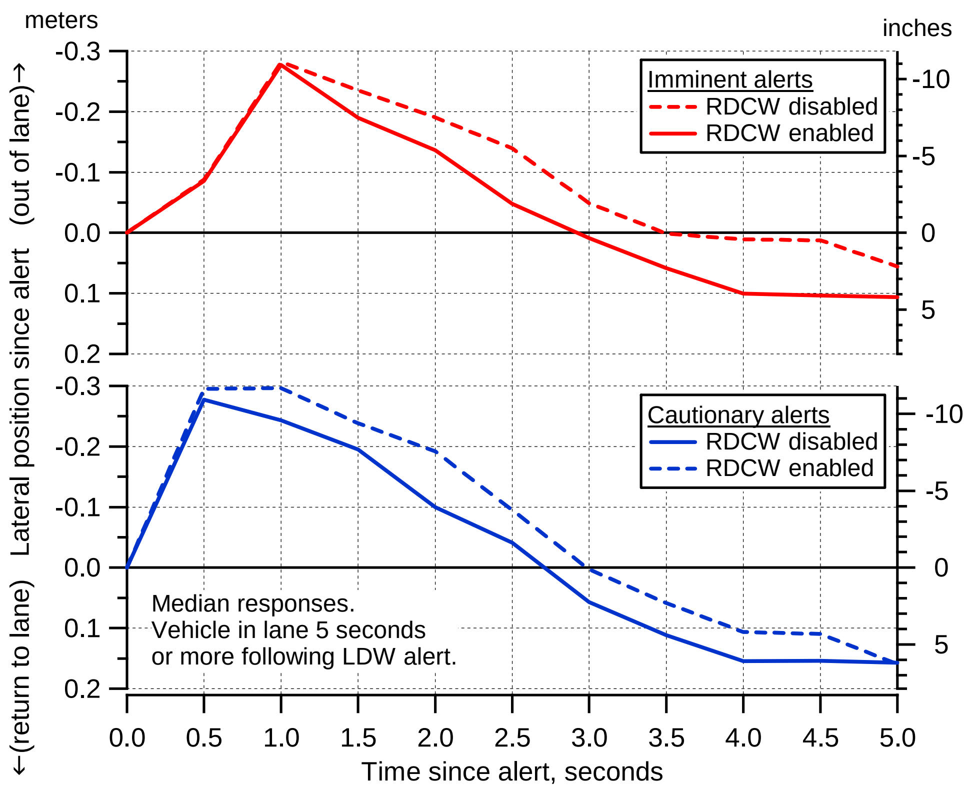


Figure 8.5 Median lateral-position responses for vehicles remaining in the lane for 5 seconds following imminent LDW alerts: with RDCW disabled and RDCW enabled

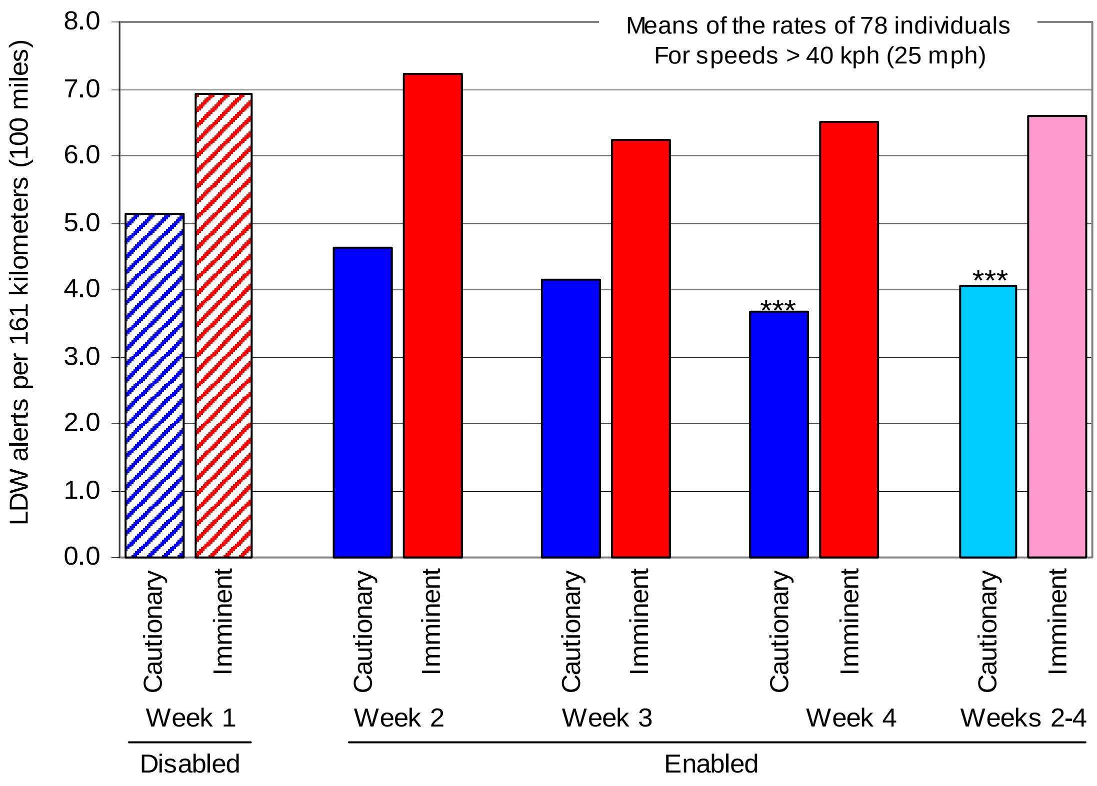
8.1.2 Changes in driving behaviors related to LDW

This section will address changes in driving behavior that *appear* to be related to the FOT drivers' exposure to the LDW system. It will be seen that certain behaviors that are closely related to the LDW functionality did, indeed, appear to change after the RDCW system was enabled. However, since RDCW is a combination of both the CSW and LDW systems, there is no formal basis for ascribing these changes to LDW specifically, although the intuitive connection will be obvious.

In several cases, statistical tests are applied to evaluate the significance of the differences of the mean performance before and after the introduction of RDCW and the resulting probabilities are often noted to be less than the traditional criterion for statistical significance ($p \leq 0.05$). However, we note explicitly that, in all such cases, the hypotheses tested were developed after the field test and during the review of the data. Formal statistical methods applied to such *post hoc* hypotheses require the use of a *Bonferroni adjustment* in establishing significance criterion, and, consequently, hold data to a stricter criterion than the traditional requirement of $p \leq 0.05$. Such adjustments were not made in the analysis of driving behavior in this FOT.

Accordingly, the results presented here should be viewed primarily as evidence suggestive of trends and perhaps as guidance for future investigations.

Reduction of cautionary LDW alerts. The subject of changes brought about by LDW was first introduced in section 7.3.1 in the discussion of figure 7.20. For convenience, that figure is reproduced here as figure 8.6. It shows a rather steady and marked decline in the rate of cautionary LDW alerts following the activation of RDCW at the start of each driver's second week in the FOT. Statistical tests (Student's t test) conducted using the alert rates for the 78 individual subjects show that the difference between the mean rates for cautionary alerts in the first and fourth weeks is highly significant (t=0.003) and that the difference between the mean rates for week 1 and weeks 2 through 4 combined is also significant (t=0.043). Accordingly, it would appear that the introduction of LDW changes some element of driving behavior in a manner that serves to reduce cautionary alerts.



*** The differences between the cautionary rate for week 1 and each of these two rates, respectively, are statistically significant at $p \leq 0.05$.

Figure 8.6 Mean rates of LDW alert by alert level and FOT week

Increased use of turn signals. The change of behavior believed to be most important in regard to the reduction of cautionary alerts with RDCW enabled was a 18-percent increase in the use of turn signals on freeways and ramps, presumably motivated by the introduction of LDW cautionary alerts. Figure 8.7 shows the mean rate of turn-signal use per mile traveled with RDCW disabled during the initial week and with RDCW enabled during the latter three weeks. Travel on freeways and ramps is distinguished from travel on surface roads in this figure. Comparing the rates of the individuals[1] with and without RDCW, there is an 18-percent increase in mean rate of turn signal use per mile on freeways and a very modest 2-percent increase on surface roads. Results of Student's t test indicates that the difference in the means for freeway travel is statistically significant ($t < 0.001$) but is not so for travel on surface roads.

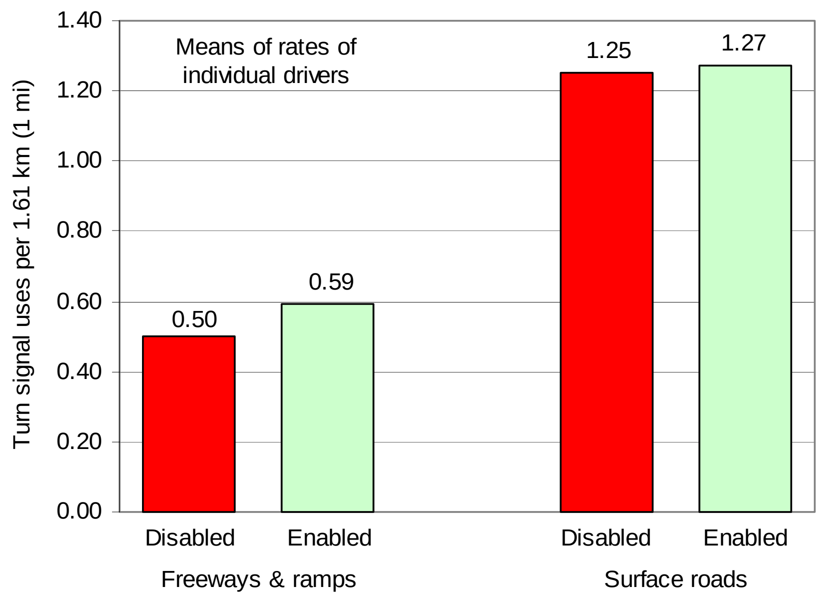


Figure 8.7 Comparison of turn-signal use with and without RDCW enabled by road type

As is typically the case, the performance of individuals varied substantially from the mean. Interestingly, in this case, there was a very strong trend for those drivers who initially exhibited the lowest rates of turn-signal use to show the most improvement after RDCW was introduced. (And, of course, those drivers who initially used their turn signals a great deal had little opportunity to increase their use very much when RDCW was enabled.) Figure 8.8 shows this trend quantitatively. The figure was produced by first ranking the individual drivers according to their initial rate of turn-signal use on freeways. Using freeway data only, each individual's improvement (increase) in rate of use was determined. Then, starting with the driver with the lowest initial rate, the mean improvement was calculated for progressively larger numbers of drivers. That is, first the "mean" improvement for the single lowest

[1] Sixty-seven individuals had adequate freeway travel and seventy-seven had adequate surface-road travel for the analysis.

driver alone was calculated, then the mean for the lowest two drivers, then the lowest three drivers, and so forth until all the drivers in the sample were include. Along with the mean, Student's t (for the difference of the means) was also calculated for each of the groups (except, of course, the initial "group" of one). Overall, turn signal use per mile increased by 9 percent over the entire driver population. For the quartile of drivers with the lowest rates of turn signal during their first week with the vehicle, the turn signal rate increased by 23 percent by their final week of RDCW system use. The results appear in figure 8.8 where the mean improvement is plotted on the ordinate and the number of drivers included in the calculation is on the abscissa.

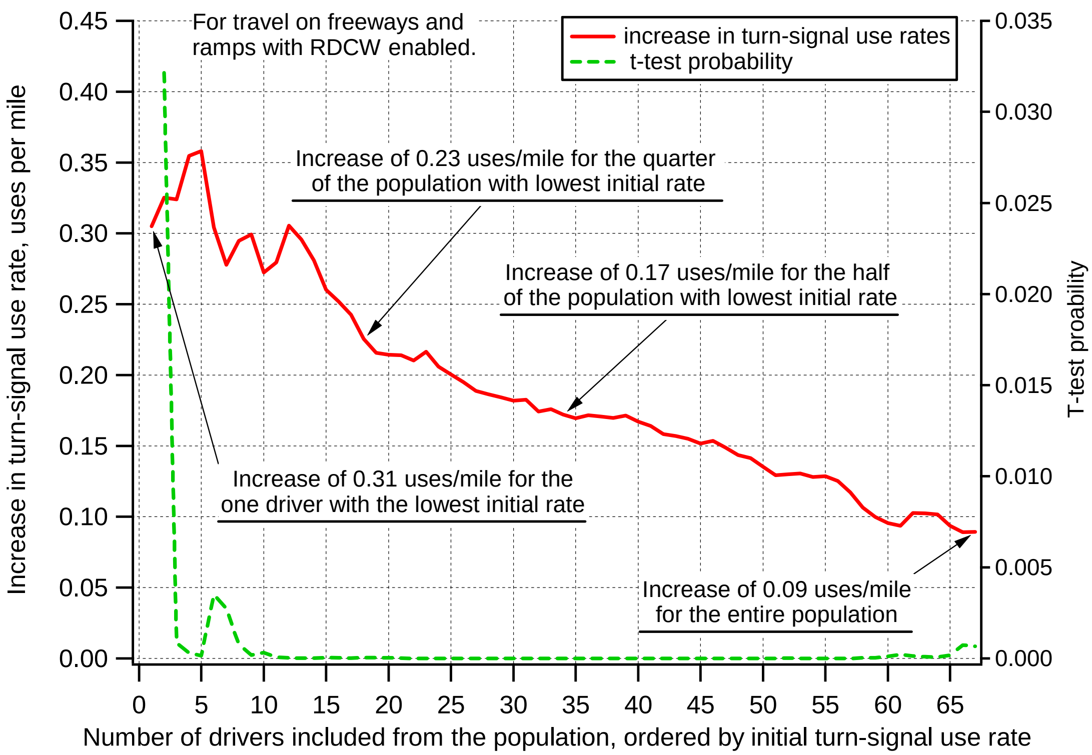


Figure 8.8 Driver's with initially low use rates tend to increase their use of turn signals the most

First note that, with only two drivers in the analysis, the value of t calculated for the difference between the mean rates is already less than 0.05. With three drivers included, t falls below 0.001 and, except for a brief excursion to 0.0035, remains below 0.001 throughout the analysis until all drivers are included.[2] As for the primary

[2] Some readers may recognize that results of the analysis of the type described here could well be susceptible to the phenomenon of *regression to the mean*. In rebuttal to that possibility, when the procedure is reversed, i.e., when the drivers are ordered from highest initial rate to lowest, Student's t does not drop below 0.05 until 57 drivers are included in the calculation. If regression to the mean was driving these results, the t-test results from the reverse orderings would be expected to be much more "symmetric."

result, it is clear that the drivers who began with a lower rate of use tended to have the greater improvement. The driver with the lowest initial rate increased his/her rate by 0.31 uses per mile. His/her initial rate was such that this was a 319-percent increase, the highest percentage increase of all drivers. The lower quarter of the sample population increased use by 0.23 uses per mile, equivalent to a 96-percent increase of the group mean. The lower half of the population increase 0.17 (55 percent), and the entire population increased its mean rate by 0.09 uses per mile (18 percent).

The objective data were also examined to look directly at the use of turn signals associated with a subset of the lane changes in the experiment.[3] Figure 8.9 shows the fraction of lane changes undertaken without the use of turn signals, distinguishing between freeways and ramps versus surface roads, and among driving weeks.

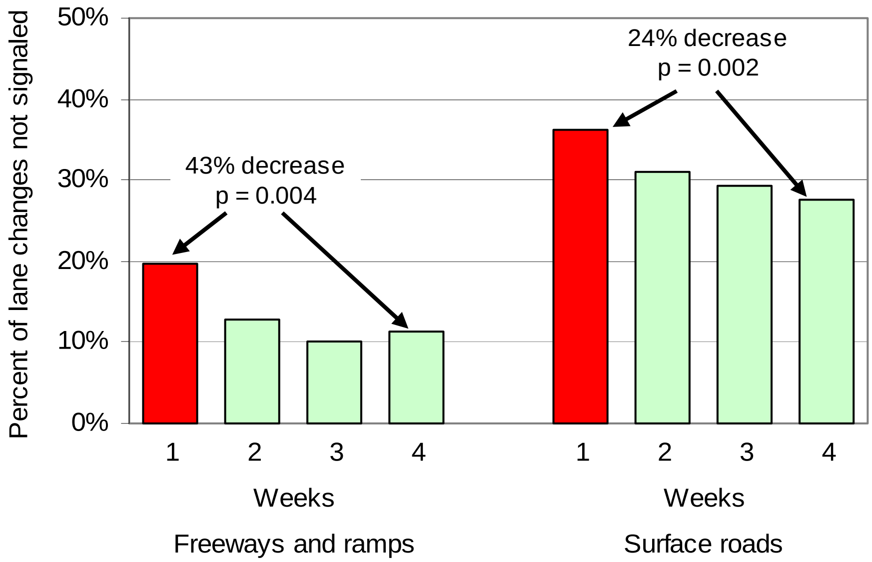


Figure 8.9 Fraction of freeway lane changes undertaken without use of the turn signal

The figure shows that, in general, the FOT drivers were more diligent about signaling lane changes while on freeways than while on surface roads. For both road types, however, the fraction of unsignaled lane changes decrease markedly following

[3] Identification of the tens of thousands of actual lane-change events during the FOT through queries of the objective data is a difficult matter; faultless identification is virtually impossible. The algorithms used were designed to minimize the capture of non-lane-change events and, therefore, surely have missed some number of actual lane changes. Nevertheless, the errors in this identification process are believed to be relatively small and, more importantly, are not likely to be biased with regard to the disabled versus enabled states of the RDCW system. Accordingly the analysis presented can be expected to be representative of the changes that would be observed across all lane changes.

the introduction of RDCW. By the fourth week, the percentage of unsignaled lane chances had fallen by 43 percent on freeways and about 28 percent on surface roads.

Improvement in lane tracking. The objective data from the FOT indicate a trend toward more accurate lane tracking by the FOT drivers following the introduction of RDCW.

Two numerics were developed and examined to evaluate lane-tracking performance: lane offset and lane intrusion. They are shown schematically in figure 8.10. Lane offset is the distance between the center line of the vehicle and the center line of the lane. If the vehicle is perfectly centered in the lane, lane offset is zero. Lane intrusion is the distance that the outside edge of the vehicle's tire extends beyond the edge of its lane (and therefore intrudes into an adjacent lane). In a small modification, we will actually consider intrusion beyond a line that is within the lane, 0.1-meter from the lane edge, shown as "intrusion past 0.1-meter buffer" in the figure.

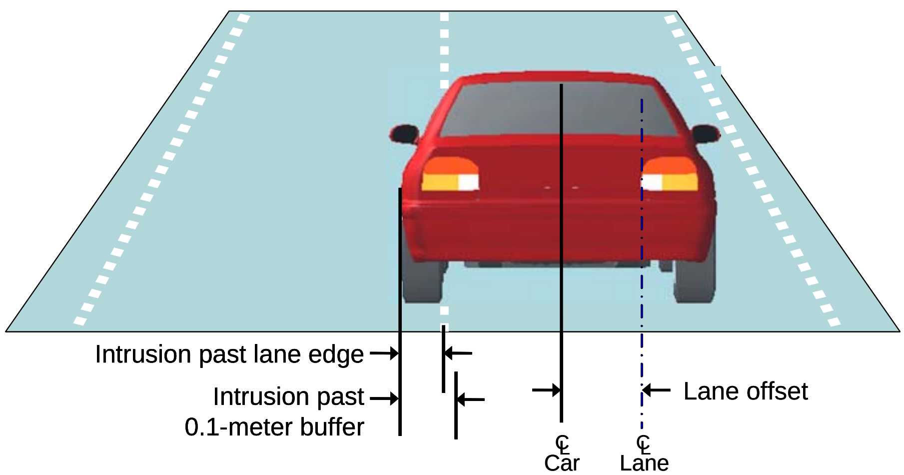


Figure 8.10 Lane offset and lane intrusion

The greatest challenge in evaluating lane-tracking performance was in identifying the appropriate times to apply the analysis, i.e., only times when the driver was, indeed, intending to track the lane. It was most important *not* to include data from times when deliberate lane changing took place, as the offset and intrusion data from a relatively small portion of these segments could well dominate the analyses. Accordingly, the procedure for choosing appropriate data was quite stringent, and it is likely that in eliminating inappropriate data, an appreciable amount of useable data was sacrificed. The filtering process identified time segments of no less than 36 seconds during which:

- speed > 40 kph (25 mph),

- road type was known,
- both lane boundaries were known and real (dashed or solid),
- lane-offset confidence was greater or equal to 90 percent,
- lane offset was between -2.49 and 2.49 meters (which is approximately the same as saying at least one tire was still within the original lane of travel), and
- there was no braking.

Following this filtering, all occurrences of either the LDW lane-change flag > 0 or of the absolute value of d(LaneOffset)/dt > 10 m/sec were identified and video of those moments examined for actual lane changes that were then, of course, excluded. The initial and final 8 seconds of all remaining segments were eliminated leaving time segments of no less than 20 seconds duration that were believed to be at least 8 seconds in time from any deliberate lane changing and within which the lane was well identified. This process resulted in a total of 183 hours of lane-offset data for use in the analyses, 147 hours on freeways and 36 hours on surface roads. Fifty-eight drivers contributed to the freeway data and forty-nine to the surface-road data.

Figure 8.11 presents the distribution of lane tracking for the fleet for travel during week 1 and week 4, respectively. The primary difference for the distributions for the two different weeks is that the week-4 distribution is taller and narrower, i.e., the standard distribution of lane offset appears lower during week 4 than during week 1, In other words, the fleet appears to track the lane “tighter” during week 4.

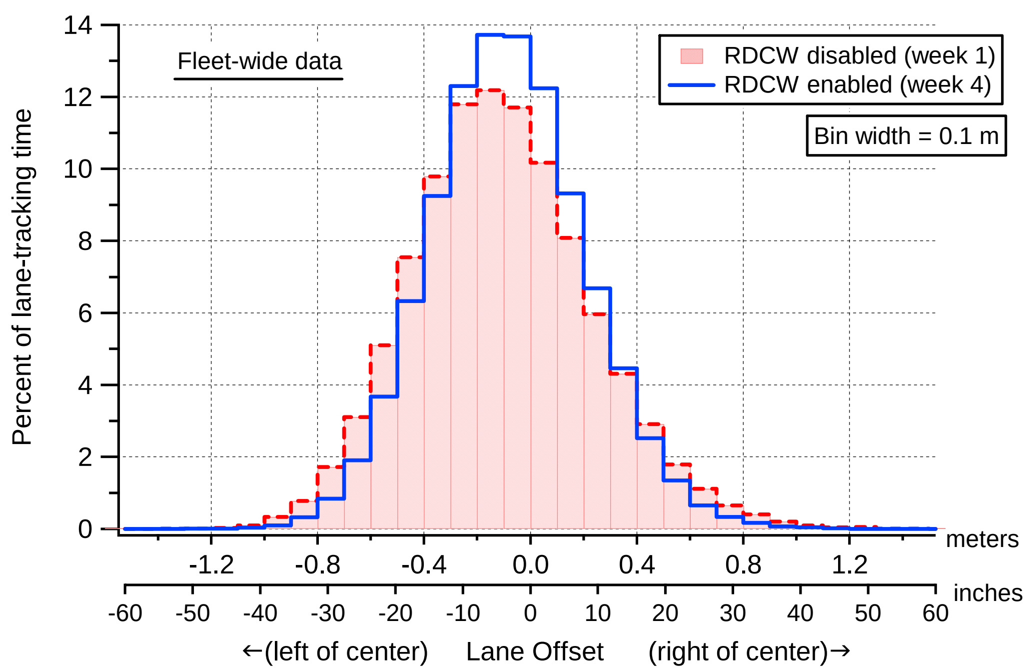


Figure 8.11 Distributions of lane offset during lane tracking, for the fleet during weeks 1 and 4

To test the hypothesis that lane tracking improved after RDCW was enabled, the standard deviations of lane offset for the individual drivers were determined by FOT driving week and by road type. The means of these individual values are shown in figure 8.12.

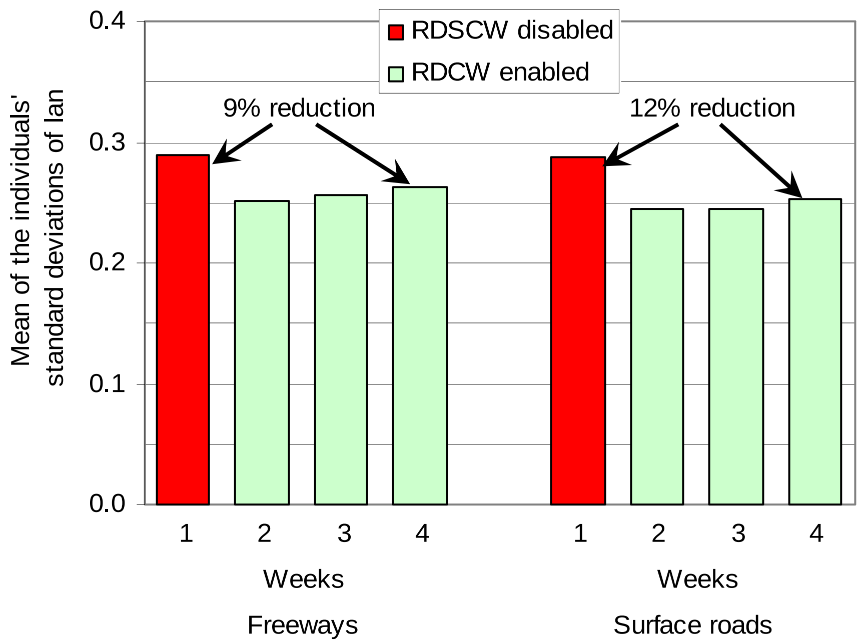


Figure 8.12 Comparison of the means of the standard deviations of lane offset by road type and FOT driving week

There is a clear trend for lower standard deviations of lane offset with RDCW enabled. Moreover, the probabilities related to difference between the means for week 1 as compared to weeks 2, 3 or 4, are less than 0.001 in every case for freeway driving and less than or equal to 0.003 for driving on surface roads. The differences between the means are largest between week 1 and week 2. After this initial drop, there is a mild tendency for the means of the standard deviations to increase again. Whether or not this trend would continue after four weeks is a matter of speculation.

The distributions of lane intrusion for travel of the FOT fleet on freeways during weeks 1 and 4 are shown in figure 8.13. These distributions are essentially the tails of the distributions of figure 8.11, with the appropriate shifts in the scales of the abscissa to convert the measure from lane offset to lane intrusion.

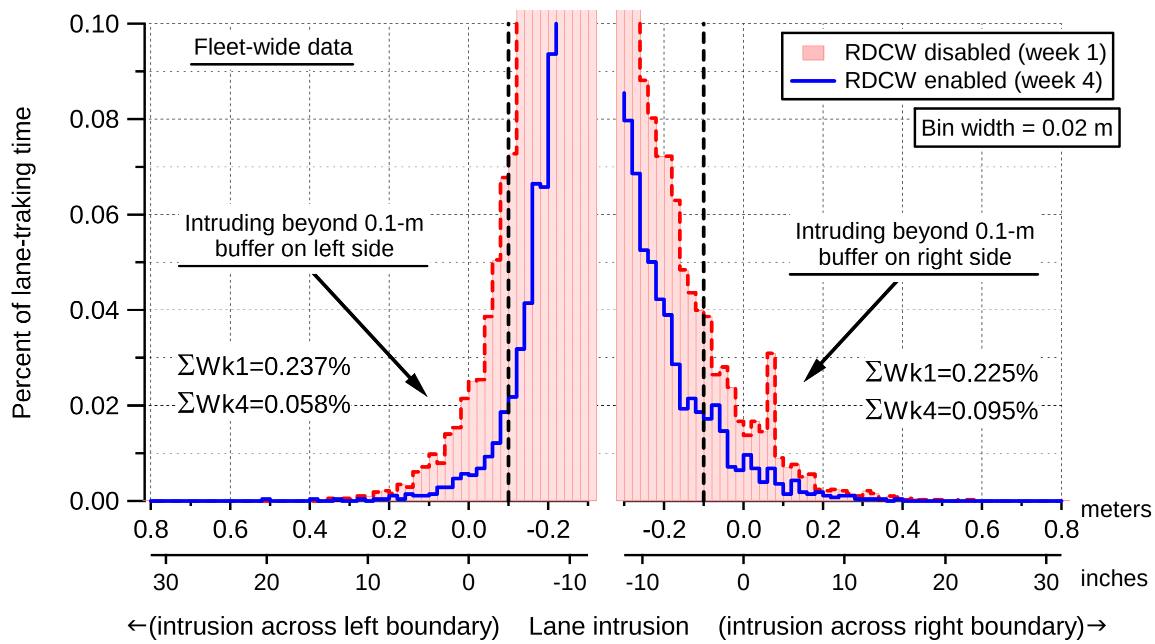


Figure 8.13 Distributions of lane intrusion during lane tracking, for the fleet on freeways during weeks 1 and 4

Comparing the week-1 and week-4 distributions in figure 8.13, there appears to be a trend for the FOT drivers to spend less lane-tracking time intruding into adjacent lanes after the introduction of RDCW. As will be described, within-driver changes in lane intrusion were analyzed to determine if this apparent trend is significant.

As noted previously, the entire FOT yielded just 183 hours of valid lane-tracking time. Figure 8.13 shows that only a small portion of that time was spent intruding into the adjacent lanes. In fact, the total out-of-lane time (i.e., positive values of lane intrusion) during the 183 hours of lane-tracking time amounted to only 36 minutes. Including the additional 0.1-m buffers (i.e., lane intrusion ≥ -0.01, see the dashed vertical lines in figure 8.13) increases the data set to a more useable 66 minutes and provides data for 71 drivers. However, this data set is not adequate for distinguishing between road types.

Figure 8.14 compares lane-intrusion performance during weeks 1 and 4, respectively. The figure presents the means (for the 71 drivers) of the percent of lane-tracking time spent intruding past the 0.1-m buffer. The graph indicates a very substantial reduction in this measure, for both right- and left-side intrusions, when comparing lane intrusion during week 4 with lane intrusion during week 1.

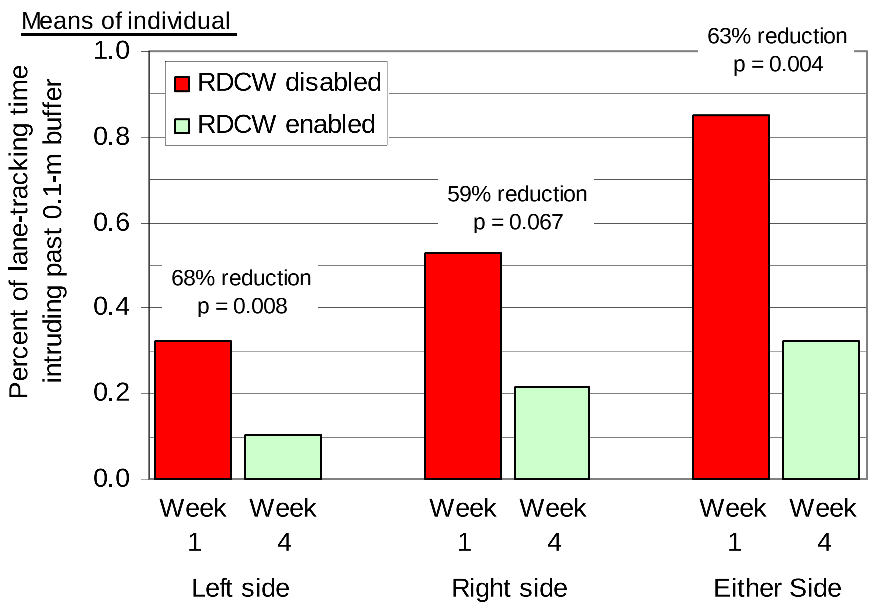


Figure 8.14 Comparison of the percent of lane-tracking time intruding into adjacent lanes, by side and FOT driving week

Although not shown in the figure, 41 of the 71 drivers improved (reduced) this measure (either side) from week 1 to week 4. The figure shows decreases of 68 percent (for the left side of the lane) and 59 percent (for the right side of the lane) in the average fraction of lane-tracking time that drivers were within 0.1 m of the lane edge, or were beyond the lane edge. Pooling results for both sides of the lane, there was a 63 percent reduction in the average time spent in that near- or beyond-the-lane-edge condition.

Figure 8.15 examines the same data set using a different measure. In this figure, the rate of lane-intrusion events, i.e., the number of events per mile (1.61 km) of lane-tracking travel, is compared between weeks 1 and 4 and by sides of the lane. It is apparent that the frequency of lane-intrusion events, as well as the total amount of time intruding, tended to decrease after the introduction of RDCW. The average rate of events in which the driver went within 0.1 m of the lane edge, or beyond the lane edge, was reduced from 0.24 events per mile to 0.12 events per mile, a 50 percent reduction.

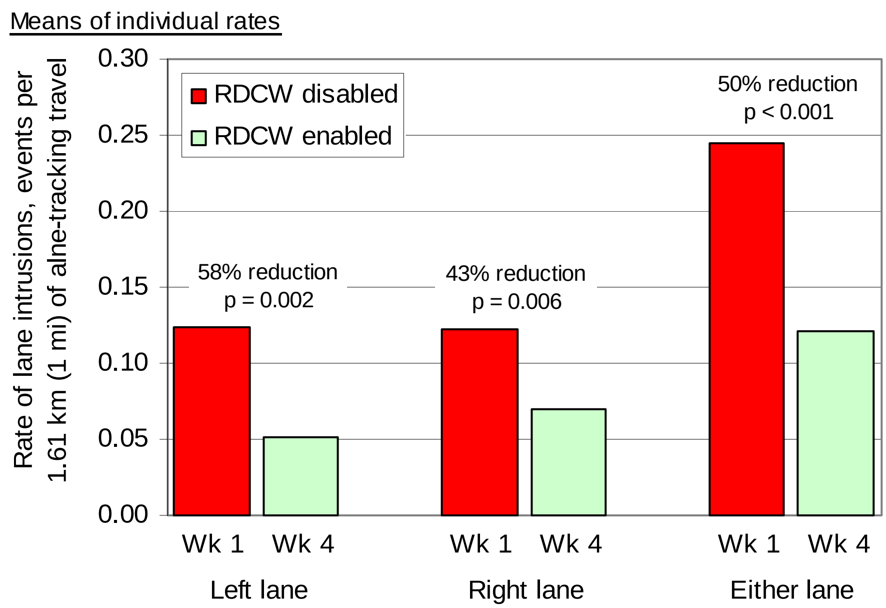


Figure 8.15 Comparison of the rates of lane-intrusion events, by side and FOT driving week

8.2 Effects of CSW on lateral acceleration in curves

To begin the analysis of data to search for CSW influences on safety, it must be acknowledged that effects may be manifested in a variety of ways. One hypothesis that can be tested is that CSW leads to a broad change in curve-taking behavior, much like the effect LDW was found to have on lane-keeping metrics, as presented in section 8.1.Another hypothesis is that CSW may provide warnings that evoke helpful driver responses in certain situations in which there is a potential risk of curve-overspeed. The first hypothesis is tested at length in this section. The second hypothesis was not addressed directly in this report, but represents a reasonable effect that may occur.

To investigate the first hypothesis, an in-depth analysis of the lateral-performance behavior of the FOT drivers was undertaken. The scope of this analysis was broad in order to cover the entire turn and curve-taking exposure for the entire time of the FOT, as opposed to a more targeted analysis of specific CSW events and their associated curves. The reason for this approach is the fact that when confounding influences are considered in the evaluation of the CSW system and its effect on driver curve taking behavior, the exposure to a given curve or class of curves becomes too small to make meaningful comparisons across a majority of the drivers that participated in the FOT.

8.2.1 Characteristics of curves in the FOT

This section summarizes the number of curves traversed in the FOT, as well as some characteristics of the curves.

A rapid review of any hour of FOT data reveals that even in the relatively flat topography of Michigan, drivers often encounter curves as they follow roadways. In addition, drivers routinely make turns onto other roadways, into driveways, and so forth. For the purposes of this study, it is reasonable to define a *curve location* as a location where a significant heading change is required to stay within a given travel lane, and the vehicle can maintain a reasonable speed through that location. Curves do not include turns onto other roadways at intersections, U-turns, or very slight changes in heading (which are referred to here as *bends*). *Turn locations* are defined here as locations – including curve locations – where the vehicle changes direction.

The algorithmic definition of a curve location that is used here for the analysis of driver curve-taking is as follows: a curve location is any location at which the vehicle took a path whose radius was less than or equal to 1000 m for at least three seconds. The magnitude of the path radius may vary during the three-second period, but cannot exceed 1000 m. Furthermore, to define the subset of curve locations from the larger set of turn locations, a curve location must have had at least one pass through that location (in the appropriate direction) with the vehicle speed always exceeding 25 mph (40 kph). This definition was developed and used in a previous FOT that studied a heavy vehicle rollover prevention device (Winkler et al., 2002), and was shown to identify deliberate, sustained turning as opposed to lane-change or lane-keeping maneuvers. The application of these rules in the RDCW FOT was found to be quite successful in isolating curve locations from turn locations.

Curve events are defined as any event during which a vehicle passes through a curve location. Note that the vehicle may in fact slow to a stop within the curve, and the event would still qualify as a curve event, as long as another traversal occurred with the speed exceeding 25 mph.

The set of all valid trips within the FOT were found to include 93,113 and 18,525 distinct turn locations and curve locations, respectively. Thus, 19.9 percent of the locations identified as turn locations also qualify as curve locations. Curves to the right account for 53 percent of the curve locations, which is a similar to the percentage of turns that are to the right. (See appendix T for details about the characteristics of turns, as well as background behind some of the results in this section.)

Table 8.1 summarizes the number of curve events associated with each curve location. The majority of curve locations, 62 percent, were identified as having just a single traversal while approximately 34 percent of the curve locations showed between 2 and 10 traversals. The remaining four percent of the curve locations had eleven or more traversals, with only 0.5 percent having more than 30 traversals. When a curve location is traversed several times in the FOT, it is almost always due to a handful of drivers and not a wide set of drivers.

Table 8.1 Number of curve locations with different numbers of traversals

Number of traversals per curve	*Curves to Left*	*Curves to Right*	*All curves*
1	5360	6038	11398
2 to 10	2943	3265	6208
11 to 20 s	306	353	659
21 to 30 s	78	90	168
30 or more	36	56	92
Number of curves	8723	9802	18,525
Left vs. Right	47%	53%	100%

This is significant because it prevents analyses that use specific curves to study the effects of CSW on curve-taking performance across a significant number of drivers. Furthermore, because of the scarcity of curve locations with traversals by many drivers, it is difficult to compare curve-taking performance across drivers based on specific curve locations.

Table 8.2 shows the overall rate of CSW alert events that occur near curve locations, as a function of road type. There were 2,606 CSW alert events associated with the curves that are being discussed. This is out of the 4,819 CSW alert events that occurred during the FOT; the remaining alerts were not associated with curves. The first two columns of the table show the number of curve traversals and the number of CSW alerts[4] for each known road type. The third column, *Alerts per traversal*, is the ratio of these two numbers. The fourth column shows the relative rate for each road type divided by the rate on the freeways.

Table 8.2 CSW alert-rate per curve traversal by road type for passes with minimum velocity > 25 mph (40 kph)

Road type	Count		Alerts per traversal	Normalized by freeway
	Traversals	Alert events		
Freeway	12292	241	0.020	1.0
Minor Arterial	12400	423	0.034	1.7
Local	6251	286	0.046	2.3
Arterial	7960	445	0.056	2.9
Ramp	7347	1211	0.165	8.4
All road types	46,250	2,606	0.056	2.8

As expected, drivers are far more likely to receive a CSW alert on ramps, which as section 7.3 discussed, often involve both significant curvature and decreasing speeds. Surface street curves are more likely than freeway curves to have CSW alert events associated with them; this is due of course to the higher curvatures found on surface roads.

Figure 8.16 shows a histogram of heading change for right and left curves. The distribution is dominated by curves with a heading change between 5 and 50 degrees.

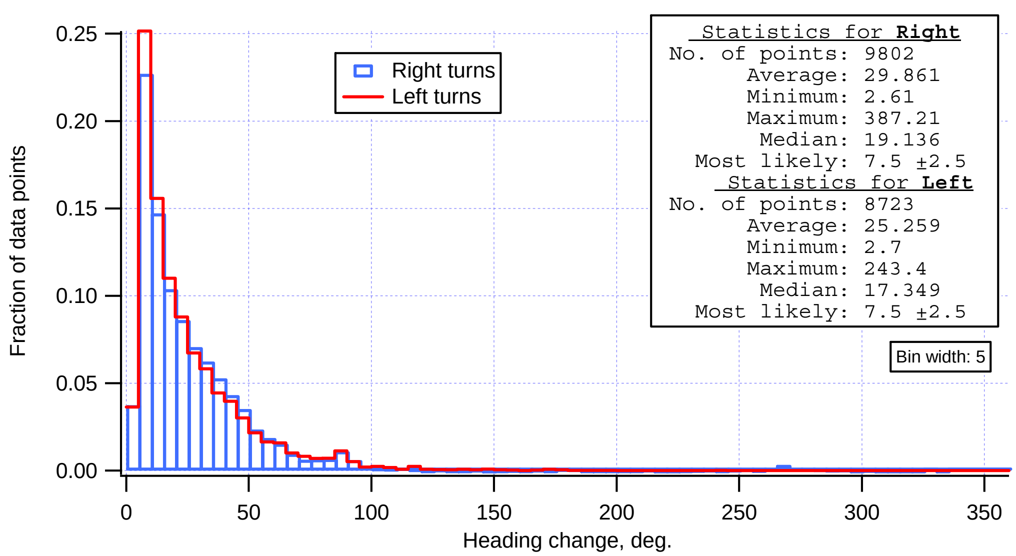


Figure 8.16 Histogram of heading change for all right and left roadway curves

[4] The count of alerts for this normalization includes the 'silent' alerts from the baseline period. The rationale behind including these alerts follows from the fact that the curve-traversal counts shown in table 8.2.3.4-1 for road type include the baseline exposure period.

The average heading change is 29.9 and 25.3 degrees for right and left curves, respectively. The only slight discontinuities in the graph are slight increases for 90 degree curves to the right and left, as well as a slight increase at 270 degree right-hand curves. Curves with heading changes beyond 120 degrees are so relatively scarce that they are imperceptible in the figure.

Figure 8.17 shows a histogram of minimum curve radius for right and left curves. The distributions for both directions are broad and distributed for minimum radius values between 50 and 500 m. Below 50 m both distributions show a step gradient with virtually no values below 20 m. (Dynamically, this makes sense since given a minimum speed threshold of 40 kph, a 20 m curve would result in a peak lateral acceleration of approximately 0.6 g.) Above 500 m both distributions decrease linearly to approximately 800 m. There are virtually no curves with a minimum radius value greater then 800 m.

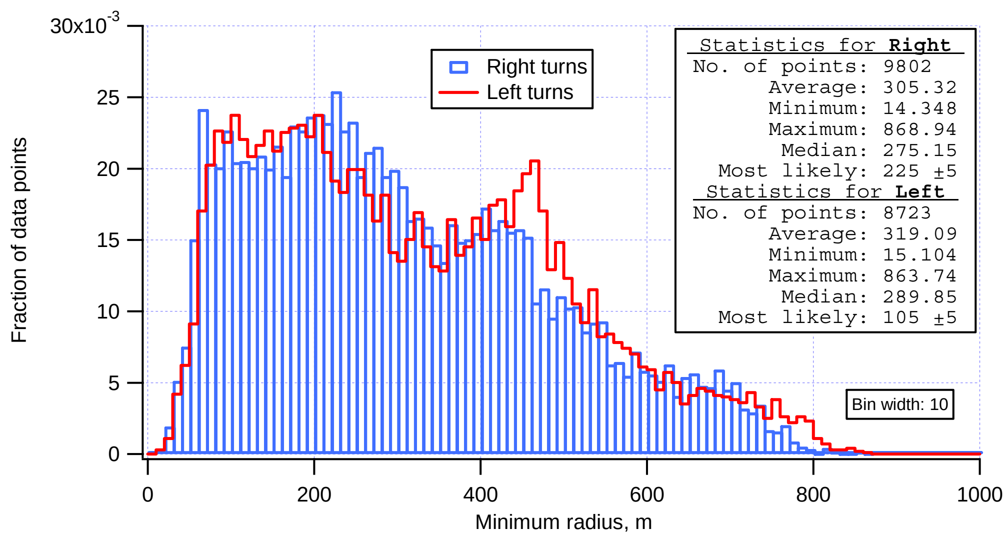


Figure 8.17 Distribution of minimum radius for roadway curves

There are differences in the right and left distributions of figure 8.17 for minimum radius values between 200 and 500 m. Curves to the right are more prevalent than curves to the left for minimum radius value between 220 and 310 m, while curves to the left are more common than those to the right for minimum radius values between 440 and 510 m. Appendix T shows that ramps are four times more likely to turn right than left, and the most likely radii for those are between 200 and 350 m. Furthermore, freeways account for the lion’s share of the curves with large radii, and the appendix shows that freeway curves are more likely to the right within the 440 to 510 m radius range.

8.2.2 Curve-taking: lateral acceleration levels in curves

This section provides context for the study of the influence of CSW on curve-taking performance by showing the distribution of lateral accelerations observed in curves in the FOT. Specifically, the distribution of the time spent at various lateral acceleration values while traveling in curves at speeds greater than 25 mph (40 kph) is presented. This is drawn from curve traversals as defined in the previous section; 109 hours of driving is contained in this data set. The insights gained from this study can address the following:

- Lateral acceleration values in curves within the FOT experiment, and
- Approximate exposure of the CSW system to higher lateral acceleration values.

Lateral acceleration is defined as the acceleration experienced at the center of gravity of the sprung mass, as measured by an accelerometer mounted at that location. The accelerometer signal was calibrated on each vehicle to minimize cross-axis components such as gravity, and post-processing was done to further improve signal quality. The Nissan Altima 3.5SE vehicle platform is rather stiff in its body roll, so that the effect of body roll is considered negligible, and the body-mounted acceleration is thus quite comparable to the acceleration parallel to the road surface.

An overall view of the lateral acceleration values observed in curves is provided by figure 8.18 on the next page, which depicts the cumulative distribution of lateral accelerations. The figure shows the fraction of travel time in curves spent above the indicated lateral acceleration values. A logarithmic scale is used on the vertical axis to view in detail the higher lateral acceleration values.

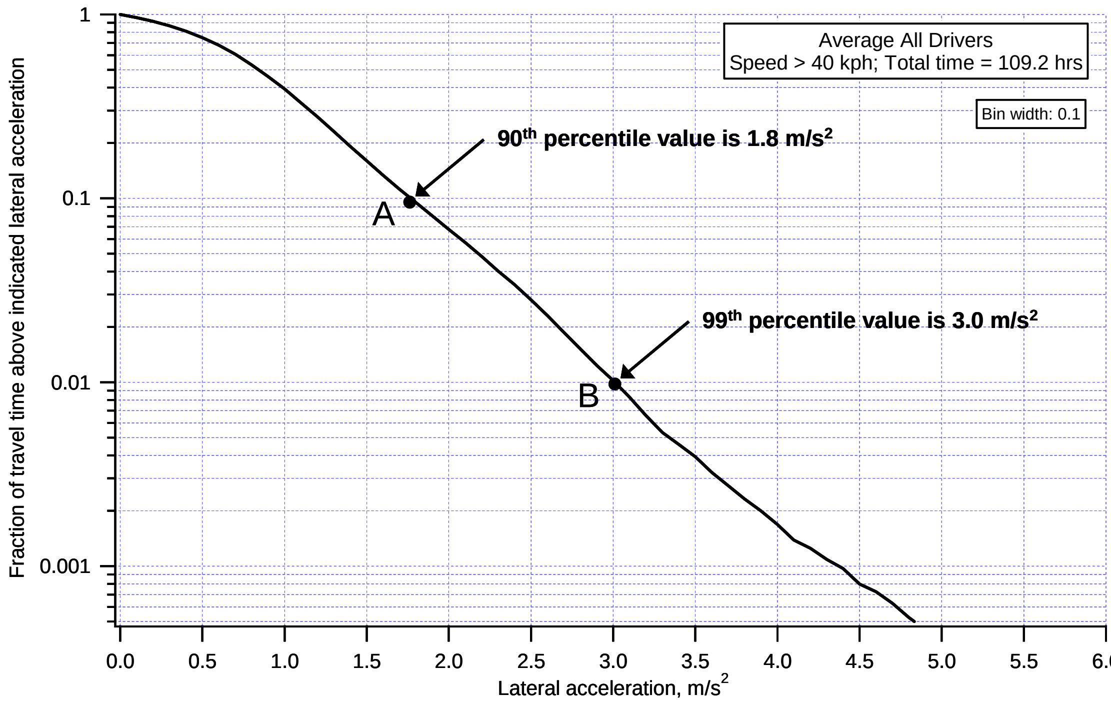


Figure 8.18 Fraction of travel time in curves spent above indicated lateral acceleration values

Point A on the figure shows that 10 percent of the curve travel time (i.e., a fraction of 0.1) is spent at lateral acceleration values that equal or exceed 1.8 m/sec^2. Thus, this identifies the 90th percentile value of lateral acceleration for this curve-travel-time data set. Similarly, the 99th percentile value of lateral acceleration is found at point B in the figure, or 3.0 m/sec^2. As benchmarks, note that the AASHTO guidelines for highway design suggest that lateral accelerations do not exceed 1.7 m/sec2 at the posted speed for a curve, and that the CSW alerts are most commonly given in anticipation of lateral accelerations of approximately 2.5 m/sec^2. These benchmarks correspond to approximately the 88 percent and 97 percent percentiles of this data set, respectively, based on figure 8.18. Based on the 109 hours of driving in the data set, approximately 13 hours is spent at lateral accelerations above the nominal AASHTO guidelines and 3 hours above the lateral acceleration threshold used by the CSW system. The duration of an individual curve traversal varies from a few seconds to several seconds, but if an estimate of the average is six seconds, then each hour of curve travel time corresponds to roughly 600 curve traversals. This suggests a suitable data set for studying curve-taking, since there are 7800 traversals above the AASHTO guidelines and, more importantly, 1800 traversals at lateral acceleration values that are within the domain of concern for the CSW system.

To study the differences between drivers in this metric, consider figure 8.19 which shows individual cumulative histograms for each of the 78 drivers. The traces for drivers 39 and 71 are shown as dotted lines to highlight the extremes of lateral-acceleration experience of the entire set of drivers. The variation of lateral accelerations among drivers is caused by both the individual travel patterns that expose them to different sets of curve geometries and posted speeds, as well as drivers' selection of speeds in the turns they encounter.

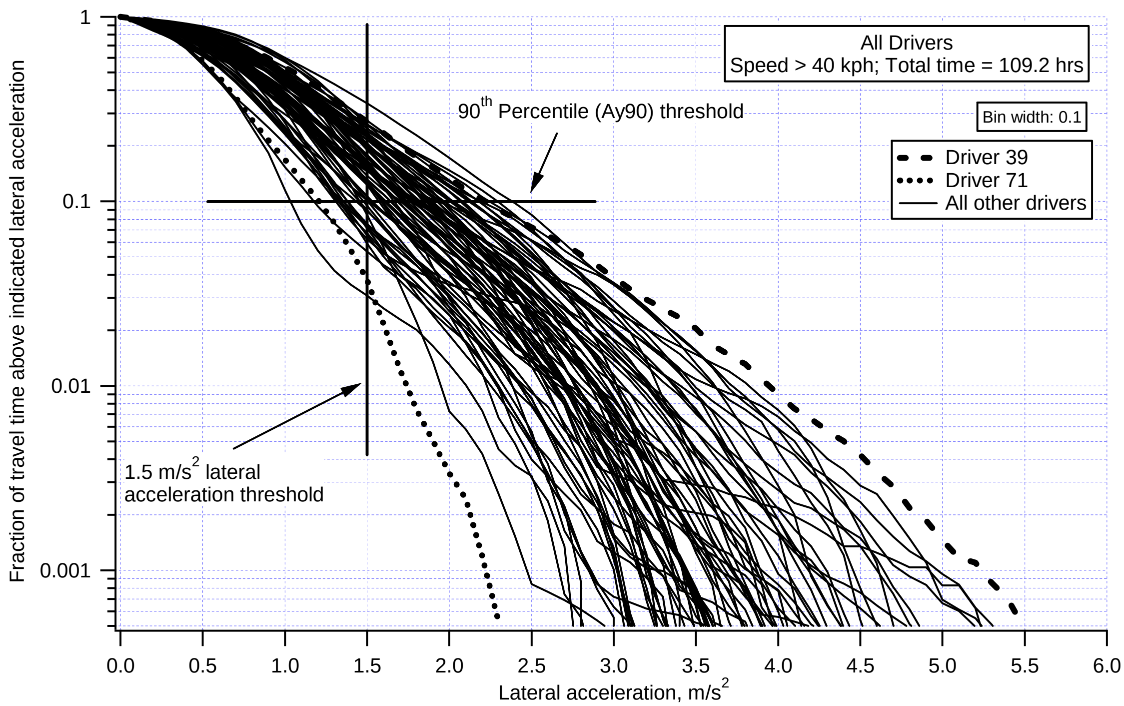


Figure 8.19 Illustration of 90th percentile lateral acceleration threshold

This report does not decouple these effects because it is very difficult to isolate driver choices, since there are many influences on lateral acceleration in individual curves, such as speed limits (generally unknown in the data), bank angles, context of the curves that influence the driver's choice of speed (e.g., whether a stop sign follows the curve, whether impeding vehicles are present). The differences in individual drivers' curve-taking behavior are illustrated in two ways using these cumulative data. Consider figure 8.19: by using a constant lateral acceleration threshold, such as the line in the figure indicating 1.5 m/s^2, the variation in drivers' distributions is apparent. The figure shows that driver 71 spent approximately 3 percent of her time in curves above this value, while driver 39 spent roughly 28 percent of his time in curves above this threshold. These two drivers represent, more or less, the extremes of the individual driver distributions in terms of exposure to curves and lateral acceleration overall during the FOT.

Similarly, a percentile threshold can be indicated and the corresponding lateral acceleration found for each of the drivers. For instance, the figure indicates that drivers 71 and 39 spent 10 percent of their time in curves above lateral acceleration values of 1.25 and 2.2 m/s2, respectively. Those same acceleration values are the 90th percentile value for those drivers' curve experiences. This will be called Ay90, since Ay is the notation used for lateral acceleration.

Figure 8.20 shows the number of drivers with various values of Ay90. The average and median of the A*y90* values for the individual drivers are 1.7 and 1.8 m/sec^2, respectively. The most likely values, representing 22 of 78 drivers, is between 1.8 and 2.0 m/s^2. The minimum and maximum values were, respectively, 1.0 m/sec^2 and 2.4 m/sec^2.

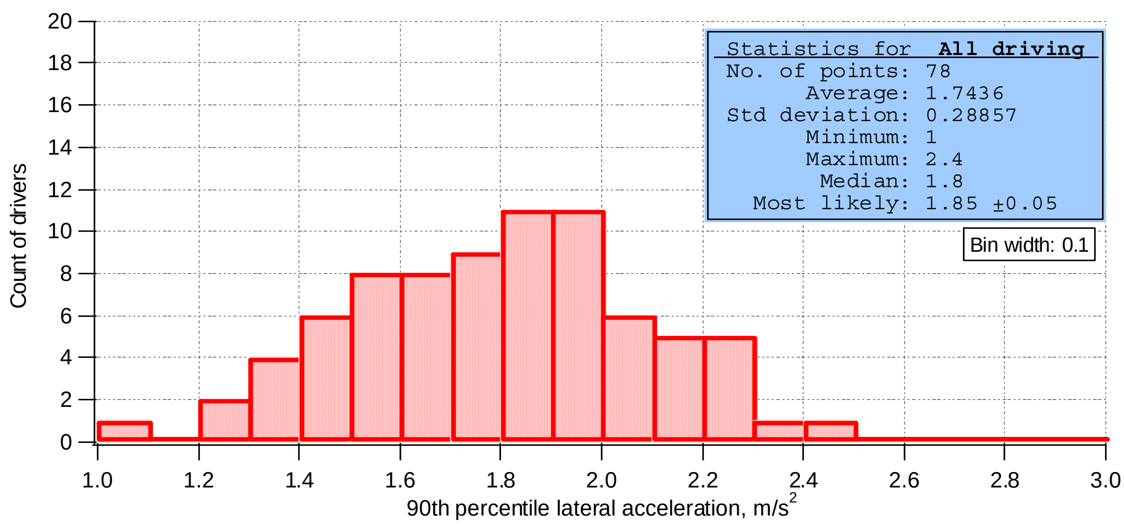


Figure 8.20 Count of drivers by 90th percentile lateral acceleration threshold

Lateral accelerations are also affected by road type, as shown in Figure 8.21. That figure is a cumulative distribution of time spent at various lateral accelerations, as a function of road types. The figure shows that given that a vehicle is on a particular road type, the probability that the lateral acceleration will be 2.0 m/sec2 or higher is much higher on ramps than other road types. Furthermore, when traveling on a freeway, the probability of being at 2.0 m/sec2 or any value higher than that will be relatively low, compared to the probabilities on other road types. Thus there is a clear difference between the lateral acceleration values on freeways, surface roads, and ramps. Not shown here is also the fact that while traveling on ramps, the lateral acceleration values are higher when the curve direction is to the right.

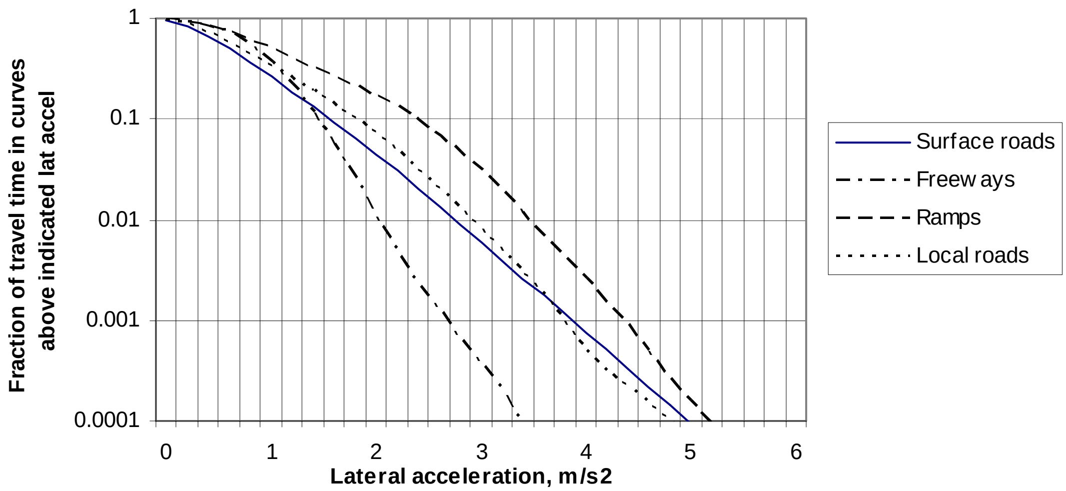


Figure 8.21 Effect of road type on the fraction of travel time in curves spent above various lateral acceleration values

8.2.3 Effects of RDCW and other factors on lateral acceleration in curves

The influence of RDCW and other independent variables on the levels of lateral acceleration values observed in curves are studied in this section. The hypothesis being tested is that the enabling of RDCW may reduce the lateral accelerations in curves (via reduced speeds), due to a heightened awareness of curve-taking risks. In turn, such a finding would suggest the potential for broad safety benefits. This is another analysis of the FOT data that is based on surrogate measures (e.g., lateral acceleration) that are assumed to be related to actual safety outcomes.

The hypothesis in this section is tested using three different methods, each employing slightly different metrics based on lateral acceleration. Two of the methods study individual factors or pairs of factors, and the third is a multifactor test that considers several factors. The results of all three methods are almost identical and the conclusions are consistent. All three methods are within-subject approaches – that is, they each include mechanisms that compare the data of individual drivers in the presence of different factors in order to identify influences of the factors themselves. In that way, the large variations of lateral accelerations between drivers, as well as the number and types of curves each driver encountered, are accounted for in the analyses. In addition, the multifactor and single-factor methods address an overlapping set of independent variables. The methods will be summarized below, and then sections that follow will address results obtained using the three methods separately. Finally, in section 8.2.3.4, a summary is presented of the results of the three methods, identifying statistically-significant influences.

Table 8.3 summarizes the three methods. Method A seeks to study the change in the tails of the distributions that represent high values of lateral accelerations in curves. Specifically, the tails studied are the set of absolute values of lateral accelerations that exceed the 90th percentile of that driver, for the appropriate conditions. (A single 90th percentile value is computed for each driver using all data on all curve traversals – this is called *Ay90*.) Method A uses a paired-sample T-test to compare the effects of the individual factors that include the presence of RDCW alerts, road type, curve direction, ambient illumination (day vs. night), and whether the windshield wipers are on (as a surrogate for wet roads and/or precipitation). This approach and its results are presented in section 8.2.3.1.

Table 8.3 Statistical methods used to study changes of lateral acceleration in curves

Method	Description of metric	Factors (indep. vars)	Multi- factor?	Statistical test
A	Time-based average of lateral acceleration* when it exceeds the driver's 90th percentile value	RDCW on/off, road type, direction of curve, ambient illumination, wiper state	No (except RDCW studied for individual road types)	T-test, paired samples
B	Average of the max lateral acceleration* in individual curves when it exceeds the driver's 90th percentile value	(same as above)	(same as above)	T-test, paired samples
C	Mean of lateral acceleration* in various combinations of the factors	Same as above, plus age	Yes	Mixed linear model

* absolute values of lateral acceleration are used

Method B is similar to method A, except that it addresses one concern with method A, which uses a time-based average that accumulates data for each 0.1 second sample of data. That approach may give curves that take longer to travel more weight in method A's analysis. Method B therefore computes a single metric for each curve traversal - the maximum lateral acceleration sustained for one second within that curve. Another 90th percentile value is computed for each driver using these peak lateral accelerations – this is used as a threshold, and is called *AySust90*. For each driver, the mean of the peak accelerations over that driver's *AySust90* value are computed with and without RDCW, and a paired T-test is computed for the set of drivers. Method B investigates the same factors as method A studied, and the results are detailed in section 8.2.3.2.

Since methods A and B will be seen to identify rather significant effects due to road type, curve direction, ambient illumination, and wiper state, Method C applies a multifactor approach to isolate the influence of RDCW itself. This method is a mixed linear model which is described in detail in subsection 8.2.3.1, and which considers the same factors as the previous methods, except age is considered as well. The results of all three methods are summarized in section 8.2.3.4. Indeed, it may be helpful to the reader of the next three sections to keep handy the summary table provided in section 8.2.3.4, in order to keep track of the results of the dozens of individual statistical tests that are reported.

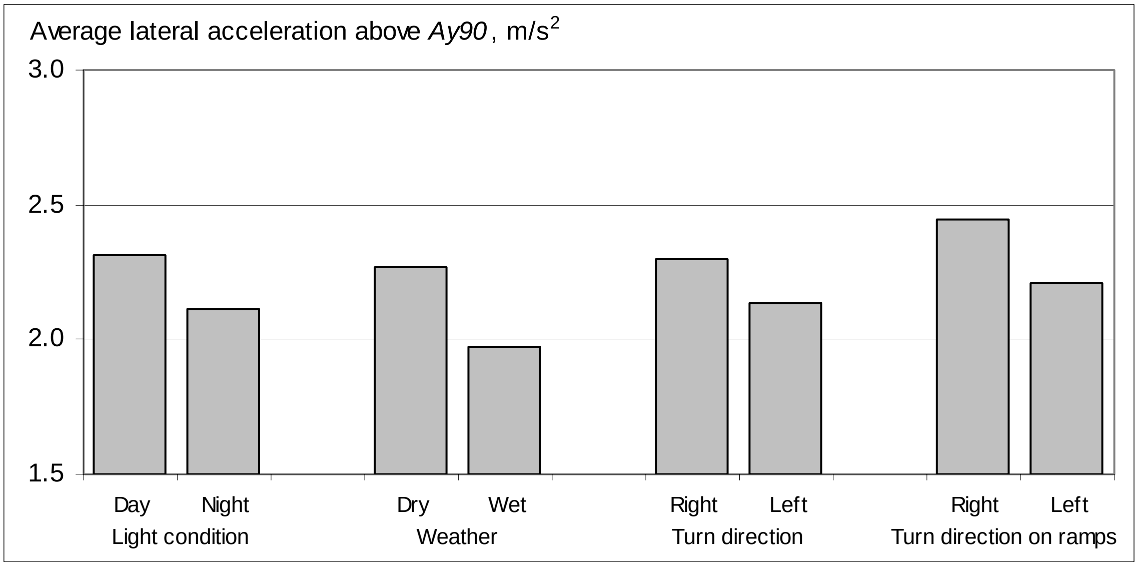
8.2.3.1 Studying effects using Method A

Method A studies the effect of several factors on the method A metric, which is the average value of lateral acceleration above each driver's 90th percentile value for curve-taking lateral acceleration (the 90th percentile value is denoted *Ay90*). While the main objective is to study the influence of RDCW, it is necessary to identify and account for the larger influences of other factors, otherwise they may confound the study of RDCW's influence.

Consider figure 8.22 on the next page, which includes both a bar graph illustrating the mean values of the metric as a function of four factors: ambient lighting state (day vs. night); windshield wiper state (on vs. off, as an approximate surrogate for precipitation or a wet road); direction of the curve; and direction of the curve when only ramps are considered.

The bars show the following effects on lateral accelerations:

- Lateral acceleration is higher in daytime than in nighttime, as defined by the sun being 6 degrees or more below the local horizon, as described earlier,
- Lateral acceleration is higher when the wipers are not on,
- Lateral acceleration is higher for curves to the right than for curves to the left, and
- Lateral acceleration is higher for curves on ramps that go to the right, compared to curves on ramps to the left.



Paired samples test	*Paired differences*			
Effect	*Difference in means, m/s2*	*t*	*df*	*Sig. (2-tailed)*
Day – Night	0.20	5.405	64.0	<0.0001
Wiper off – Wiper on	0.30	7.540	63.0	<0.0001
Right curve – left curve	0.16	3.869	77.0	0.0002
Right – left (on ramps)	0.23	5.321	67.0	<0.0001

Figure 8.22 Main effect of ambient lighting, wiper state, and direction of turning

The table in the figure shows details of the statistical test results for these four factors:

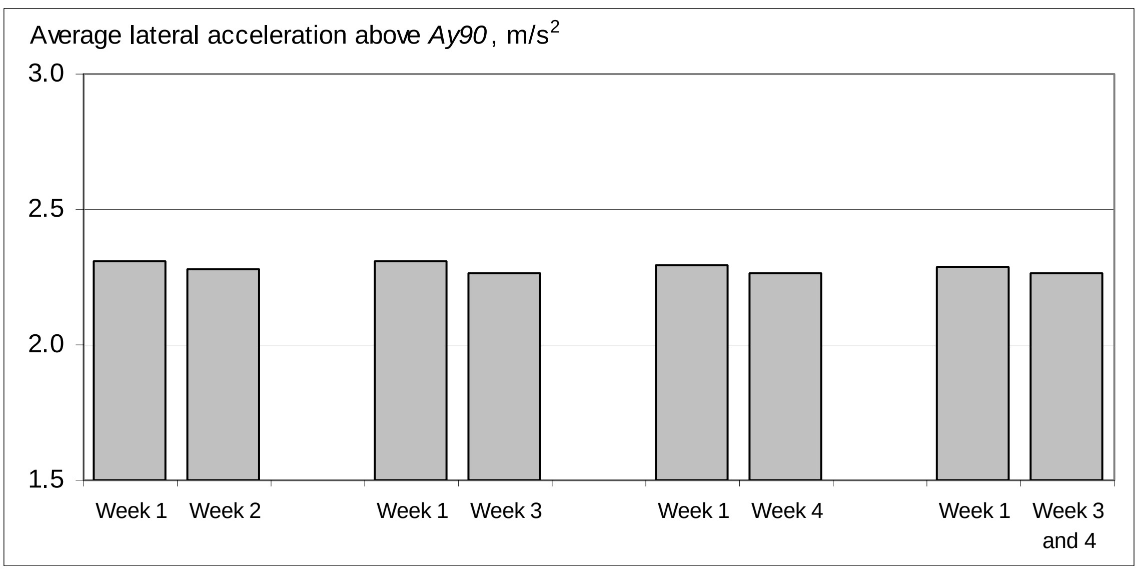
- difference in the means of the drivers,
- t-test statistic (t), which is the ratio of the difference between the two means to a measure of the variability of the scores.
- degrees of freedom (df), which is the number of the scores in each group minus one (this is also one less than the number of drivers with sufficient data for the test, as described below), and
- significance level (sig), or the odds that the observed result is due to chance.

For this discussion, a paired test condition is said to show statistical significance if the significance probability is less than 0.05 or 5 percent. That is, if the significance probability is less than 0.05 than the difference in the two variables is not random but is indeed a result of drivers actually performing differently, in terms of their lateral acceleration levels above their individual 90 percentile thresholds. Each of the results shown in figure 8.22 is highly statistically significant, as indicated by the *sig* values being much less than 0.05.

The comparison with different ambient lighting conditions was done with 65 of the 78 FOT drivers due to the fact the 13 drivers did not have adequate lateral acceleration exposure during the night-time hours, where adequate exposure was more than 10 s (100 points) of data at speeds above 25 mph, and above that driver's *Ay90* threshold. The table in figure 8.22 indicates how many drivers' data sets were used in the study (i.e., *df* + 1).

The figure gives further details of the statistics for the other factors as well. As noted earlier, the effect of turn direction is amplified when these data are restricted to curves on ramps as shown in the right-most comparison of the figure. Not only does the magnitude of lateral acceleration increase for these curves, relative to all curves, but the difference in turn direction becomes more pronounced with ramps.

To investigate the influence of RDCW itself, consider figure 8.23. The figure compares the mean of the drivers' method-A metric between various weeks of their four-week exposure.



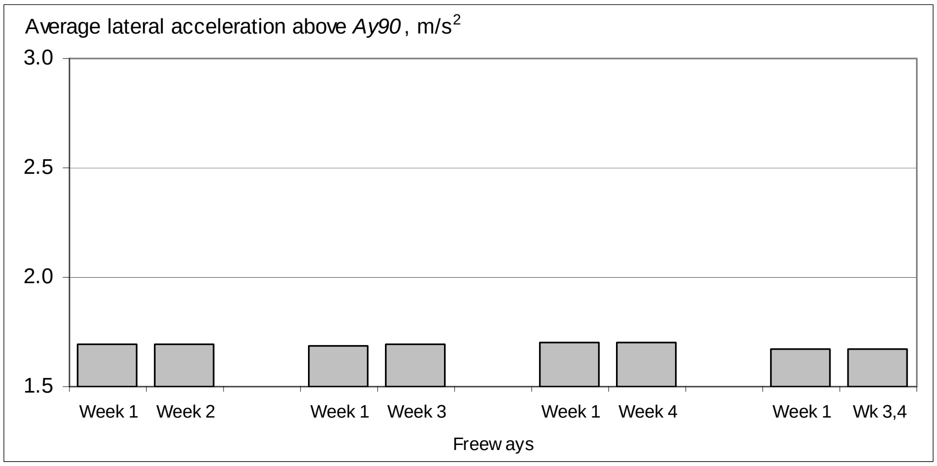
Paired samples test	*Paired differences*			
Effect	*Mean*	*t*	*df*	*Sig. (2-tailed)*
Week 1 - Week 2	0.033	1.672	69.0	0.0991
Week 1 - Week 3	0.043	1.803	67.0	0.0758
Week 1 - Week 4	0.027	1.254	71.0	0.2139
Week 1 - Week 3 and 4	0.023	1.111	72.0	0.2701

Figure 8.23 Main effect of test period on *Ay90*

The figures shows that for each of the test period comparisons there is a slight decrease when the RDCW system is enabled to provide alerts, however none of these comparisons reach a level of statistical significance.

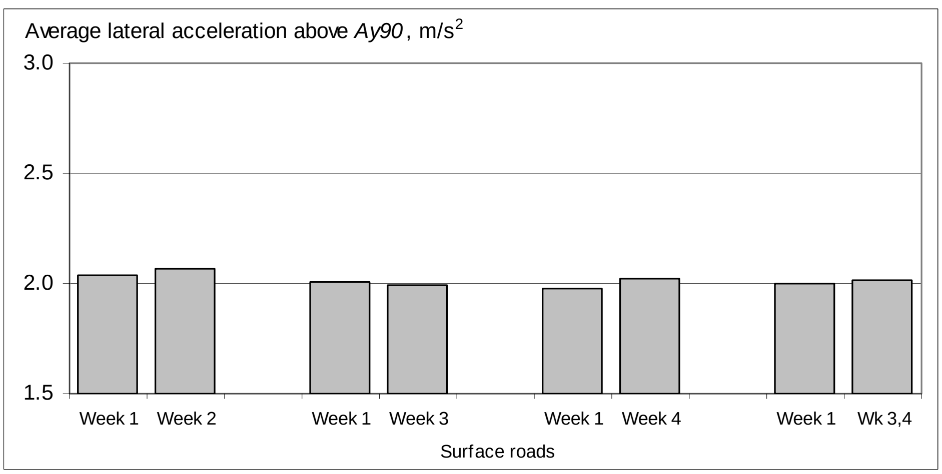
It was shown in section 8.2.2 that road type is a major influence on the levels of lateral acceleration in curves. Therefore it is worth studying the influence of RDCW in the individual road type conditions. Consider figures 8.24 through 8.27, which compare the effect of enabling RDCW on the average lateral acceleration values above the driver's 90th percentile value on four road types: freeways, surface roads, local roads (minor surface roads), and ramps. Comparisons of the values of the method-A metric are made for each road type, along with the same four combinations of weeks that were presented in figure 8.23.

Of these sixteen comparisons, there is one with a result that is statistically significant to $p < 0.05$. On local roads, the metric increases from week 1 to week 2 from approximately 2.2 m/sec2 to 2.3 m/sec2. In fact, the metric increases from week 1 to week 2 on the other three road types as well, but with smaller changes and without reaching statistical significance. In general, the lateral acceleration metric usually increases from the baseline week 1 to the other weeks on freeways and surface roads (including local roads), but decreases on ramps from week 1 to the other weeks – but again, using method A, these changes are without statistical significance except for the single case cited. The conclusions from these results are presented in section 8.2.3.4, after results from all three methods have been presented.



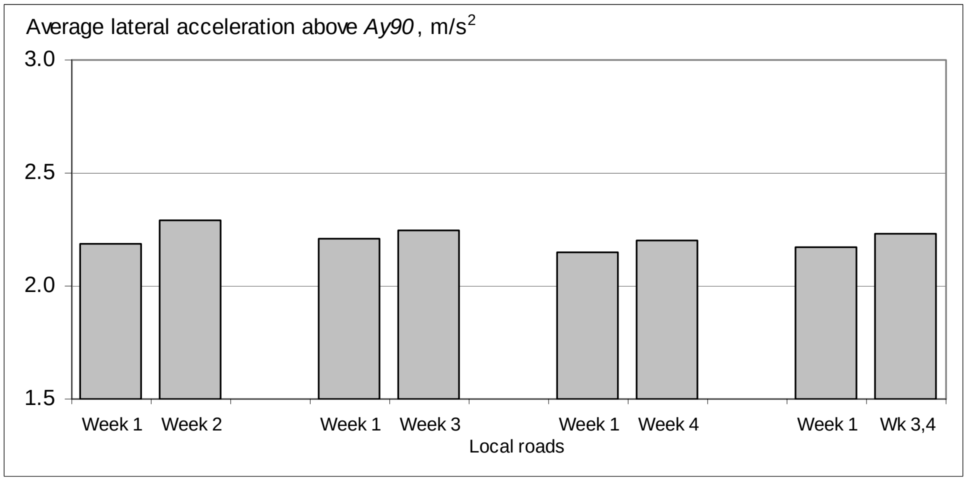
Paired samples test	*Paired differences*			
Effect	*Difference in Means*	*t*	*df*	*Sig. (2-tailed)*
Week 1 - Week 2	-0.002	-0.102	32.0	0.9197
Week 1 - Week 3	-0.005	-0.206	38.0	0.8376
Week 1 - Week 4	-0.001	-0.071	42.0	0.9441
Week 1 - Week 3 and 4	-0.004	-0.309	48.0	0.7583

Figure 8.24 Main effect of test period on *Ay90* for freeways



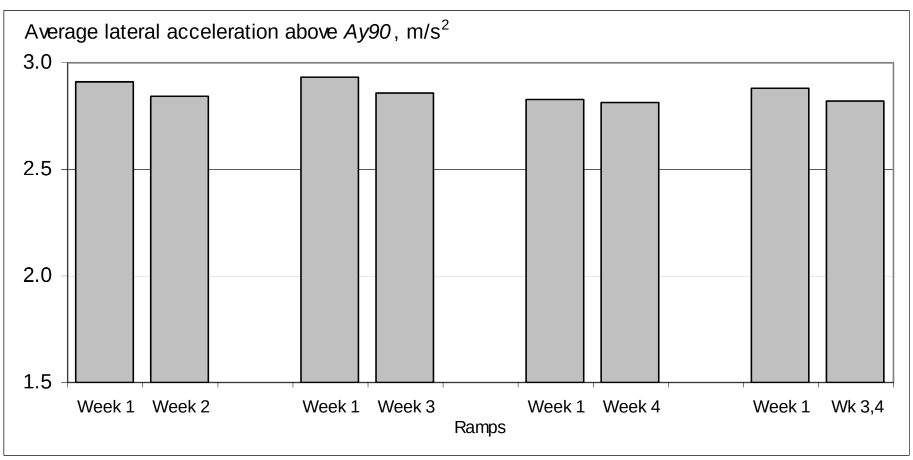
Paired samples test	*Paired differences*			
Effect	*Difference in Means*	*t*	*df*	*Sig. (2-tailed)*
Week 1 - Week 2	-0.034	-1.759	57.0	0.0840
Week 1 - Week 3	0.015	0.629	53.0	0.5324
Week 1 - Week 4	-0.045	-1.855	53.0	0.0692
Week 1 - Week 3 and 4	-0.012	-0.602	64.0	0.5494

Figure 8.25 Main effect of test period on *Ay90* for surface roads



Paired samples test	*Paired differences*			
Effect	*Difference in Means*	*t*	*df*	*Sig. (2-tailed)*
Week 1 - Week 2	-0.101	-2.653	26.0	0.0134
Week 1 - Week 3	-0.040	-0.905	18.0	0.3772
Week 1 - Week 4	-0.050	-1.214	23.0	0.2372
Week 1 - Week 3 and 4	-0.057	-1.754	27.0	0.0907

Figure 8.26 Main effect of test period on *Ay90* for local roads



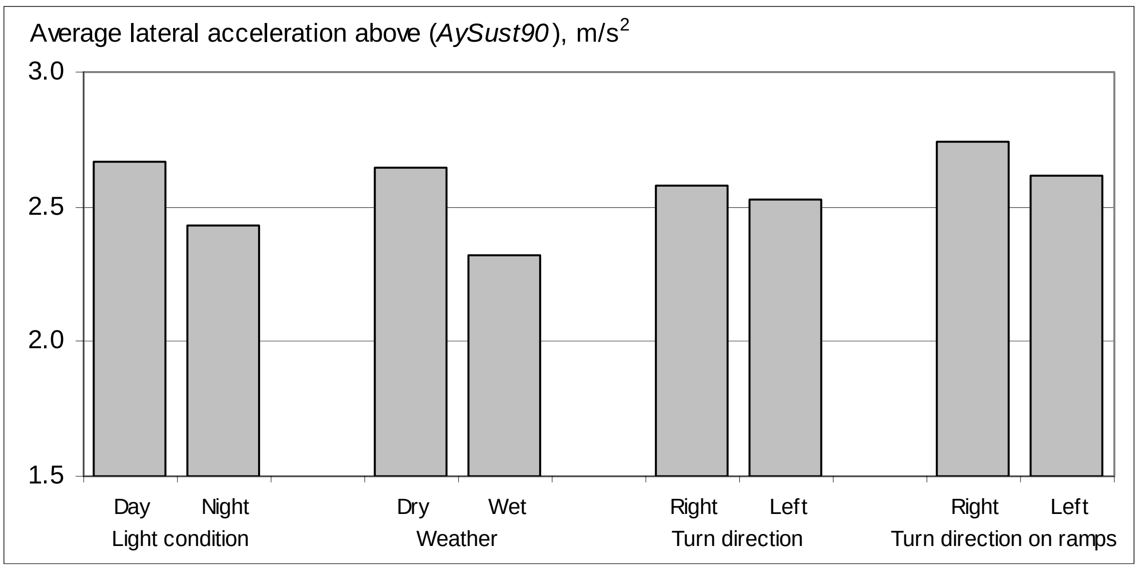
Paired samples test	*Paired differences*			
Effect	*Difference in Means*	*t*	*df*	*Sig. (2-tailed)*
Week 1 - Week 2	0.060	1.777	35.0	0.0843
Week 1 - Week 3	0.072	1.787	35.0	0.0826
Week 1 - Week 4	0.016	0.392	43.0	0.6972
Week 1 - Week 3 and 4	0.063	1.798	51.0	0.0781

Figure 8.27 Main effect of test period on *Ay90* for ramps

8.2.3.2 Studying effects using Method B

Recall from section 8.2.3 that the method B metric is the average of peak lateral accelerations on curves, when the peak exceeds the particular driver's 90th percentile value of the peak lateral acceleration in curves. This threshold is called *AySust90,* referring to the acceleration in the lateral (*y*) direction, sustained for at least one second.

Figure 8.28 shows the values of the main effects of comparing ambient light condition, wiper state (a surrogate for weather), and turn direction on driver curve taking behavior, as represented by the average of accelerations exceeding *AySust90*. The figure shows a statistically significant difference due to changes in ambient light, weather, and turn direction (only on ramps). Turn direction, in general though, is not significantly different which differs from the same comparison using method A.

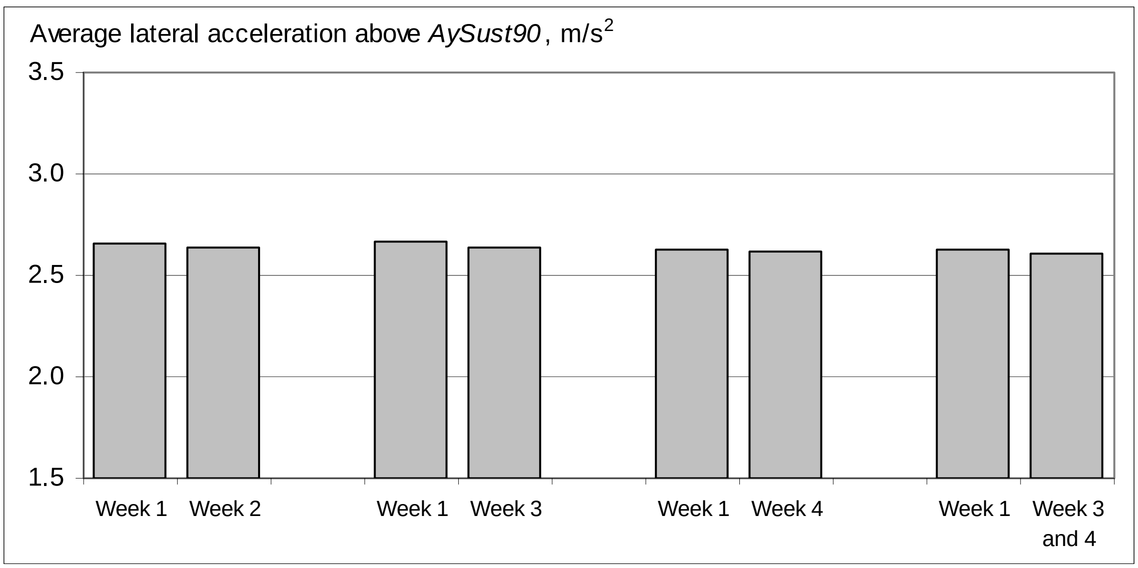


Paired samples test	*Paired differences*			
Effect	*Difference in Means*	*t*	*df*	*Sig. (2-tailed)*
Light condition	0.24	5.972	57.0	<0.0001
Weather	0.32	7.243	46.0	<0.0001
Turn direction	0.05	1.199	76.0	0.2342
Turn direction on ramps	0.13	2.394	56.0	0.0201

Figure 8.28 Main effect of light condition, weather, and turn direction above the *AySust90* threshold

For the ambient light condition, the method B metric shows a mean reduction at nighttime of 0.24 m/s^2 when compared to daytime, with a significance level of less than 0.0001. Similarly, wet conditions (defined by having the wipers on) are associated with a decrease of 0.32 m/s^2 when compared to wiper-off conditions with a significance level of less than 0.0001. Turn direction on ramps shows a modest average reduction of 0.13 m/s^2 when comparing right to left turns, however the significance level is 0.02 when based on *AySust90* as compared to less than 0.0001 for the method A analysis.

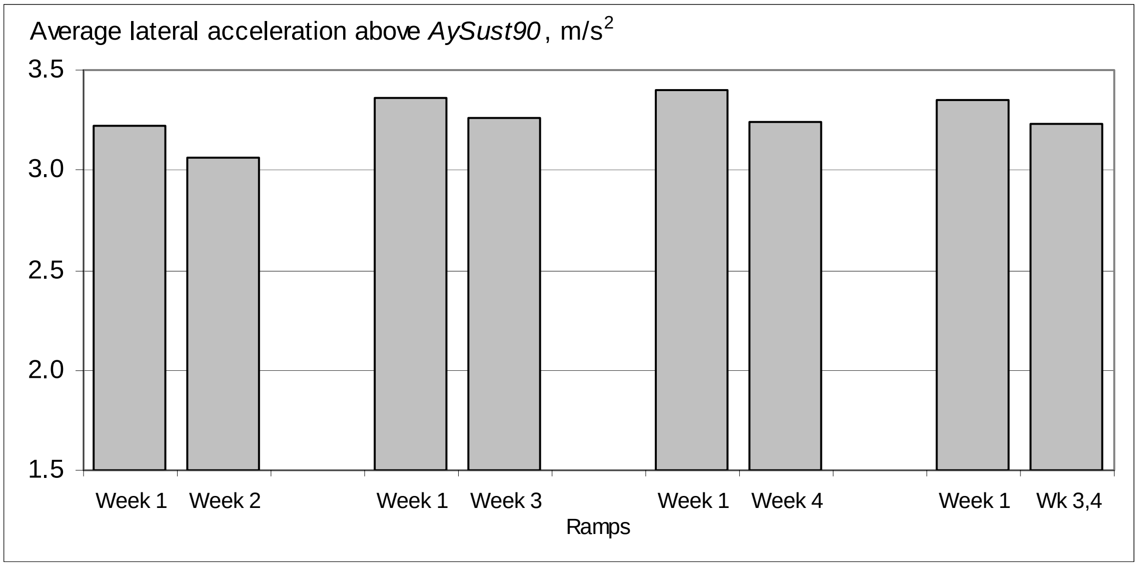
Figure 8.29 shows the average lateral acceleration above the 90th percentile threshold for different test periods. Similar to the analysis using method A, none of these test period comparisons show a significant difference that might support the hypothesis that the CSW system effects a drivers choice of curve speed and hence their lateral acceleration level while in curves.



Paired samples test	Paired differences			
Effect	*Difference in Means*	*t*	*df*	*Sig. (2-tailed)*
Week 1 - Week 2	0.020	0.829	65.0	0.4099
Week 1 - Week 3	0.032	1.177	62.0	0.2437
Week 1 - Week 4	0.014	0.612	65.0	0.5427
Week 1 - Week 3 and 4	0.021	0.964	70.0	0.3386

Figure 8.29 Main effect of test period on *AySust90*

This same method B analysis is also performed for freeways, surface roads, local roads, and ramps. Given the four road types and four comparisons of different week-periods, there are 16 statistical comparisons. Two of these comparisons gave results that reached statistical significance ($p < 0.05$). These were when comparing the method B metrics on ramps, before and after RDCW was enabled. Figure 8.30 shows the comparisons of this metric for travel on ramps. The lateral acceleration metric was significantly reduced when RDCW was enabled during week 4 < 0.05) as well as during weeks 3 and 4 combined. Note that the comparisons suggest a possible trend of reduced values of the lateral acceleration metric while RDCW is enabled, and that the comparison of week 2 vs. week 1 barely misses significance (p = 0.0503).



Paired samples test	*Paired differences*			
Effect	*Difference in Means*	*t*	*df*	*Sig. (2-tailed)*
Week 1 - Week 2	0.158	2.107	17.0	0.0503
Week 1 - Week 3	0.103	1.408	15.0	0.1797
Week 1 - Week 4	0.167	2.230	17.0	0.0395
Week 1 - Week 3 and 4	0.122	2.062	26.0	0.0493

Figure 8.30 Main effect of test period on *AySust90* on ramps

The possible conclusion from this will be discussed in section 8.2.3.4, which brings together the results of all three methods of studying the influences on curve-taking. Recall that method A did not find any significant results when addressing curves in ramps, although there was a similar trend of reduced values of metrics during weeks 2, 3, and 4. However, one item of note in figure 8.30 is that the results are based on a smaller number of drivers – between 15 and 26 drivers, as seen from the column *df*.

8.2.3.3 Studying effects using Method C

As described in section 8.2.3, method C is a mixed linear model test that measures the correlation and non-constant variability between a set of independent variables and a dependent variable. The dependent variable is called *SustAy,* and is defined as the magnitude of the maximum lateral acceleration sustained over a one-second time window for a given curve.

The independent variables and dimensions used in the mixed linear model are:

- driver index (considered a random variable)
- age group, which is a between-subjects co-variable that accounts for differences in age. The age groups are younger, middle-aged, and older (20-30, 40-50, and 60-70 yrs. old, respectively)[5]
- ambient lighting, which is a two-level independent variable, and is defined in earlier sections.
- windshield wiper state, which is a two-level independent variable that is a surrogate for the presence of precipitation and possibly a compromised road-tire friction level. All settings of wiper switch on (delay state included) were grouped together for this analysis.
- curve direction, which is either left or right,
- road type, including freeways, ramps, and surface roads. Unlike methods A and B, the surface-road category includes local roads as well.
- RDCW enabled state, which is a two level independent variable that signals the availability of the RDCW system. For this analysis, the first week baseline driving is compared to weeks three and four combined.

The primary findings for method C are shown in table 8.4. The columns in the table are:

- Factor—independent variables and interactions of multiple independent variables.
- Numerator df—degrees-of-freedom for the corresponding source variables
- Denominator df—degrees-of-freedom calculated for the denominator of the model

[5] Gender was also considered as an independent variable in preliminary tests but was subsequently dropped since it was not significant as a stand-alone variable nor did it show any major interactions with many of the other independent variables.

- F—the F statistic is the ratio of the variances for the two estimators adjusted for degrees of freedom.
- Sig.—is the significance level or the odds that the observed result is due to chance. Generally a level below 5 percent is considered significant. That is, if the significance probability is less than 0.05 than the difference in the two variables is not random.

Table 8.4 Mixed linear model fixed effects results on *SustAy*

Factor	*Numerator df*	*Denominator df*	*F*	*Sig.*
		Main effects		
AgeGroup	2	111.856	22.120	.000
Ambient lighting	1	60.717	12.083	.001
Wiper	1	55.319	64.049	.000
Curve Direction	1	79.243	50.855	.000
RDCW	1	117.979	0.479	.490
Road type	2	162.786	93.248	.000
		Two-way effects		
AgeGroup * RDCW	2	67.955	2.920	.061
Lighting * RDCW	1	1524.032	0.776	.379
Wiper * RDCW	1	1286.767	0.013	.909
Curve Direction * RDCW	1	1417.619	1.337	.248
RDCW * Roadtype	2	1496.934	1.368	.255
		Three-way effects		
Lighting * RDCW * Roadtype	4	1522.157	3.226	.012 Not due to RDCW

The main effects of age, ambient lighting condition, wiper state, curve direction and road type all show a measured significance value of less than 0.1 percent indicating that the influence of these conditions on the dependent measure of *SustAy* are not random and that variations of these conditions produce consistent and measurable changes in the dependent measure. These findings are not a surprise since they have been documented in the previous subsections. The only tested main effect that did not produce a significant result on the dependent variable is RDCW. For RDCW the measure of significance was 0.49. Thus, as a main effect, whether or not RDCW warnings were present is not proven to influence the lateral acceleration metric used in this method.

The remaining main effects that are computed as significant are shown in figure 8.31. The largest measured change is shown in the road type variable where the difference between mean difference in *SustAy* between ramps and freeways is 0.49 m/s^2. For the age group category, not surprisingly, the largest change comes from comparing younger to older drivers, with younger drivers having a mean *SustAy* that is 0.32 m/s^2 larger than that of older drivers. The smallest significant mean change in *SustAy* was found when comparing daytime to nighttime curve taking behavior. For these data, this difference was found to be only 0.08 m/s^2 or less than 0.01 gs.

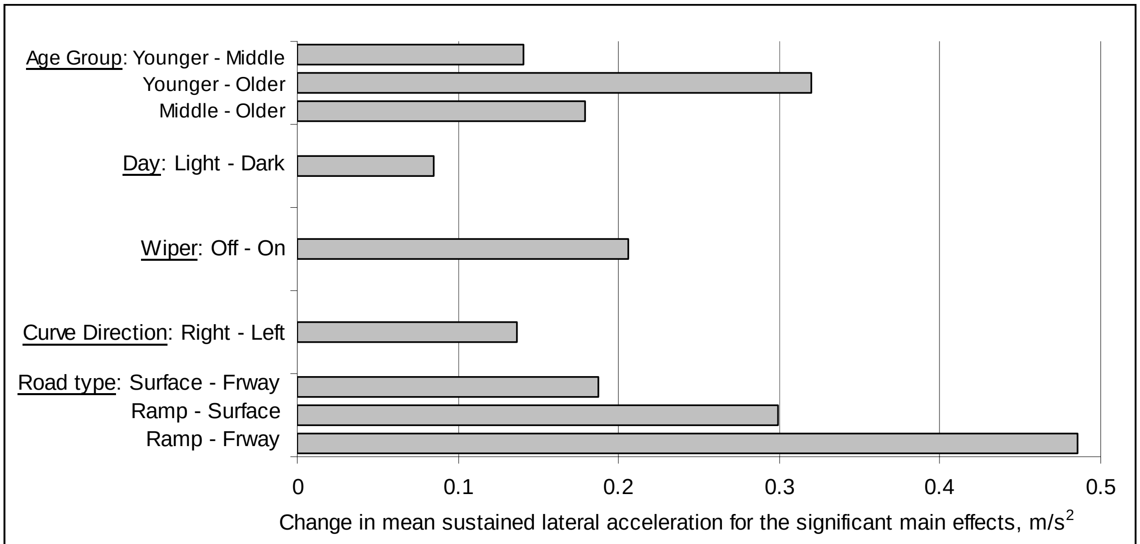


Figure 8.31 Differences in mean *SustAy* for the significant main effect variables

Table 8.4 also shows the two-way interactions of the main effects and RDCW. As the table shows, none of these two-way effects had a significance score of less than 0.05. Hence, it is not apparent with these data that some combination of main-effects and the presence of RDCW resulted in change in lateral acceleration in curves

Similarly, an analysis was run of all three-way interactions of the main effects and RDCW. However, since all but one of these interactions was well above the 0.05 threshold they have been excluded from table 8.4. The only three-way interaction that resulted in a score below the 0.05 threshold was the combination of lighting, RDCW state, and road type. For this combination of 3-way effects the statistical significance was measured to be 0.012. Consider figure 8.32 which shows the mean and upper and lower 95 percent confidence intervals for all the combinations of these three variables. The figure is divided into thirds and shows the results for freeways on the left, ramps in the center. and surface roads on the right.

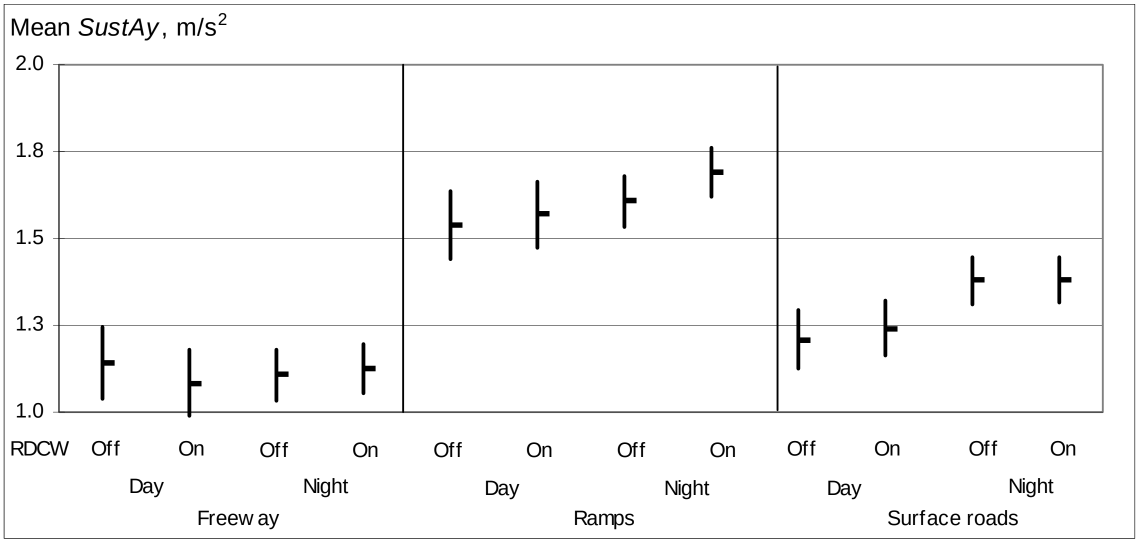


Figure 8.32 Three-way effect of RDCW, day and road type

The figure clearly shows a large difference when the data are segregated by road type, especially when comparing the values of the lateral acceleration metric *SustAy* on ramps to the values on surface and freeway roads. The figure also shows some differences when considering the effect of ambient light. For example, there is a significant difference on surface roads between the day and night condition. However, these method-C results do not show a significant difference when considering RDCW along with the other two main effects, which means that within these specific quadrants of analysis, there does not seem to be a measurable effect of the RDCW system on sustained lateral acceleration while in curves.

8.2.3.4 Summary: Factors influencing lateral acceleration in curves

A summary of the statistical comparisons from methods A, B, and C, as presented in the three preceding sections, is given in table 8.5 (factors other than RDCW) and table 8.6 (RDCW-related factors) on the following pages. Table 8.5 shows that there is a consistent finding that road type, age, curve direction, ambient illumination, and windshield washer state are associated with observed changes on the various lateral acceleration metrics for curve-taking.

When addressing the main topic of whether there is an influence of RDCW on curve-taking patterns of drivers, however, table 8.6 suggests that there is no sweeping influence. That is, the lateral accelerations in curves neither increases nor decreases. This suggests that RDCW may not have a broad effect on curve-taking that either reduces or increases safety due to changes in drivers' curve-speed selections.

The table shows that on freeways and major surface roads, none of the tests revealed any statistically significant result for any of the compared periods of testing. There are, however, some statistical comparisons that did find that one of the three lateral acceleration metrics was statistically different when RDCW was enabled during particular weeks on either local roads or ramps. Specifically, method A resulted in identifying a significant increase in lateral acceleration in curves on local roads during week 2, the first week that RDCW alerts are available. Since there are no other significant findings on local roads, or for week-2 driving, there are three possible explanations:

1. confounding variables were not considered in method A's single-factor approach, and when a multifactor approach is used (method C), the effect vanishes, and/or
2. drivers experimented briefly with CSW alerts by using exaggerated speeds on local roads,
3. statistical chance resulted in a positive test, even though there may be no actual influence.

Table 8.5 Summary of tests addressing factors affecting lateral acceleration in curve-taking (excluding RDCW)

Factor	**Values**	**Significant at 5% level?**			**Conclusions**
		Method A	**Method B**	**Method C**	
Road type	Surface, freeway, ramps	*Not tested*	*Not tested*	Yes	Ramps have highest lat accels, followed by surface and then fwys
Curve direction	Left, right	Yes	No	Yes	Curves right have higher lat accels in some conditions
Curve direction on ramps	Left, right	Yes	Yes	*Not tested*	Curves right on ramps have higher lat accels
Wiper state	On, off	Yes	Yes	Yes	Lower lat accels when wipers are on
Ambient illumination	Daytime, nighttime	Yes	Yes	Yes	Lower lat accels at nighttime
Age	Younger (20-30), Middle (40-50), Older (60 and up)	*Not tested*	*Not tested*	Yes	Younger drivers have higher lat accels than middle aged (who have higher values than older drivers)

Table 8.6 Summary of tests addressing whether RDCW affects lateral acceleration in curve-taking, including breakdown by road type

Road type	Comparing week 1 against which weeks?	Significant result at 5% level?			Conclusions
		Method A	Method B	Method C	
All types combined	week 2	No	No	*Not tested*	No evidence of influence
	week 3	No	No	*Not tested*	No evidence of influence
	week 4	No	No	*Not tested*	No evidence of influence
	weeks 3 & 4 combined	No	No	*Not tested*	No evidence of influence
Freeways only	week 2	No	No	*Not tested*	No evidence of influence
	week 3	No	No	*Not tested*	No evidence of influence
	week 4	No	No	*Not tested*	No evidence of influence
	weeks 3 & 4 combined	No	No	No	No evidence of influence
Surface roads only	week 2	No	No	*Not tested*	No evidence of influence
	week 3	No	No	*Not tested*	No evidence of influence
	week 4	No	No	*Not tested*	No evidence of influence
	weeks 3 & 4 combined	No	No	No	No evidence of influence
Local roads only	week 2	Yes, lat accel increase	No	*Not tested*	Possible short-term influence
	week 3	No	No	*Not tested*	No evidence of influence
	week 4	No	No	*Not tested*	No evidence of influence
	weeks 3 & 4 combined	No	No	*(see surf.)*	No evidence of influence
Ramps only	week 2	No	No	*Not tested*	No evidence of influence
	week 3	No	No	*Not tested*	No evidence of influence
	week 4	No	Yes – lat accel decrease	*Not tested*	May reduce lat accels on ramps
	weeks 3 & 4 combined	No	Yes – decrease in lat accel	No	

There appears to be no simple argument that clearly proves any or all of these explanations. The first explanation seems most plausible, however, and the proposed conclusion regarding the week-2, local-road result is that RDCW or CSW is not expected to lead to higher lateral accelerations on minor surface roads. It is further argued that this result does not provide insight into the effects of RDCW or CSW on driver curve-taking.

There is a second set of comparisons that lead to statistical significance – method B suggests that there is an association of RDCW being enabled with decreased lateral accelerations on ramps. This is significant for week 4, and for weeks 3 and 4 combined, but not weeks 2 or 3. This same result was not identified with either methods A or C, either. There does seem to be a reduction in the levels of lateral accelerations on ramps at the tails of those distributions when RDCW is enabled – it simply does not reach statistical significance. Therefore, once again, the conclusion that is suggested is that while there is some evidence that RDCW may have an effect of curve-taking on ramps, the evidence is not conclusive.

8.3 Effects of RDCW on driver engagement in secondary task activities

This section addresses a different aspect of driver behavior: how often drivers engage in secondary task activities, that is, activities that are not essential to driving. Examples of secondary tasks include eating, conversing with passengers, talking on mobile phones, and grooming. Secondary task activity is studied here to determine whether there is a clear increase or decrease in this activity when RDCW becomes enabled. A clear increase might suggest that drivers may be decreasing their vigilance and relying on the RDCW system, which could have the potential to decrease safety. A decrease in secondary activity could be caused by drivers' increased awareness of the need to pay attention to driving, perhaps brought about by the driver alerts. This could indicate a possible increase in safety due to enhanced driver awareness. The specific effects of performing secondary tasks on driving performance are not addressed in this report, but instead can be found in an associated report by Sayer, Devonshire and Flannagan (2005).

Secondary task activity was studied by using video clips captured regularly throughout the FOT that captured the forward driving scene and the driver's head and shoulders. The data acquisition system captured a five-second video clip every five minutes from the face camera, regardless of the driving situations or driver activity, creating a random sample of driver activity. Over the FOT, a total of 18,281 such clips were collected. However, it was not possible to examine this many clips in the analysis reported here.

A random sample of these five-second videos from 36 drivers (6 randomly selected drivers from each gender-by-age group combination) was analyzed for evidence of secondary behaviors while driving. Drivers had to have at least ten, five-second exposure video clips per week to be included in the random sample, so that a total of 1,440 video clips were examined. The coding key used to analyze the exposure videos for non-driving behaviors can be found in Appendix U. Only video clips in which the vehicle was traveling at speeds in excess of 25 mph, the minimum speed at which both CSW and LDW were active, were considered in the analyses described below.

Chi-square (χ^2) tests were performed in order to investigate whether the incidence of secondary, non-driving behaviors changed when the RDCW was enabled. As a result of the limited number of observations for many of the non-driving behaviors, the χ^2 tests reported below compare the total number of non-driving behaviors in week 1 to weeks 2-4 for each of the groups. A significance level of $p < .05$ was employed. Frequency counts of non-driving behaviors that were observed in the exposure clips are displayed in table 8.7 and they are also depicted in figure 8.33.

Table 8.7 Exposure review counts of non-driving behaviors by week

Non-driving behavior	Week 1 - Manual	Week 2 - RDCW	Week 3 - RDCW	Week 4 - RDCW	Week 2,3,4 (RDCW mean)	Total Clips
Conversation	51 (14.2%)	68 (18.9%)	47 (13.1%)	54 (15.0%)	56 (15.6%)	220 (15.3%)
Grooming	18 (5.0%)	24 (6.7%)	35 (9.7%)	17 (4.7%)	25 (7.0%)	94 (6.5%)
Cell phone	16 (4.4%)	17 (4.7%)	21 (5.8%)	20 (5.6%)	19 (5.4%)	74 (5.1%)
Other/multiple behaviors	19 (5.3%)	12 (3.3%)	13 (3.6%)	11 (3.1%)	12 (3.3%)	55 (3.8%)
Eating	6 (1.7%)	7 (1.9%)	1 (0.3%)	4 (1.1%)	5 (1.3%)	18 (1.3%)
Drinking	3 (0.8%)	2 (0.6%)	2 (0.6%)	3 (0.8%)	2 (0.6%)	10 (0.7%)
Smoking	2 (0.6%)	1 (0.3%)	1 (0.3%)	5 (1.4%)	2 (0.6%)	9 (0.6%)
Hands-free cell phone	2 (0.6%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (0.1%)	2 (0.1%)
Clips with non-driving behavior	117 (32.5%)	131 (36.4%)	120 (33.3%)	114 (31.7%)	122 (33.8%)	482 (33.5%)
None	243 (67.5%)	229 (63.6%)	240 (66.7%)	246 (68.3%)	238 (66.2%)	958 (66.5%)
Total Clips	360	360	360	360		1440

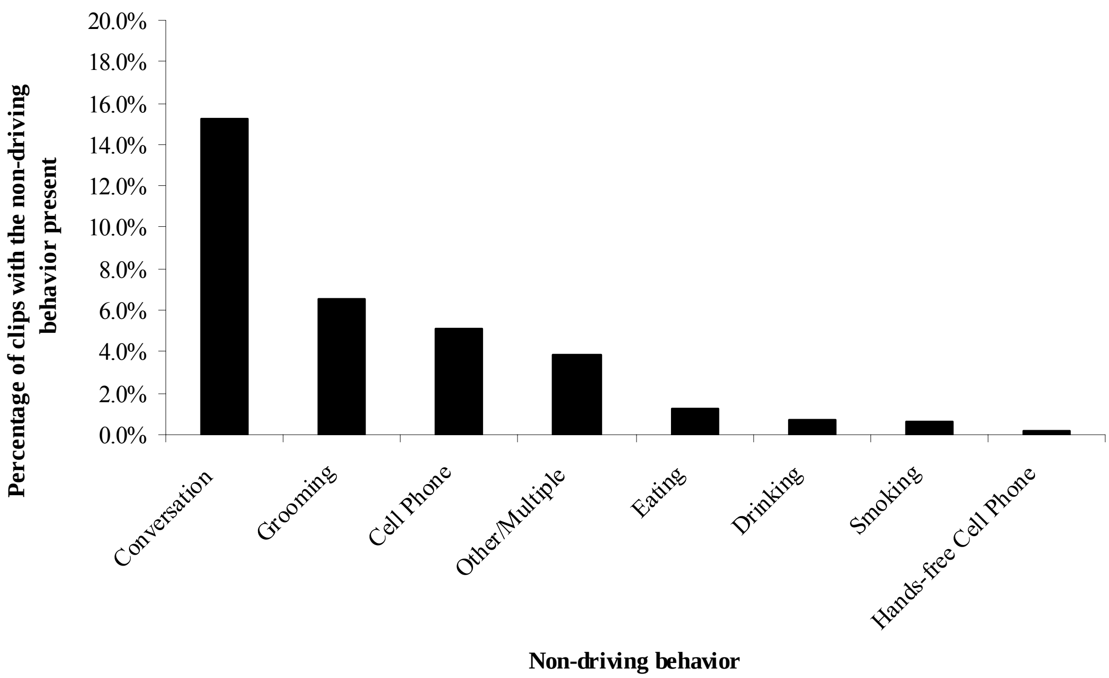


Figure 8.33 Non-driving behavior percentages by individual behavior

Overall, participants were engaged in non-driving behaviors in about one-third of the reviewed exposure clips. The most common behavior was *conversation with another passenger in the car*. This was present in 220 of the 1440 clips reviewed or about 15 percent of the time. *Grooming* was the second most common, non-driving behavior, noted in about 7 percent of the clips, and *hand-held cell phone* was the third most common, noted in 5 percent of the clips.

There was little variation from week to week in terms of the relative frequency of secondary, non-driving behaviors. The difference between week 1, the week when the RDCW system was not enabled, and weeks 2 – 4, the RDCW-enabled period, was not statistically significant. Week 2 saw the highest percentage of non-driving behaviors (present in 36 percent of exposures) while week 4 had the lowest percentage at 32 percent. Non-driving behavior percentages, by week, are displayed in Figure 8.34.

The higher percentage present in week 2 was mainly driven by an especially high frequency of exposures with *conversation* (19 percent in week 2, 15 percent average overall.). This may have been a result of drivers' enthusiasm to explain the RDCW system to passengers during the first week that the RDCW system was enabled. *Grooming* and *hand-held cell phone* were at their highest in week 3, while *conversation* was at its lowest. Individual non-driving behavior percentages by week are displayed in Figure 8.35.

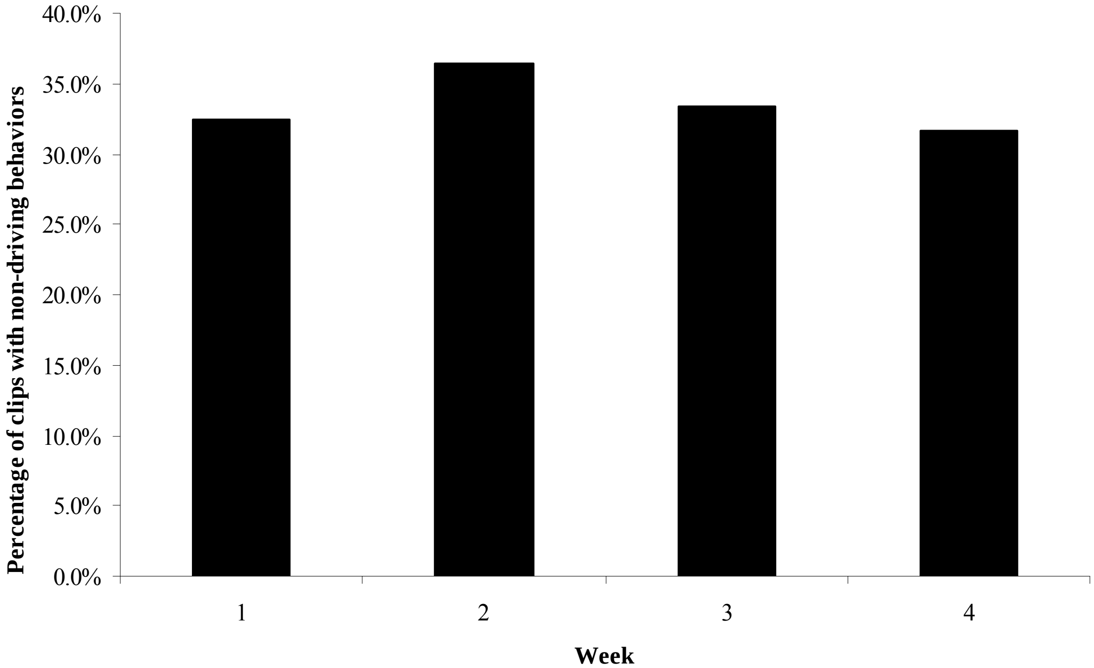


Figure 8.34 Percentages of non-driving behavior by week

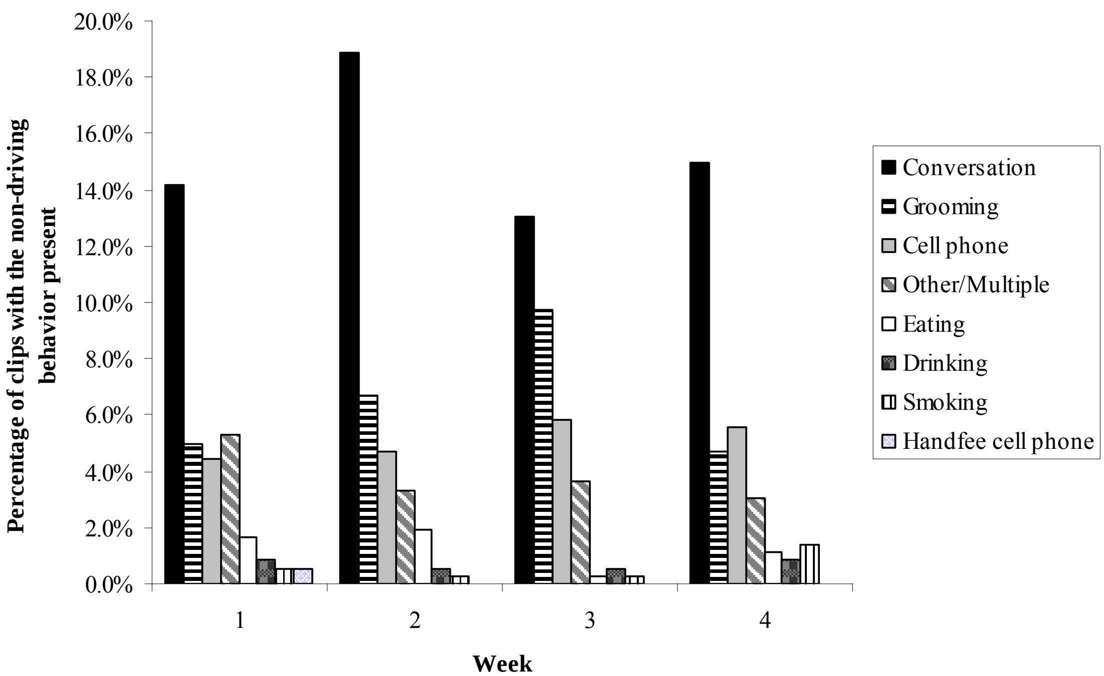


Figure 8.35 Frequency of individual non-driving behaviors by week

Counts of the non-driving behaviors as a function of age group are provided in Tables 8.8 and 8.9. While not statistically significant, the total percentage of non-driving behaviors increased for all age groups once the RDCW system was enabled. Not surprisingly, older drivers engaged in the fewest number of secondary tasks for both Week 1 and the RDCW-enabled period.

Table 8.8 Exposure review of non-driving behaviors, counts by age group for Week 1

Non-driving behavior	Younger	Middle-aged	Older	Total Clips	% of Total Week1 clips
Conversation	13	19	19	51	14.2%
Grooming: low involvement	6	10	2	18	5.0%
Cell phone:conversation,in use	10	4	2	16	4.4%
Other/multiple behaviors	6	4	3	13	3.6%
Eating:low involvement	4	0	1	5	1.4%
Drinking:low involvement	0	2	1	3	0.8%
Smoking	0	2	0	2	0.6%
Eating:high involvement	1	0	0	1	0.3%
Headset/hands-free phone:conversation	1	0	0	1	0.3%
Headset/hands-free phone: unsure if any activity	1	0	0	1	0.3%
In-car system use	0	1	0	1	0.3%
Cell phone:reaching for	0	0	0	0	0.0%
Cell phone:dialing	0	0	0	0	0.0%
Drinking:high involvement	0	0	0	0	0.0%
Grooming: high involvement	0	0	0	0	0.0%
Headset/hands-free phone:reaching for headset	0	0	0	0	0.0%
Smoking:lighting a cigarette	0	0	0	0	0.0%
Smoking:reaching for cigarettes or lighter	0	0	0	0	0.0%
None	78	78	92	248	68.9%
Total Clips	120	120	120	360	
Clips w/ non-driving behavior	42	42	28	112	
Clips w/ non-driving behaviors(%)	35%	35%	23%	31%	

Table 8.9 Exposure review of non-driving behaviors, counts by age group for Weeks 2-4

Non-driving behavior	Younger	Middle-aged	Older	Total Clips	% of Total week2-4 clips
Conversation	52	59	58	169	15.6%
Grooming: low involvement	28	24	23	75	6.9%
Cell phone:conversation,in use	29	23	4	56	5.2%
Other/multiple behaviors	15	13	5	33	3.1%
Eating:low involvement	4	3	4	11	1.0%
Drinking:low involvement	2	4	0	6	0.6%
Smoking	2	4	0	6	0.6%
In-car system use	0	2	2	4	0.4%
Cell phone:dialing	1	1	0	2	0.2%
Drinking:high involvement	1	0	0	1	0.1%
Eating:high involvement	1	0	0	1	0.1%
Grooming: high involvement	0	0	1	1	0.1%
Smoking:reaching for cigarettes or lighter	1	0	0	1	0.1%
Cell phone:reaching for	0	0	0	0	0.0%
Headset/hands-free phone:conversation	0	0	0	0	0.0%
Headset/hands-free phone:reaching for headset	0	0	0	0	0.0%
Headset/hands-free phone: unsure if any activity	0	0	0	0	0.0%
Smoking:lighting a cigarette	0	0	0	0	0.0%
None	224	227	263	714	66.1%
Total Clips	360	360	360	1080	
Clips w/ non-driving behavior	136	133	97	366	
Clips w/ non-driving behaviors(%)	38%	37%	27%	34%	

The counts of the non-driving behaviors presented in tables 8.10 and 8.11 are a function of gender. The total percentage of clips with secondary, non-driving behaviors by women did not change between week 1 and the RDCW-enabled period. While the total percentage of non-driving behaviors increased for men, from 26 percent to 32 percent, the increase was not statistically significant.

Table 8.10 Exposure review of non-driving behaviors, counts by gender for Week 1

Non-driving behavior	Female	Male	Total Clips	% of Total Week1 clips
Conversation	35	16	51	14.2%
Grooming: low involvement	9	9	18	5.0%
Cell phone:conversation,in use	9	7	16	4.4%
Other/multiple behaviors	6	7	13	3.6%
Eating:low involvement	2	3	5	1.4%
Drinking:low involvement	1	2	3	0.8%
Smoking	2	0	2	0.6%
Eating:high involvement	1	0	1	0.3%
Headset/hands-free phone:conversation	0	1	1	0.3%
Headset/hands-free phone: unsure if any activity	0	1	1	0.3%
In-car system use	0	1	1	0.3%
Cell phone:reaching for	0	0	0	0.0%
Cell phone:dialing	0	0	0	0.0%
Drinking:high involvement	0	0	0	0.0%
Grooming: high involvement	0	0	0	0.0%
Headset/hands-free phone:reaching for headset	0	0	0	0.0%
Smoking:lighting a cigarette	0	0	0	0.0%
Smoking:reaching for cigarettes or lighter	0	0	0	0.0%
None	115	133	248	68.9%
Total Clips	180	180	360	
Clips w/ non-driving behavior	65	47	112	
Clips w/ non-driving behaviors(%)	36%	26%	31%	

Table 8.11 Exposure review of non-driving behaviors, counts by gender for Weeks 2-4

Non-driving behavior	Female	Male	Total Clips	% of Totoal week2-4 clips
Conversation	95	74	169	15.6%
Grooming: low involvement	33	42	75	6.9%
Cell phone:conversation,in use	25	31	56	5.2%
Other/multiple behaviors	21	12	33	3.1%
Eating:low involvement	7	4	11	1.0%
Drinking:low involvement	3	3	6	0.6%
Smoking	6	0	6	0.6%
In-car system use	1	3	4	0.4%
Cell phone:dialing	1	1	2	0.2%
Drinking:high involvement	1	0	1	0.1%
Eating:high involvement	1	0	1	0.1%
Grooming: high involvement	0	1	1	0.1%
Smoking:reaching for cigarettes or lighter	1	0	1	0.1%
Cell phone:reaching for	0	0	0	0.0%
Headset/hands-free phone:conversation	0	0	0	0.0%
Headset/hands-free phone:reaching for headset	0	0	0	0.0%
Headset/hands-free phone: unsure if any activity	0	0	0	0.0%
Smoking:lighting a cigarette	0	0	0	0.0%
None	345	369	714	66.1%
Total Clips	540	540	1080	
Clips w/ non-driving behavior	195	171	366	
Clips w/ non-driving behaviors(%)	36%	32%	34%	

Table 8.12 and table 8.13 display counts of non-driving behaviors for each of the gender-by-age group combinations, with table 8.12 showing week 1 data and table 8.13 showing weeks 2-4 data. During week 1, middle-aged, female drivers were the most likely to engage in non-driving behaviors (43 percent), while older males were the least likely (17 percent). During weeks 2-4, the RDCW-enabled period, younger females engaged in secondary behaviors the most frequently (43 percent). Older females were the least likely (26 percent) to engage in non-driving behaviors with the RDCW system enabled. The data shows that among each gender-age group, there were slight changes in the fraction of video clips that exhibited non-driving behaviors. The fraction increased for three gender-age groups, and decreased for three groups. When applying statistical tests, however, there were no statistically significant differences found between the frequencies of non-driving behaviors for week 1 as compared to weeks 2-4 for any of these gender-age groups.

Overall, given the data that was used to study secondary task activities by drivers with and without the RDCW system, there were no statistically significant changes observed. Thus it is not possible to conclude that the RDCW system is either enhancing or decreasing safety through the encouragement or discouragement of secondary task activities. It is possible that further work with a much larger sample of the might isolate changes, should they exist, but it is not possible from the existing analysis to speculate on the direction of any such changes.

Table 8.12 Exposure review of non-driving behaviors, counts by age by gender groups for Week 1

Non-driving behavior	Younger female	Middle-aged Female	Older Female	Younger Male	Middle-aged Male	Older Male	Total Clips	% of Total Week1 clips
Cell phone:conversation,in use	5	4	0	5	0	2	16	4.4%
Cell phone:reaching for	0	0	0	0	0	0	0	0.0%
Cell phone:dialing	0	0	0	0	0	0	0	0.0%
Conversation	9	13	13	4	6	6	51	14.2%
Drinking:high involvement	0	0	0	0	0	0	0	0.0%
Drinking:low involvement	0	1	0	0	1	1	3	0.8%
Eating:high involvement	1	0	0	0	0	0	1	0.3%
Eating:low involvement	1	0	1	3	0	0	5	1.4%
Grooming: high involvement	0	0	0	0	0	0	0	0.0%
Grooming: low involvement	1	6	2	5	4	0	18	5.0%
Headset/hands-free phone:conversation	0	0	0	1	0	0	1	0.3%
Headset/hands-free phone:reaching for headset	0	0	0	0	0	0	0	0.0%
Headset/hands-free phone: unsure if any activity	0	0	0	1	0	0	1	0.3%
In-car system use	0	0	0	0	1	0	1	0.3%
None	39	34	42	39	44	50	248	68.9%
Other/multiple behaviors	4	0	2	2	4	1	13	3.6%
Smoking:lighting a cigarette	0	0	0	0	0	0	0	0.0%
Smoking:reaching for cigarettes or lighter	0	0	0	0	0	0	0	0.0%
Smoking	0	2	0	0	0	0	2	0.6%
Total Clips	60	60	60	60	60	60	360	
Clips w/ non-driving behavior	21	26	18	21	16	10	112	
Clips w/ non-driving behaviors(%)	35%	43%	30%	35%	27%	17%	31%	

Table 8.13 Exposure review of non-driving behaviors, counts by age by gender groups for Weeks 2-4

Non-driving behavior	Younger female	Middle-aged Female	Older Female	Younger Male	Middle-aged Male	Older Male	Total Clips	% of Totoal week2-4 clips
Cell phone:conversation,in use	11	13	1	18	10	3	56	5.2%
Cell phone:reaching for	0	0	0	0	0	0	0	0.0%
Cell phone:dialing	1	0	0	0	1	0	2	0.2%
Conversation	31	31	33	21	28	25	169	15.6%
Drinking:high involvement	1	0	0	0	0	0	1	0.1%
Drinking:low involvement	1	2	0	1	2	0	6	0.6%
Eating:high involvement	1	0	0	0	0	0	1	0.1%
Eating:low involvement	3	1	3	1	2	1	11	1.0%
Grooming: high involvement	0	0	0	0	0	1	1	0.1%
Grooming: low involvement	14	11	8	14	13	15	75	6.9%
Headset/hands-free phone:conversation	0	0	0	0	0	0	0	0.0%
Headset/hands-free phone:reaching for headset	0	0	0	0	0	0	0	0.0%
Headset/hands-free phone: unsure if any activity	0	0	0	0	0	0	0	0.0%
In-car system use	0	1	0	0	1	2	4	0.4%
None	103	109	133	121	118	130	714	66.1%
Other/multiple behaviors	11	8	2	4	5	3	33	3.1%
Smoking:lighting a cigarette	0	0	0	0	0	0	0	0.0%
Smoking:reaching for cigarettes or lighter	1	0	0	0	0	0	1	0.1%
Smoking	2	4	0	0	0	0	6	0.6%
Total Clips	180	180	180	180	180	180	1080	
Clips w/ non-driving behavior	77	71	47	59	62	50	366	
Clips w/ non-driving behaviors(%)	43%	39%	26%	33%	34%	28%	34%	

9 Driver Perceptions: Analysis of Subjective Responses

Drivers' subjective assessments of the RDCW system were obtained through several different mechanisms. These included the post-drive questionnaire (representing the bulk of the subjective data), utility ratings of specific alerts (elicited during the debriefing sessions), and a series of focus groups. Taken together, these data provide a sense of the extent to which drivers accepted the RDCW system and what changes they might want to see in future implementations.

All 78 drivers completed the post-drive questionnaire and reviewed some of their warning events upon returning the vehicle. However, specific analyses may not include all 78 drivers (due to questionnaire items that were skipped, the fact that some drivers did not receive every type of warning, etc.). In addition, the focus groups involved a subset of only 25 of the 78 drivers, although the strength of focus group data comes not so much from the number of participants, but rather the depth and breadth of subjective response.

9.1 Post-drive questionnaire results: RDCW, LDW, and CSW

Appendix M provides the entire post-drive questionnaire with descriptive statistics for individual questions by driver age group and gender (e.g., frequency distributions, overall/group means and standard deviations). Additionally, Appendix V provides a summary of all open-ended responses on the post-drive questionnaire. Almost all of the items on the post-drive questionnaire were 7-point, Likert-type scales with higher scores corresponding to positive attributes. Because the questionnaire was separated into three sections (RDCW, LDW, and CSW), most of the following analyses are similarly separated into an examination of the three different questionnaire sections.

In order to reduce the inherent complexity of analyzing and interpreting multiple items on lengthy questionnaires, methods of data reduction are often used. These can involve *a priori* decisions about how the questionnaire items conceptually group together, as well as analyses that look at how the responses to particular items correlate with each other (and thus what items might theoretically be measuring the "same thing"). Both approaches were used for the following analyses. For example, prior to launching the FOT, items in each of the three primary sections of the post-drive questionnaire (RDCW, LDW and CSW) were grouped into four *a priori* subscales: comfort and convenience, ease of use, safety, and willingness to purchase. To provide an overall picture of how drivers responded to the questionnaire, we present in this section descriptive statistics for these *a priori* subscales (mean scores by age and gender, and summaries of responses to specific questionnaire items).

Inferential statistics, however, were reserved for a more bottom-up approach that included two steps. First, a series of exploratory factor analyses were performed on the questionnaire items. Factor analyses offer a way to group items together based not upon the researchers' *a priori* assumptions, but rather based on how drivers actually responded. They thus offer an advantage in that they may more accurately reflect the variance in drivers' responses, and may therefore provide a more appropriate model for the data. Three separate factor analyses were performed (RDCW, LDW, and CSW), and the results are reported below.

The primary function of the factor analyses was data reduction; they did not directly lend themselves to inferences about what kinds of things may have predicted how drivers responded to questionnaire items. For example, were there certain personality traits that made one more accepting of RDCW? How did LDW alert rate affect drivers' willingness to purchase LDW? To examine questions such as these, the results of the factor analyses were coupled with regression analyses. This section reports the results of a series of multiple regressions in which the factor scores (from the factor analyses) were the dependent variables.

Finally, we conclude this section with an analysis of the Van der Laan scores of acceptance for RDCW, and compare these results to those of another field operational test. The Van der Laan scale represents one way to broadly capture drivers' subjective assessments of usefulness and satisfaction with a new automotive technology. This scale was included in the post-drive questionnaire, and is described in section 9.1.4, along with an analysis of how RDCW was rated by the drivers.

9.1.1 Four a priori subscales

For each subscale, scores of the corresponding questionnaire items were averaged together. Thus, each subscale score represents the mean response for all of the items belonging to that scale. Tables 9.1 through 9.3 provide means for these subscales on each RDCW subsystem by age group and gender, as well as an overall mean and standard deviation for all drivers (the mean scores for the individual questions contained in each subscale are examined in greater detail later in this section). Again, subscale scores had a 1-7 range, with higher scores indicating positive attributes. The left-most column of each table contains the name of the subscale, and the specific questionnaire items that belong to each subscale appear in parentheses.

Table 9.1 Means for the RDCW *a priori* subscale by age group and gender

RDCW Subscale	Means by Gender		Means by Age Group			Statistics for All Drivers	
	Male	Female	Young	Middle	Older	Mean	St. Dev.
Comfort and Convenience (1, 24)	6.1	6.2	6.0	6.2	6.2	6.1	0.9
Ease of Use (1-3, 5-9, 12, 15-21, 25, 26)	6.1	6.2	6.2	6.2	6.2	6.2	0.6
Safety (27, 28, 30)	5.7	5.8	5.3	5.7	6.1	5.7	1.2
Willingness to Purchase (34, 37)	4.7	4.6	4.3	4.6	5.0	4.6	1.8
All RDCW scales combined	5.65	5.70	5.45	5.68	5.88	5.65	1.13

Table 9.2 Means for the LDW *a priori* subscale by age group and gender

LDW Subscale	Means by Gender		Means by Age Group			Statistics for All Drivers	
	Male	Female	Young	Middle	Older	Mean	St. Dev.
Comfort and Convenience (14, 21, 24, 25, 42)	4.9	5.1	5.0	4.8	5.3	5.0	1.2
Ease of Use (1-3,5-8,10-13,18-20,23,32,33)	6.0	6.1	5.9	6.0	6.1	6.0	0.8
Safety (24, 25, 34, 35, 37-39)	5.1	5.4	5.0	5.2	5.6	5.3	1.2
Willingness to Purchase (47, 50)	5.3	5.1	4.9	5.1	5.5	5.2	1.8
All LDW scales combined	5.33	5.43	5.20	5.28	5.63	5.38	1.25

Table 9.3 Means for the CSW *a priori* subscale by age group and gender

CSW Subscale	Means by Gender		Means by Age Group			Statistics for All Drivers	
	Male	Female	Young	Middle	Older	Mean	St. Dev.
Comfort and Convenience (14,21,24,25,42)	4.3	4.8	4.6	4.1	5.1	4.6	1.5
Ease of Use (1-3,5-8,10-13,18-20,23,32,33)	5.9	6.1	6.0	6.0	6.0	6.0	0.9
Safety (24, 25, 34, 35, 37-39)	4.7	5.2	5.1	4.6	5.1	4.9	1.5
Willingness to Purchase (47, 50)	4.1	4.0	4.1	3.7	4.3	4.0	2.1
All CSW scales combined	4.75	5.03	4.95	4.60	5.13	4.88	1.50

From the tables it can be seen that mean subscale scores for both LDW and CSW were generally positive in all four categories. When assessing the RDCW system as a whole, drivers tended to rate items more positively than when assessing LDW or CSW by themselves. In addition, ratings for the LDW system were typically higher than those for CSW, although ratings for CSW generally had more variability, as can be seen by the higher standard deviations across all four subscales. Note also that, when considering all of the drivers, there was no difference in their perception of *ease of use* between LDW and CSW.

While not a strong tendency, females rated many aspects of the RDCW system more positively than males, but were also slightly less willing to purchase the system. It can also be seen from the tables that ratings generally increased with age for RDCW and LDW (especially for *safety* and *willingness to purchase* items), but that this was not true for CSW. For CSW, ratings decreased for middle age drivers but increased for older drivers (with the exception of *ease of use* items). In general, *ease of use* was rated highest across all sections of the questionnaire, although ratings for *willingness to purchase* were comparatively lower.

Below is a summary of mean responses to the individual items of the four subscales for each section of the post-drive questionnaire.

RDCW: Comfort and convenience

Overall, drivers reported feeling comfortable driving the car with RDCW (RDCW24, mean = 6.3)

RDCW: Ease of use

Drivers found it easy to become familiar with the RDCW system, and it was easy for them to develop a good understanding of the system after a brief description and a test drive (means of 6.4 and 6.5 respectively) (RDCW25, RDCW26). Drivers reported that it was easy to use and understand the graphics presented in the RDCW display (means of 5.9, 6.3, and 6.3) (RDCW1-RDCW3). Furthermore, they responded that it was easy to become familiar with the layout of the display (RDCW15, mean = 6.4). Drivers also reported that the sensitivity adjustment switches were easy to use (RDCW5), easy to locate (RDCW6), and easy to determine which switch controlled which system (RDCW7) (means of 6.8, 6.6, and 6.8 respectively). Drivers found it easier to understand how changes to the LDW sensitivity setting affected LDW warnings than they did with the CSW counterparts (means of 6.0 and 5.5) (RDCW9 and RDCW12). Drivers found it easier to distinguish between the RDCW auditory warnings than they did the RDCW seat vibration warnings (means of 6.3 and 5.7 respectively) (RDCW16, RDCW18). When either the auditory or the seat vibration warnings occurred, drivers understood the meaning and required response (means of 5.9 and 5.6 respectively) (RDCW17, RDCW19). While overall drivers could easily identify the urgency of the RDCW warnings (RDCW21, mean = 5.9), it was easier for them to recognize the warning condition (e.g. LDW left cautionary, CSW imminent, etc.) for the auditory warnings (RDCW20b, mean = 6.3) than it was for the visual warnings (RDCW20a, mean = 5.1) or for the seat vibration warnings (RDCW20c, mean = 5.8).

RDCW: Safety

When asked if RDCW is going to increase driving safety, drivers' mean response was 5.6 (RDCW30). Drivers reported that they were not distracted by the RDCW system components (RDCW27, mean = 5.6). Drivers felt that the RDCW system made them more aware of their lane position and of upcoming curves (RDCW28, mean = 5.9).

RDCW: Willingness to purchase

When drivers disregarded the cost of an RDCW system, they were more willing to consider purchasing one than when they considered purchasing an RDCW system at a price of $800 (means of 5.0 and 4.3 respectively) (RDCW34 and RDCW37).

LDW: Comfort and convenience

Overall, the frequency with which drivers received LDW warnings was less annoying for the seat vibrations than it was for the auditory warnings (LDW21, mean = 6.0, LDW14, mean = 5.5). When asked about the timeliness of the warnings, drivers' responses resulted in a mean of 5.2 for the LDW auditory warnings (LDW24) and a mean of 5.6 for the LDW seat vibrations (LDW25). Drivers reported receiving fewer false LDW warnings (LDW29, mean = 4.5) than unnecessary ones (LDW28, mean = 4.1). When asked if they would feel more comfortable performing additional tasks while driving with an LDW system than manual driving, the mean response was 4.3 (LDW42).

LDW: Ease of use

In general, drivers felt that it was easy to become familiar with the LDW system and to develop a good understanding of the system after a brief description and a test drive (LDW32, mean = 6.3 and LDW33, mean =6.4). Additionally, they reported being able to easily identify the urgency of the LDW warnings (LDW23, mean = 6.0). Drivers found the graphics associated with the LDW system easy to see and understand (LDW1 – LDW3, means of 6.2, 6.4, and 5.5 respectively). When asked if they knew what to do when they received the LDW warnings, drivers' responses resulted in a mean of 5.3 for the visual warnings (LDW5), a mean of 6.4 for the auditory warnings (LDW10), and a mean of 6.3 for the seat vibrations (LDW18).

While overall, drivers were not distracted by the LDW warnings, they found the auditory warnings more distracting than either the visual warnings or the seat vibrations (mean scores of 5.6, 5.9, and 6.0 respectively) (LDW6, 13, and 20). Drivers did not find the LDW availability icons to be distracting (LDW7, mean = 6.1). Furthermore, drivers responded that the availability icons helped them to understand and to use the LDW system (LDW8, mean = 5.9). Drivers reported being able to easily hear the LDW auditory warnings (LDW11, mean = 6.6). When asked how easily they could recognize from which direction the LDW auditory warning was coming, the mean response was 5.2 (LDW12). Drivers found it easy to determine under which leg the LDW seat vibration was presented (LDW19, mean = 6.1).

LDW: Safety

When asked if LDW is going to increase driving safety, the mean response was 5.6. Drivers reported that the LDW system made them more aware of their lane position (LDW34, mean = 6.2) and more attentive to using their turn signals when changing lanes (LDW35, mean = 5.9). Drivers did not find the LDW system particularly useful in adverse weather conditions (LDW39, mean = 3.9). When asked if they found the LDW system useful in providing warnings in situations that had potential for resulting in a crash, the drivers' mean response was 4.6 (LDW37). Overall, drivers felt that the LDW seat vibrations were provided in a more timely manner than the LDW auditory warnings (LDW25, mean = 5.6, LDW 24, mean = 5.2).

LDW: Willingness to purchase

When asked how likely it was that they would consider purchasing an LDW system, disregarding cost, the responses produced a mean of 5.2 (LDW47), which was identical to the mean of the responses when people were asked how likely it was that they would consider purchasing an LDW system at a price of $300 (LDW50).

CSW: Comfort and convenience

In terms of how annoying the frequency with which CSW warnings were received, drivers' responses produced the same means for the auditory warnings and the seat vibration warnings. (CSW14, CSW21, mean = 5.4). Drivers' ratings of the timing of the auditory and seat vibration warnings were similar (means of 4.9 and 5.1 respectively) (CSW24, CSW25). When asked if they had received unnecessary CSW warnings drivers' responses produced a mean of 3.8 and a mean of 3.7 in reference to receiving false CSW warnings (CSW28, CSW29). In general, drivers did not strongly feel more comfortable performing additional tasks while driving with CSW than they did while driving manually (CSW42, mean = 3.9).

CSW: Ease of use

Overall, drivers reported that it was easy to become familiar with the CSW system (CSW32, mean = 6.2) and to understand how the system worked after a brief description and test drive (CSW33, mean = 6.3). When asked to report how easy it was to identify the urgency of the CSW warnings, drivers' mean response was 5.8 (CSW23). When asked to appraise how easy it was to see and to use the graphics in the display, drivers answered the questions in the CSW section consistently with the same questions in the LDW section (CSW1-CSW3, means of 6.4, 6.5, and 5.3 respectively). Drivers rated their understanding of what to do when they received a warning similarly for the CSW auditory and seat vibration warnings, but slightly lower for the visual warnings (means of 6.2, 6.0, and 5.1 respectively) (CSW5, 10 and 18). Drivers reported that they were generally not distracted by the CSW warnings and rated the three modalities nearly identically (visual, CSW6, mean = 5.7, auditory, CSW13, mean = 5.6 and seat vibrations, CSW20, mean = 5.9). Drivers were not distracted by the CSW availability icons (CSW7, mean = 6.3), rather they reported that the icons helped them to understand and to use the CSW system (CSW8, mean = 5.8). Drivers reported being able to easily hear the CSW auditory warnings (CSW11, mean = 6.7) and knew that they were coming from the front speakers (CSW12, mean = 6.1). When asked if they could easily recognize that the CSW seat vibration warnings were being presented in the front part of the seat, drivers' responses resulted in a mean of 6.0 (CSW19).

CSW: Safety

Overall, drivers agreed that CSW is going to increase safety (CSW38, mean = 5.2). When drivers were asked if CSW was useful in providing warnings about situations that might result in a crash, the mean response was 3.9 (CSW37). Drivers did not find the CSW system particularly useful in adverse weather (CSW39, mean = 4.4). They did, however, report that the CSW system made them more aware of upcoming curves (CSW34, mean = 5.3) and more attentive to slowing down for curves (CSW35, mean = 5.5).

CSW: Willingness to purchase

When drivers disregarded the cost of a CSW system, they were more willing to consider purchasing one (cost aside) than when they considered purchasing a CSW system at a price of $500 (means of 4.3 and 3.8 respectively) (CSW47 and CSW50).

9.1.2 Exploratory factor analyses

The 118 post-drive questionnaire items that specifically utilized 7-point, Likert-type scales were grouped by questionnaire section (i.e., RDCW, LDW, and CSW) and factor analyzed. Factor analysis is a data reduction procedure that endeavors to identify underlying factors that explain most of the variance observed in a much larger number of variables. These factor analyses utilized the principle component method with varimax rotation. This rotation strives to maximize the variance of each extracted factor, and produces factors that are orthogonal (uncorrelated with each other).

Given that there is missing data in the data set, albeit very little, two different analyses were used to accommodate the missing data. The analyses were first run using listwise deletion whereby drivers who failed to answer all of the questions were excluded from the factor analyses. Secondly, the analyses were run replacing any missing data with the mean response for that question. The results differed little. Therefore, missing values were replaced with means so that a complete data set would be included in the factor analyses. For each of the extracted factors, factor loadings, the correlations between the original variable (the questionnaire item) and the factor were examined in order to understand the nature of the extracted factor. Finally, for each driver, factor scores were calculated for every extracted factor.

For the RDCW section (32 questions), seven factors were extracted accounting for 73.4% of the total variance. The scree plot, a graph of eigenvalues (factor variances) plotted against the factor number, is displayed in figure 9.1.

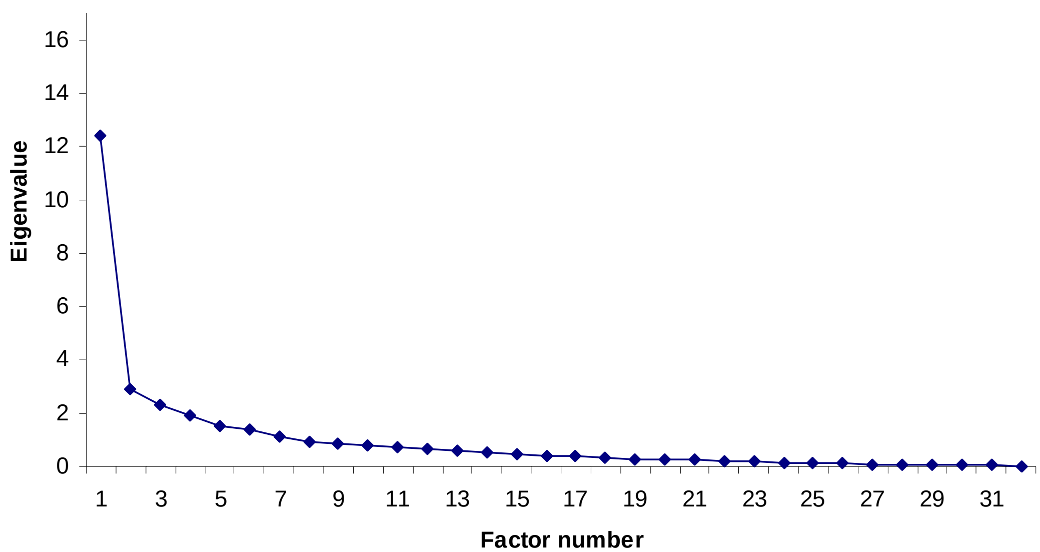


Figure 9.1 Scree plot of RDCW factors

The Cattell scree test is commonly used to determine how many factors to retain. Cattell's recommendation is to retain only the factors whose eigenvalues are above the inflection point in the graph. In this case, only the first factor would be retained, which indicates that a substantial grouping of questionnaire items were correlated with each other. Incidentally, this was a consistent finding among all three factor analyses (RDCW, LDW, and CSW).   This is interesting because it suggests that, to a certain extent, drivers either liked or disliked the RDCW system. That is, drivers who gave higher ratings for one particular item were more likely to also give higher ratings on other items, and vice versa. One could also interpret this finding to mean that, from the drivers' perspective, the post-drive questionnaire was largely measuring a single quality of the RDCW system.

Despite the absolute amount of variance accounted for by the first factors in these analyses, only retaining the first factor would provide relatively little information for further analyses. Thus, in an effort to more clearly understand drivers' perceptions and observations concerning the RDCW system, the top three factors in each of the three factor analyses were retained. For the RDCW section, a second factor analysis was conducted constraining the analysis to only three factors. The three factors extracted in this analysis accounted for 44.6% of the total variance.

The correlations between the questions and each factor were examined. Loadings in excess of .50 (accounting for 25% of the variance) were considered. Factors were interpreted based upon which questions loaded onto which factors (Table 9.4). The rotated RDCW factors and suggested names for them are as follows:

- Factor 1 which accounted for 16.2% of the total variance: Willingness to purchase and safety
- Factor 2 which accounted for 15.4% of the total variance: Ease of use
- Factor 3 which accounted for 13.0% of the total variance: System design clarity

Table 9.4 RDCW factors and their loadings by question. Correlations greater than or equal to .50 are shaded

Question	Willingness to purchase & safety	Ease of use	System design clarity
RDCW1	-0.04	0.51	0.16
RDCW2	0.39	0.74	0.00
RDCW3	0.20	0.68	0.29
RDCW4	0.40	0.53	-0.09
RDCW5	-0.14	0.56	0.08
RDCW6	-0.14	0.56	0.36
RDCW7	-0.14	0.45	0.47
RDCW8	0.00	0.60	0.01
RDCW9	0.11	0.49	0.38
RDCW10	-0.06	0.06	0.36
RDCW12	-0.02	0.53	0.34
RDCW13	-0.05	0.25	0.50
RDCW15	0.15	0.41	0.16
RDCW16	0.40	0.33	0.20
RDCW17	0.12	0.21	0.52
RDCW18	0.21	0.21	0.69
RDCW19	0.30	0.02	0.79
RDCW20a	0.22	0.14	0.53
RDCW20b	0.30	-0.22	0.41
RDCW20c	0.10	0.04	0.72
RDCW21	0.26	0.14	0.61
RDCW22	0.47	0.13	0.26
RDCW23	0.42	0.18	0.23
RDCW24	0.69	0.38	-0.05
RDCW25	0.66	0.51	0.15
RDCW26	0.48	0.64	0.03
RDCW27	0.60	0.39	0.10
RDCW28	0.67	-0.06	0.27
RDCW29	0.43	-0.30	0.14
RDCW30	0.80	-0.04	0.14
RDCW34	0.80	-0.05	0.01
RDCW37	0.65	-0.10	-0.03

The results of the first factor analysis for the LDW section (43 questions) produced nine factors that accounted for 75.7% of the total variance. The second factor analysis produced three factors accounting for 44.7% of the total variance. The three rotated factors and the questions that load onto them are displayed in Table 9.5.

The three LDW factors and their suggested names are:

- Factor 1 which accounted for 20.8% of the total variance: General acceptance
- Factor 2 which accounted for 15.7% of the total variance: Ease of use
- Factor 3 which accounted for 8.1% of the total variance: Warning conspicuity

Table 9.5 LDW factors and their loadings by question. Correlations greater than or equal to .50 are shaded

Question	General Acceptance	Ease of use	Warning conspicuity
LDW1	-0.20	0.57	0.27
LDW2	-0.05	0.55	0.34
LDW3	-0.07	0.48	0.39
LDW4	0.05	0.34	0.55
LDW5	0.07	0.42	0.43
LDW6	0.20	0.75	-0.04
LDW7	0.06	0.67	-0.05
LDW8	0.04	0.69	0.09
LDW9	0.09	0.04	0.69
LDW10	0.52	0.16	0.57
LDW11	0.00	0.04	0.77
LDW12	0.31	0.07	0.43
LDW13	0.39	0.54	-0.08
LDW14	0.63	0.41	-0.08
LDW15	0.07	-0.18	0.51
LDW17	0.28	0.58	0.04
LDW18	0.61	0.39	0.07
LDW19	0.43	0.55	-0.09
LDW20	0.41	0.67	-0.17
LDW21	0.45	0.55	0.03
LDW22	0.07	0.05	-0.10
LDW23	0.58	0.29	0.35
LDW24	0.47	0.29	0.17
LDW25	0.42	0.60	0.05
LDW26	0.56	0.28	-0.06
LDW27	0.58	0.02	0.17
LDW28	0.39	0.27	-0.14
LDW29	0.42	0.14	-0.11
LDW30	0.47	0.08	-0.03
LDW32	0.29	0.77	-0.01
LDW33	0.28	0.72	-0.08
LDW34	0.68	0.10	0.18
LDW35	0.52	-0.07	0.53
LDW36	0.54	0.08	0.08
LDW37	0.72	-0.01	0.31
LDW38	0.74	0.14	0.04
LDW39	0.59	-0.03	0.10
LDW40	0.57	0.19	0.16
LDW41	0.70	0.25	0.02
LDW42	0.40	0.28	0.08
LDW43R	0.47	0.04	-0.22
LDW47	0.81	0.16	0.03
LDW50	0.74	0.08	0.07

When the 43 questions of the CSW section were factor analyzed, nine factors were extracted accounting for 79.3% of the variance. The three factors extracted from the second factor analysis accounted for 51.7% of the total variance. The CSW factors and suggested names are as follows:

- Factor 1 which accounted for 23.1% of the total variance: General acceptance
- Factor 2 which accounted for 18.0% of the total variance: Ease of use
- Factor 3 which accounted for 10.6% of the total variance: Warning frequency and distraction

The factors and their associated loadings are in Table 9.6.

Table 9.6 CSW factors and their loadings by question. Correlations greater than or equal to .50 are shaded

Question	Factor 1	Ease of use	Warning frequency & distraction
CSW1	0.08	0.74	-0.05
CSW2	0.20	0.81	-0.06
CSW3	0.14	0.47	0.34
CSW4	0.15	0.37	0.26
CSW5	0.12	0.45	0.31
CSW6	0.25	0.62	0.32
CSW7	0.25	0.59	0.17
CSW8	0.24	0.68	0.02
CSW9	0.38	0.58	-0.11
CSW10	0.52	0.54	0.11
CSW11	0.17	0.23	0.31
CSW12	-0.06	0.34	-0.02
CSW13	0.21	0.53	0.53
CSW14	0.30	0.24	0.78
CSW15	0.32	0.11	-0.52
CSW17	0.11	0.82	-0.11
CSW18	0.30	0.65	0.17
CSW19	0.06	0.48	0.29
CSW20	0.28	0.40	0.54
CSW21	0.38	0.13	0.74
CSW22	0.11	-0.06	0.28
CSW23	0.49	0.45	0.19
CSW24	0.61	0.19	0.26
CSW25	0.57	0.29	0.18
CSW26	0.60	0.33	0.43
CSW27	0.50	0.25	0.46
CSW28	0.45	0.01	0.48
CSW29	0.53	0.08	0.40
CSW30	0.03	-0.10	0.72
CSW32	0.28	0.70	0.13
CSW33	0.20	0.82	-0.06
CSW34	0.78	0.20	0.20
CSW35	0.75	0.22	0.21
CSW36	0.66	0.06	0.22
CSW37	0.77	0.19	0.11
CSW38	0.73	0.31	0.19
CSW39	0.81	0.12	0.06
CSW40	0.77	0.17	-0.07
CSW41	0.80	0.17	0.05
CSW42	0.71	0.13	0.11
CSW43R	0.41	0.29	0.32
CSW47	0.79	0.17	0.17
CSW50	0.74	0.16	0.12

9.1.3 Regression Analyses

Stepwise regression analyses were run to determine if models could be constructed to predict drivers' perceptions of the RDCW system based upon a host of independent variables. Each of the nine factor scores, which were derived in the factor analyses described previously, served as the dependent variable in a series of multiple linear regressions. The independent variables for each analysis were age (3 levels), gender, education (3 levels: high school graduate, some college, and Bachelor's degree or greater), median family income (obtained by driver zip code from the 2000 U.S. Census), CSW cautionary alerts/100 miles, fraction of repeated (i.e., same curve) CSW cautionary alerts (a proxy for alerts on familiar curves), fraction of CSW cautionary alerts which were false, CSW imminent alerts/100 miles, fraction of repeated CSW imminent alerts, fraction of CSW imminent alerts which were false, LDW cautionary alerts/100 miles, LDW imminent alerts/100 miles, composite scores from the DBQ (error, lapse, and violation) and composite scores from the DSQ (calmness, deviance, focus, planning, speed, and social resistance).

Because cautionary and imminent alert data (alerts/100 miles, false alert ratios and repeat alert ratios) were highly correlated, they were not all included as potential predictors in the same stepwise regressions. Rather, two regressions were performed on each factor score: one that included cautionary alert data and one that included imminent alert data. In most cases, the significant predictors for each pair of models were identical. In such cases, the models that contain cautionary alert data as potential predictors are reported here. This was done because two of the 78 drivers did not receive any imminent CSW alerts (and thus no imminent alert data could be calculated for those drivers). Therefore, the models with cautionary alert data include more drivers. In cases where the models did not produce identical predictors, the models that produced the greatest number of significant predictors are reported. Finally, because dummy variables were used for categorical variables such as level of education and age group, the number of significant predictors is sometimes greater than the number of significant independent variables.

The next few sections provide ANOVA statistics for each of the significant regression models, descriptive and inferential (t-test) statistics for the significant predictors within each model, and scatter plots for these predictors.

9.1.3.1 RDCW models

Younger drivers perceived fewer safety benefits and were less willing to purchase an RDCW system (Factor 1) than their cohorts, $F(1, 74) = 8.07$, $p = .006$ ($R^2 = .10$). This finding is consistent with the results using the *a priori* subscales (above). No effect of gender was observed.

Drivers who rated themselves as not prone to inattention or slips in memory found the RDCW system easier to use (Factor 2) than drivers with higher lapse scores, $F(1, 74) = 8.62$, $p = .004$ ($R^2 = .10$).

For *system design clarity* (Factor 3), the best regression model had five significant predictors, $F(5, 68) = 7.47$, $p < .001$ ($R^2 = .36$). As drivers' education level increased, their understanding of the various RDCW warnings and the required responses decreased (surprisingly). In addition, drivers who reported staying calm in dangerous and fast-paced situations, as well as drivers who reported that they were not prone to mistakes and misjudgments while driving, found the system easier to understand than those drivers who reported lower calmness scores and higher error scores. Finally, as the fraction of repeated imminent CSW alerts received decreased, system design clarity increased. Tables 9.7 – 9.9 display these results in tabular form while Figures 9.2 – 9.7 on the following pages display the relationships visually as scatter plots.

Table 9.7 Significant predictor of RDCW factor, *safety and willingness to purchase*

Variable	B	Std. error	Beta (standardized)	t	p
Age group (20-30)	-0.664	0.234	-0.314	-2.840	0.006

Table 9.8 Significant predictor of RDCW factor, *ease of use*

Variable	B	Std. error	Beta (standardized)	t	p
Lapse score	-0.775	0.264	-0.323	-2.935	0.004

Table 9.9 Significant predictors of RDCW factor, *system design clarity*

Variable	B	Std. error	Beta (standardized)	t	p
Education (Some college)	0.925	0.217	0.459	4.263	<.001
Education (High school)	1.05	0.313	0.355	3.346	0.001
Calmness score	0.575	0.172	0.384	3.339	0.001
Error score	-0.833	0.318	-0.303	-2.624	0.011
Repeat imminent CSW alerts	-1.65	0.660	-0.249	-2.504	0.015

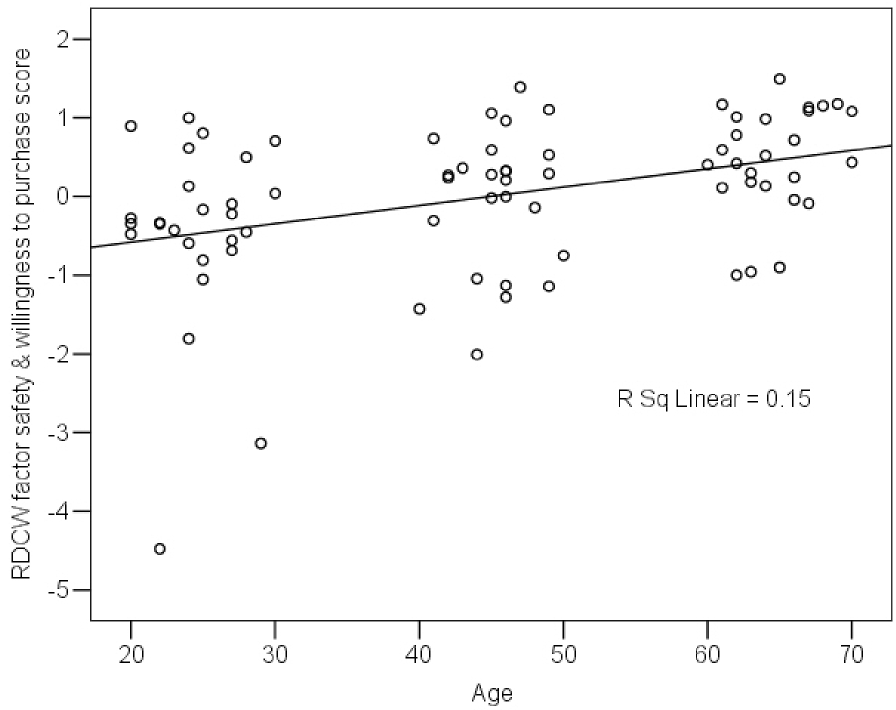


Figure 9.2 Scatter plot of RDCW factor, *safety and willingness to purchase, a*s a function of age

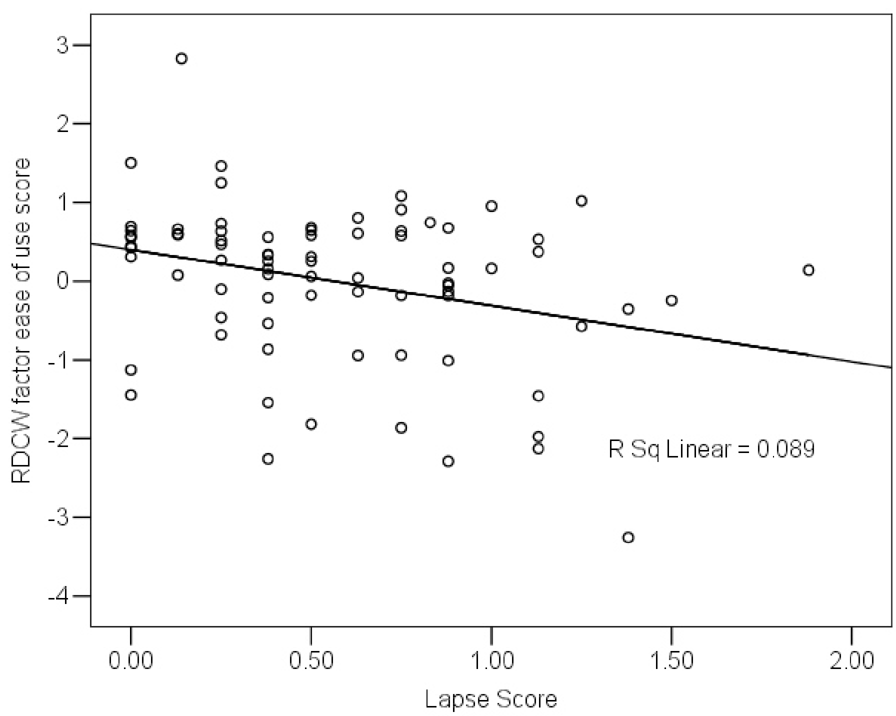


Figure 9.3 Scatter plot of RDCW factor, *ease of use,* as a function of lapse score

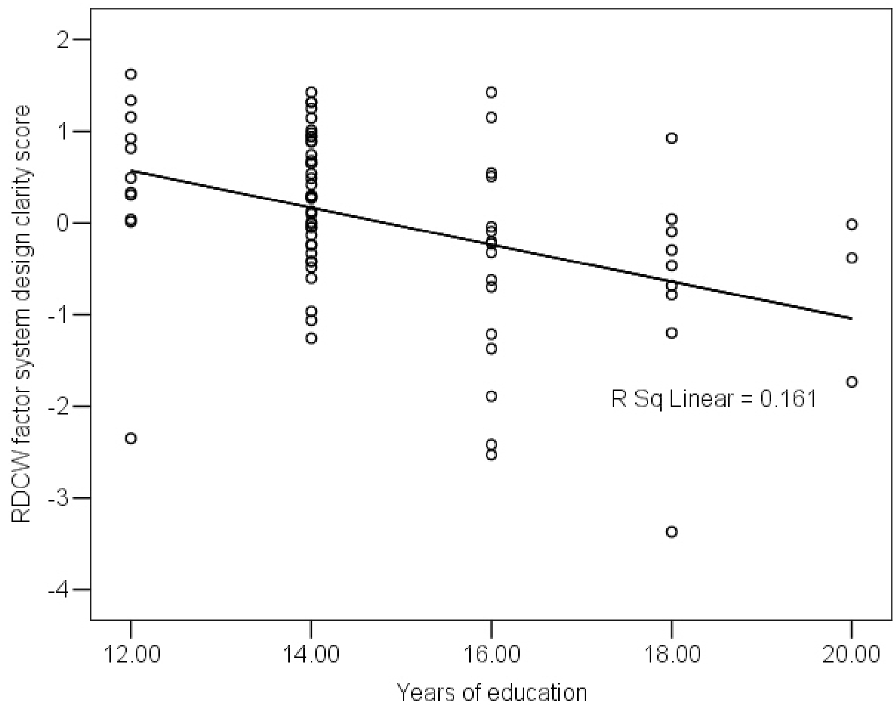


Figure 9.4 Scatter plot of RDCW factor, *system design clarity*, as a function of education

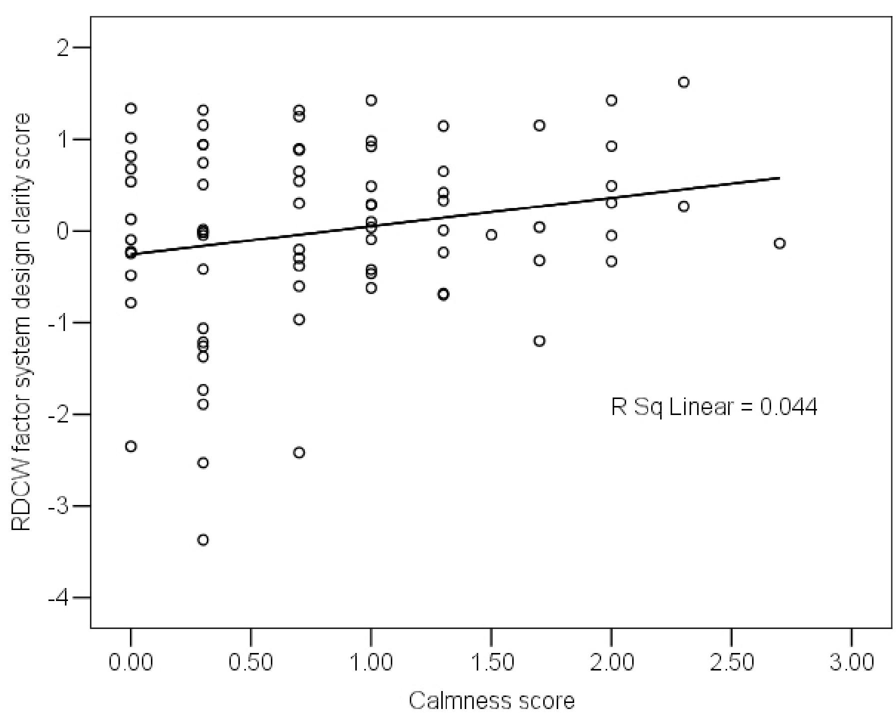


Figure 9.5 Scatter plot of RDCW factor, *system design clarity*, as a function of calmness score

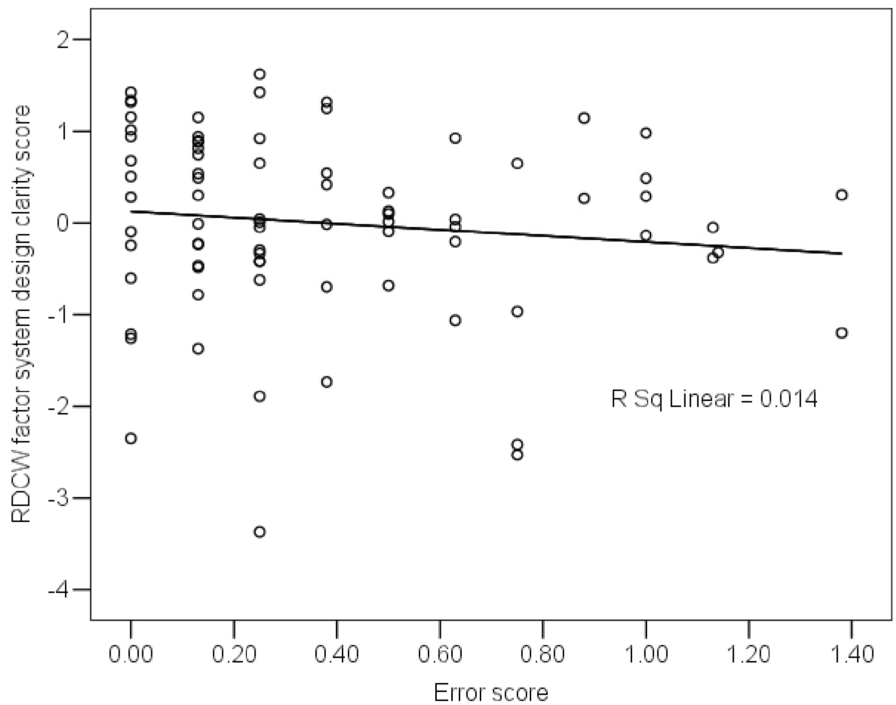


Figure 9.6 Scatter plot of RDCW, *system design clarity*, as a function of error score

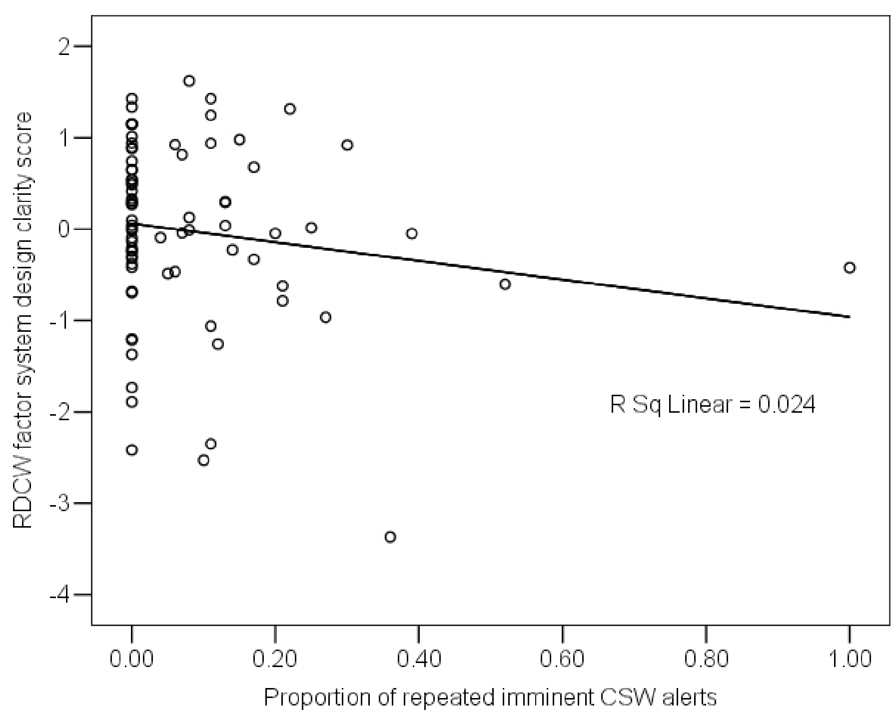


Figure 9.7 Scatter plot of RDCW factor, *system design clarity*, as a function of repeated imminent CSW alerts

9.1.3.2 LDW models

As planning scores increased, LDW *general acceptance* factor increased, $F(1, 74) = 7.5$, $p = .008$ ($R^2 = .09$). Drivers who rated themselves as not prone to inattention or slips in memory found the LDW system easier to use (Factor 2) than drivers with higher lapse scores, $F(1, 74) = 6.8$, $p = .011$ ($R^2 = .08$). This result is consistent with the RDCW *ease of use* factor discussed above. In addition, as LDW cautionary alerts/100 miles decreased, the LDW alerts became more conspicuous (Factor 3), $F(1, 74) = 9.6$, $p = .003$ ($R^2 = .12$). Perhaps at lower cautionary alert rates, the drivers are less saturated with alerts and the alerts they do receive capture their attention more. The results are presented in tabular format in Tables 9.10-9.12 and visually in Figures 9.8-9.10 in the following pages.

Table 9.10 Significant predictor of LDW factor, *general acceptance*

Variable	B	Std. error	Beta (standardized)	t	p
Planning score	0.308	0.112	0.304	2.747	0.008

Table 9.11 Significant predictor of LDW factor, *ease of use*

Variable	B	Std. error	Beta (standardized)	t	p
Lapse score	-0.70	0.269	-0.290	-2.602	0.011

Table 9.12 Significant predictor of LDW factor, *warning conspicuity*

Variable	B	Std. error	Beta (standardized)	t	p
LDW Cautionary Alerts/100 miles	-0.70	0.23	-0.339	-3.102	0.003

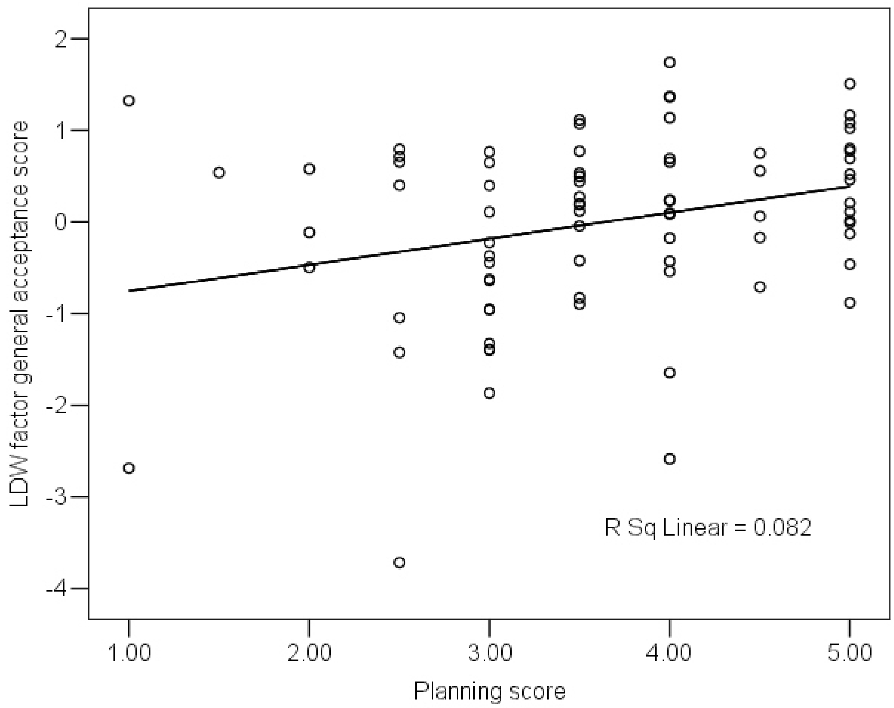


Figure 9.8 Scatter plot of LDW factor, *general acceptance,* as a function of planning score

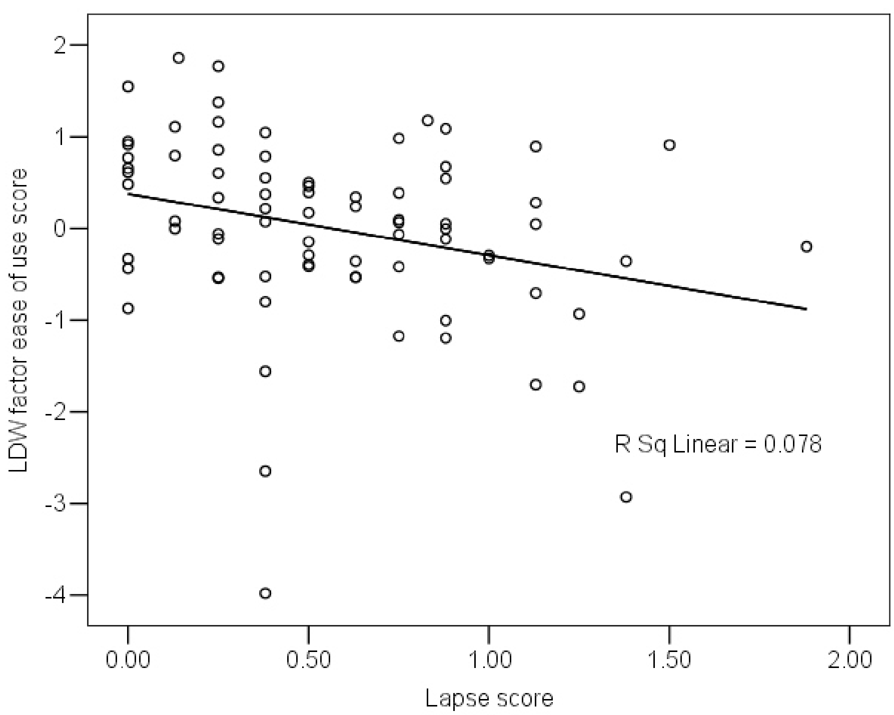


Figure 9.9 Scatter plot of LDW factor, *ease of use,* as a function of lapse score

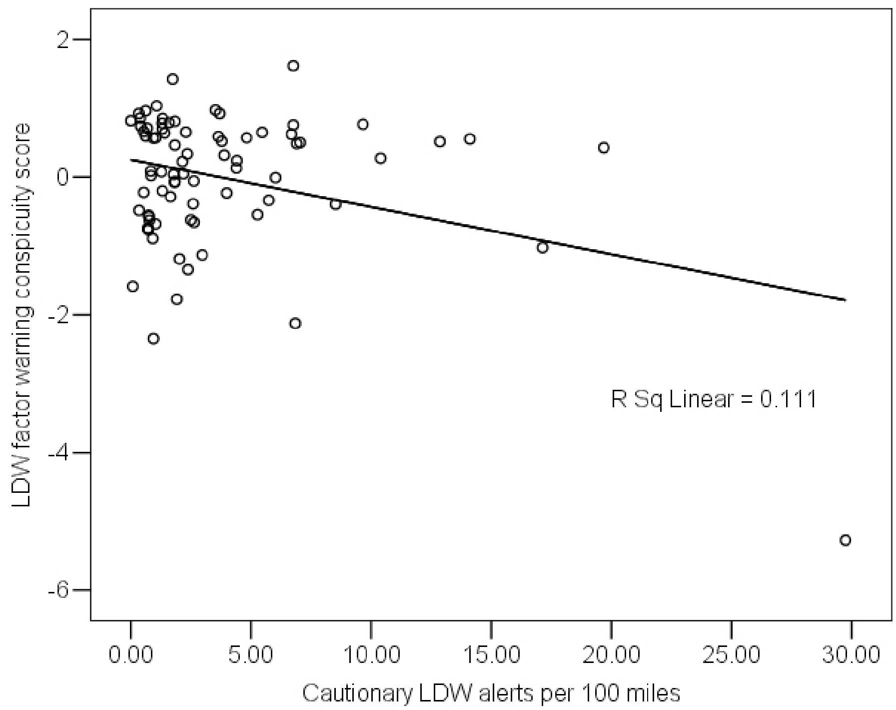


Figure 9.10 Scatter plot of LDW factor, *warning conspicuity*, as a function of cautionary LDW alerts/100 miles

9.1.3.3 CSW models

CSW factor, *general acceptance*, had no significant predictors. Drivers who rated themselves as not prone to inattention or slips in memory found the CSW system easier to use (Factor 2) than drivers with higher lapse scores, $F(1, 74) = 11.5$, $p = .001$ ($R^2 = .14$). This result is consistent with the RDCW and LDW *ease of use* factors discussed above.

As driver age increased, the distraction associated with CSW alerts and annoyance with the frequency of these alerts (Factor 3) decreased $F(2, 73) = 7.6$, $p = .001$ ($R^2 = .17$). This last result is somewhat consistent with the drivers' utility ratings of specific alert scenarios, in which older drivers rated CSW alerts as generally more useful (see Section 9.2). However, the relationship in this regression analysis is relatively linear whereas the utility scores in Section 9.2 followed a curvilinear trend (with the middle age group giving lower ratings of utility than either the younger or older age groups). Tables 9.13 and 9.14 display these results in tabular format and Figures 9.11-9.12 display the results visually.

Table 9.13 Significant predictor of CSW factor, *ease of use*

Variable	B	Std. error	Beta (standardized)	t	p
Lapse score	-0.888	0.262	-0.367	-3.392	0.001

Table 9.14 Significant predictors of CSW factor, *warning frequency and distraction*

Variable	B	Std. error	Beta (standardized)	t	p
Age group (20-30)	-0.961	0.264	-0.454	-3.636	0.001
Age group (40-50)	-0.809	0.264	-0.382	-3.062	0.003

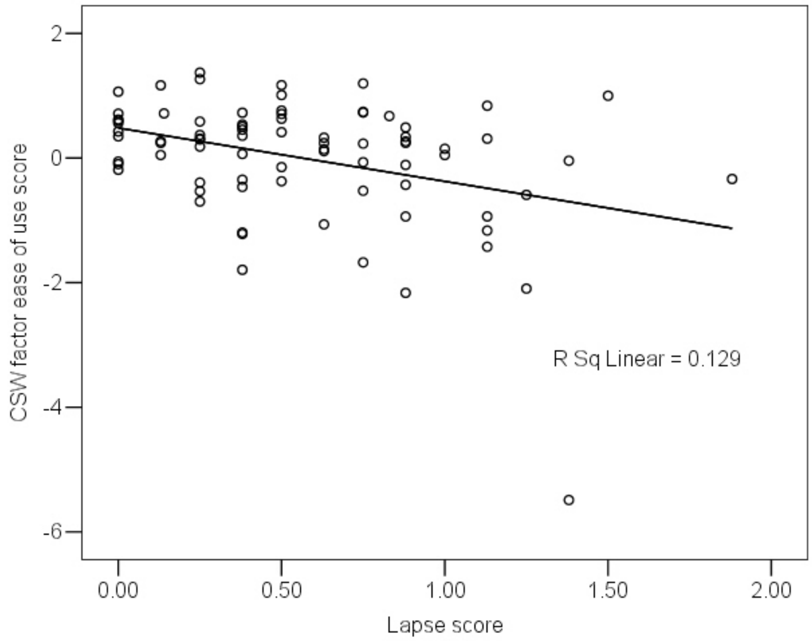


Figure 9.11 Scatter plot of CSW factor, *ease of use,* as a function of lapse score

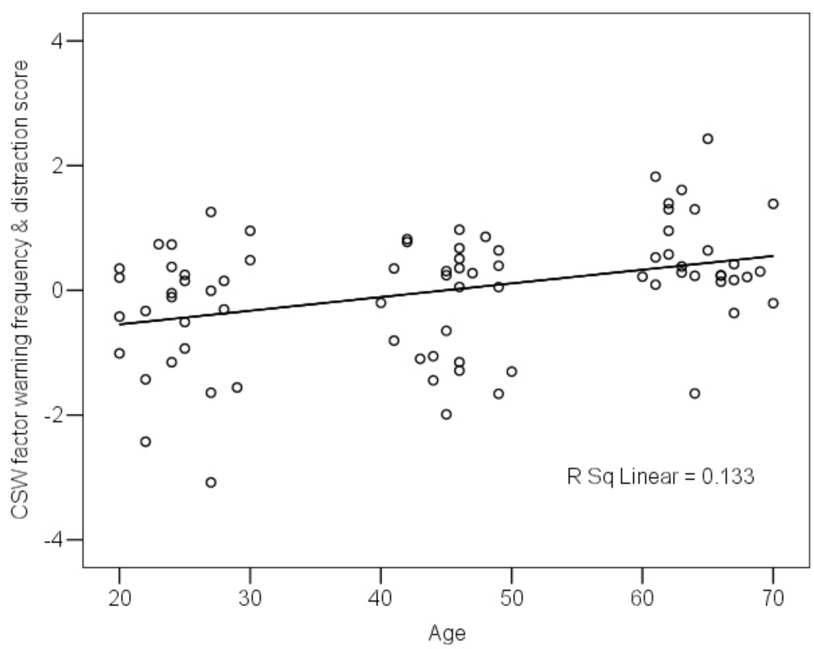


Figure 9.12 Scatter plot of CSW factor, *warning frequency and distraction,* as a function of age

9.1.4 Van Der Laan scale of acceptance

Although there currently exists no standardized measure of driver acceptance for new automotive technologies, one scale in particular offers a step in this direction. This measure, first described in Van der Laan, Heino, and De Waard (1997) uses a 5-point scale to assess nine different attributes of a given technology. Because the scale is sufficiently broad, researchers can use the scale to directly compare the acceptance of different technologies across studies. In this study, we used the Van der Laan scale to measure acceptance of both LDW and CSW, as well as for the entire RDCW system as a whole. The scale was integrated into the post-drive questionnaire near the end of each subsystem section (i.e., the scale appeared three times within the questionnaire). A description of the scale follows, along with the results from the present study. In addition, a comparison is presented between the RDCW Van der Laan results and the results from another field operational test of forward collision warning and adaptive cruise control.

Each item on the Van der Laan scale is anchored by two polar adjectives, such as *good* and *bad*, and the driver is asked to rate their perception of the technology by marking a box along a continuum between these two poles. An example of one item is presented below:

useful						useless

Most of the adjective pairs are presented such that the positive adjective is on the left (as above), although a few items present the positive adjective on the right. The scale is usually scored from -2 to +2, with higher numbers corresponding to values closer to the positive adjectives and vice versa. For example, a mark in the left-most box in the above example would by scored as +2. The nine adjective pairs are: useful—useless, pleasant—unpleasant, good—bad, nice—annoying, effective—superfluous, likeable—irritating, assisting—worthless, desirable—undesirable, and raising alertness—sleep inducing. References to scale item numbers (see paragraph below) refer to these nine adjective pairs, in the order that they were written above.

A series of principal component analyses carried out by Van der Laan, et al. suggests that the scale can usually be reliably reduced to two components, a *usefulness* composite measure (consisting of items 1, 3, 5, 7, and 9) and a *satisfaction* composite measure (consisting of items 2, 4, 6, and 8). The authors also provide some guidelines for how to use the scale and analyze the results, such as how to assess whether the two components fit a particular set of data. They first suggest using scale reliability analyses (e.g., Cronbach's alpha) to determine how well items in each component correlate with each other. Their recommended criterion for the Cronbach's alpha is at least 0.65 for each component. They then suggest averaging the component scores for each subject to arrive at one *usefulness* and one *satisfaction* score for each subject. These two scores, averaged across subjects, represent the overall perceptions of usefulness and satisfaction associated with the technology. Positive numbers correspond to positive perceptions about the technology, and negative numbers correspond to negative perceptions. All of these recommended steps were carried out for the three Van der Laan scales in the present study (RDCW, LDW, and CSW).

9.1.4.1 RDCW section

One driver did not complete one item on the RDCW Van der Laan scale, an item that was included in the *usefulness* component. Consequently, the responses to the other four items in this component were averaged to calculate the usefulness score for this driver.

Scale reliability tests were run for the RDCW components of usefulness and satisfaction. Cronbach's alphas for RDCW usefulness and satisfaction were 0.88 and 0.86 respectively.

The usefulness component had a mean score of 1.23 (SD = 0.76), which indicates positive perceptions of usefulness about the RDCW system as a whole (recall that scores range from -2 to +2). The satisfaction component had a mean score of 0.6 (SD = 0.87), indicating a marginally positive feeling of satisfaction associated with the RDCW system. Additionally, usefulness and satisfaction scores in this analysis were significantly correlated ($r = .719$, $p < .001$), indicating that drivers who reported the RDCW to be useful were also likely to report the system to be satisfying (and vice-versa).

9.1.4.2 LDW section

Scale reliability tests for the LDW components of usefulness and satisfaction showed Cronbach's alphas of 0.93 and 0.88 respectively. The usefulness component for LDW had a mean score of 1.34 (SD = 0.78) while the satisfaction component had a mean score of 0.78 (SD = 0.87), indicating a marginally positive feeling of satisfaction associated with the RDCW system. LDW usefulness and satisfaction scores were also significantly correlated ($r = .746$, $p < .001$).

9.1.4.3 CSW section

Similar to the RDCW section, one driver did not complete one item on the CSW Van der Laan scale, an item that was included in the *usefulness* component. Again, the responses to the other four items in this component were averaged to calculate the usefulness score for this driver.

Scale reliability tests for the CSW components of usefulness and satisfaction showed Cronbach's alphas of 0.96 and 0.93 respectively. The usefulness component for CSW had a mean score of 0.89 (SD = 1.09) while the satisfaction component had a mean score of 0.42 (SD = 1.1), indicating a marginally positive feeling of satisfaction associated with the RDCW system. Similar to the scores for RDCW and LDW, CSW usefulness and satisfaction scores were significantly correlated ($r = .807$, $p < .001$).

9.1.4.4 Comparison across studies

In sum, while drivers had generally positive perceptions of the RDCW system, including each individual subsystem, they found LDW more useful and satisfying than CSW. Thus, as might be expected, the scores for the entire RDCW system fell in between those of LDW and CSW. Note also that drivers generally gave higher ratings for usefulness than they did for satisfaction. This was true for the entire system as well as for LDW and CSW individually. This supports the findings from the focus groups and the rest of the post-drive questionnaire that drivers saw a functional or conceptual value to RDCW, but were not completely satisfied with some aspects of the system.

It is useful to compare these results to Van der Laan scores from a study of a different driver assistance technology. Doing so allows one to see how RDCW was perceived relative to other systems, and so may add a larger context within which to interpret the results from the present study. The study under consideration is the Automotive Collision Avoidance System (ACAS) FOT (Ervin et al., 2005). The ACAS FOT evaluated two different driver assistance systems: forward collision warning (FCW) and adaptive cruise control (ACC).

The FCW system was intended to warn the driver of an emerging conflict that could lead to a rear-end crash. It accomplished this via a combination of a forward radar and visual and auditory warnings as the driver approached another object.

The ACC system was designed to be an enhancement of conventional cruise control. In addition to controlling speed at a value selected by the driver (the *set speed*), the ACC system also managed the distance to a preceding vehicle by automatically adjusting the vehicle's throttle and brakes.

Ervin et al. (2005) was similar in many ways to the present study, in that both ACC and FCW were packaged together in one vehicle. In fact, the ACAS FOT was almost identical in design and method to the present study. Drivers in the ACAS FOT were randomly selected, licensed Michigan drivers. They drove an ACAS-equipped vehicle for 26 days, experienced the same system-disabled and enabled periods, and experienced almost identical orientation and debriefing procedures as in the RDCW FOT. In fact, the only substantial differences between the studies were the specific technologies being evaluated and slightly different sample sizes. This makes a comparison between the two studies particularly compelling.

Table 9.15 summarizes the mean Van der Laan scale scores for both studies. Notice that of all the technologies evaluated, ACC resulted in the highest usefulness and acceptance scores. While this is interesting in and of itself, it is important to point out that ACC was not, first and foremost, a crash avoidance or warning feature, but rather a convenience feature. Thus, in terms of crash warning or mitigation, FCW has more in common with LDW and CSW. When comparing these Van der Laan scores, it can be seen that perceptions for CSW and FCW were very similar (i.e., both marginally positive). Additionally, the scores for LDW (and RDCW as a whole) were higher than those of CSW or FCW.

Table 9.15 Mean Van der Laan scale scores from the RDCW FOT and ACAS FOT

	RDCW FOT			ACAS FOT	
Subscale	RDCW	LDW	CSW	FCW	ACC
Usefulness	1.23	1.34	0.89	0.9	1.49
Satisfaction	0.6	0.78	0.42	0.5	1.48

Another interesting finding is the difference between the LDW usefulness and satisfaction scores, especially when compared to the same difference for ACC. For ACC, these two scores are almost identical. LDW, however, has a satisfaction score that is 0.56 lower than its usefulness score. This would suggest that while drivers found a similar level of utility with LDW and ACC, they were less satisfied with the LDW system. Here it must be stressed that the same drivers did not rate both systems; each FOT has its own unique set of drivers.

Finally, an interesting relationship emerges when one compares the FOT alert rates experienced by drivers for each system to their respective Van der Laan scores. Figure 9.13, for example, displays a scatterplot of satisfaction scores by imminent alert rate for the three crash avoidance systems of LDW, CSW, and FCW. The FCW and CSW systems had similar alert rates, 1.09 and 1.8 alerts per 100 miles traveled, respectively. However, despite the fact that LDW was associated with a much higher alert rate (6.58 alerts per 100 miles traveled), this system received higher Van der Laan scores. Combined with the observation that drivers on average did not feel that LDW warned too often (see Question LDW30 in Appendix M), it seems clear that drivers felt relatively comfortable with the high LDW alert rate.

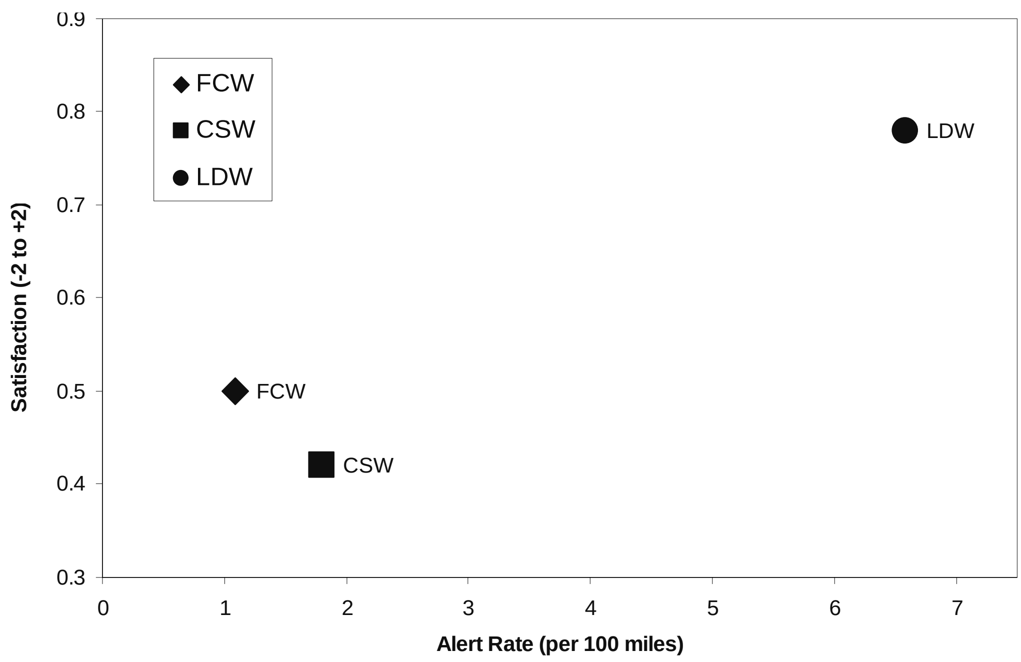


Figure 9.13 Satisfaction scores for FCW, CSW, and LDW as a function of imminent alert rate

There may be various reasons why the average driver ratings were higher for LDW than for CSW or FCW, and why none of those systems fared as well overall in ratings as the ACC system. First, an ACC system delivers a convenience to the driver by maintaining speed and headway, and delivers this only when the driver engages the system. Thus, to some degree, the driver can avoid unwanted ACC behavior by not engaging the system in environments or situations that they expect may trigger the unwanted behavior. Everytime ACC is engaged, it delivers a service that drivers may find valuable, whereas the utility of crash warning systems may seem less tangible and immediate for some drivers. For the crash warning systems in these FOTs, however, drivers did not have the option to temporarily turn off the alerting functions. Thus drivers received alerts that included those that they may have found valuable as well as those that they may not have found desirable. (See section 9.2 for a study of which scenarios were associated with higher driver utility ratings for RDCW.) Thus the warning functions bore a burden that ACC did not bear in terms of not allowing drivers to have control of the circumstances in which the system was active.

Second, given the ratings for LDW, CSW and FCW, there are hypotheses about why LDW was rated higher than CSW and FCW. The logic of LDW may seem relatively transparent to the driver. Alerts are provided when drivers approach thresholds of lane position; the thresholds vary with a variety of factors (see section 3.5) and may be inside or outside the estimated edges of the lane. Furthermore, since a steering correction can so quickly reverse the lateral direction of a passenger vehicle, and since there was a smaller driver response time used in the LDW algorithm, the system did not need much anticipation of future steering motions by the driver or other events that would alter the perceived risk of the situation. Overall, then, the LDW behavior may have been perceived by drivers as approximating a system that issues alerts when the vehicle is crossing a lane boundary. Drivers can see lane boundaries and thus may form a simple concept of the system that seems consistent with the performance they observe.

On the other hand, the CSW and FCW systems in the ACAS and RDCW projects both issued alerts that were intended to allow most inattentive drivers enough time to respond and then apply brakes to reduce the likelihood or harm of striking the rear-end of another vehicle or traveling through a curve at lateral accelerations that exceeded a threshold. In general, decelerating a vehicle takes significantly longer time than correcting its lateral direction. Thus these CSW and FCW systems were issuing alerts based on assumptions about events in the future – a significantly longer future than LDW was addressing. These particular systems were more "predictive" than the LDW that was tested. These events included not only the intended actions of an alert driver of the host vehicle, but (for FCW) assumptions about the motion of other traffic during the driver response time period, as well as the period allowed for slowing the vehicle. Sometimes the period over which events were predicted by the algorithms was several seconds, and oftentimes the situation would change during this time and the assumptions under which the alert was provided did not actually occur. For example, a CSW alert for a curve on an upcoming branch may become unnecessary because the driver did not take the branch, or because the driver was about to apply brakes anyway when the alert occurred. In some of these situations, then, attentive drivers who were anticipating the change in system state during these time periods may not have understood or appreciated the CSW or FCW alert, and felt less satisfied with the system. Thus a possible way to improve CSW acceptance is to reduce the amount of time over which it predicts events, with the disadvantage that a later alert may reduce the safety benefits in a few situations.

Another possible hypothesis for CSW being rated lower than LDW is that perhaps the frequency that drivers find themselves driving too fast in a curve is very low, so that few drivers in the FOT experience the "beneficial" side of CSW. They may only experience the negative (nuisance) side. Drivers commonly exceed lane boundaries, however, so that the resulting LDW alerts may create an awareness in some drivers that their lane-keeping may become a safety problem someday. In future FOTs with a CSW system, it may be useful to consider this possibility during the experimental design period.

9.2 Utility of RDCW alert events

As part of the debriefing session, drivers viewed forward-camera and face-camera video for several of the alerts that they received during weeks 2 through 4, and they were asked to provide a rating of usefulness for these alerts. The goal of presenting video to drivers was to ascertain a rating of usefulness as it applied to alerts in a variety of road scenarios, allowing the driver to "re-live" actual events they had previously experienced. Between 10 and 12 alerts (M = 10.9, SD = 1.5) were selected to be replayed to the returning driver (or fewer if the driver did not experience a particular type of warning). Later in this section, we examine whether certain types of alerts were over- or under-represented in this sample by comparing the results of this selection process to a sample of randomly selected RDCW alerts.

All 78 drivers reviewed video, and provided usefulness ratings for 870 alerts (441 LDW and 429 CSW). Twenty-two of these alerts were excluded from the following analyses because they occurred during trips that were later deemed invalid, leaving 848 alerts. In addition, ratings from drivers 1 and 2 were excluded because a different scale was used to measure their utility ratings (the protocol changed starting with driver 3). Consequently, an additional 23 alerts were excluded, leaving a final total of 825 alerts (414 LDW and 411 CSW).

After having viewed a particular alert, the driver was asked whether the alert was useful (yes or no). The driver was also asked to rate how useful the alert was on a five-point Likert-type scale, presented below:

1	2	3	4	5
Not at all Useful	Slightly Useful	Somewhat Useful	Fairly Useful	Quite Useful

The drivers were asked to evaluate the alert not in terms of whether the alert was useful in a general sense, but rather to base their evaluation upon the specific driving situation and their behavior at the time of the alert. They were asked to recall, as much as possible, their state of mind and attentiveness to the driving task at the time when they received the alert. They were also instructed that *usefulness* could be defined as any quality that enhanced their driving experience or added some benefit to their driving. The drivers could review the alert as many times as they needed to. After providing the numerical rating, the drivers were asked to briefly explain in their own words why they provided the rating that they did for each alert. While these verbal explanations are not extensively used in the following analyses, a complete list of the responses can be found in Appendix W.

Below, statistics are presented for the utility ratings across a range of different variables. Because the ratings of utility were not on an interval scale, this section draws heavily on descriptive statistics. However, inferential statistics are generally not inappropriate provided that the data meets certain assumptions. In this case, the results of linear mixed-effects models analyses are presented in each section to show whether any of the observed differences in mean utility ratings across groups were statistically significant. The mixed-effect model is a broader form of the general linear model, and this type of analysis was chosen for several reasons. First, because the structure of the data represent a within-subjects design (i.e., there were multiple observations of the same conditions on the same driver), a repeated-measures analysis was required. However, because of the observational nature of the data, there were largely unequal n's among the levels of the independent/predictor variables (e.g., not all drivers reviewed the same number of alerts). More traditional forms of the general linear model (such as the ANOVA) exclude entire cases from the data set if an observation on one variable is missing. Finally, using mixed-effects models allow one to model the variance/covariance structure of the data (e.g., the particular way each individual driver rates his/her alerts), a feature that can lead to more accurate parameter estimates and test statistics.

Linear mixed-effects models were fit on LDW and CSW utility ratings. In each case, a series of models were selectively compared to find the best fit. Each model initially included the dependent variable of utility rating, and the independent variables of age group (3 levels), gender, alert type (2 levels: cautionary and imminent), the scenario associated with the alert, and whether the alert was associated with nondriving behaviors. Each model was then refit multiple times, each time excluding the main effect that was least significant. When only significant main effects remained, the model was refit again to include those main effects and their interaction terms. The nonsignificant interactions were removed to obtain the final model for each analysis. Each analysis also included random effects of "driver" and "driver by [within-subjects factor]" interactions. In other words, the random variance between drivers was included as a parameter within each model. Thus, if the effects of between-subjects variables (e.g., age or gender) or within-subjects variables (e.g., nondriving behaviors) were not significantly greater than random variance among drivers, they would not reach statistical significance in the model. Bonferroni corrections were used for all pairwise comparison tests. Finally, please note the following conventions: Standard deviation = *SD*; Standard error = *SE*.

9.2.1 Utility ratings of RDCW by subsystem and alert type

When asked whether alerts were useful or not, drivers said that 74.9% of the LDW alerts were useful, compared to 54.3% of the CSW alerts (note that in both cases, the majority of alerts were rated as useful). When asked to give numerical utility ratings, drivers similarly rated LDW alerts as more useful than CSW alerts. The mean overall utility rating for LDW (collapsed across both cautionary and imminent alerts) was 3.3 (*SD* = 1.4) while that of CSW alerts was 2.4 (*SD* = 1.4). Because the mixed-effects model analyses did not directly compare subsystems, it is unclear whether this difference is statistically significant. The frequency distributions for both subsystems are shown in Figure 9.14.

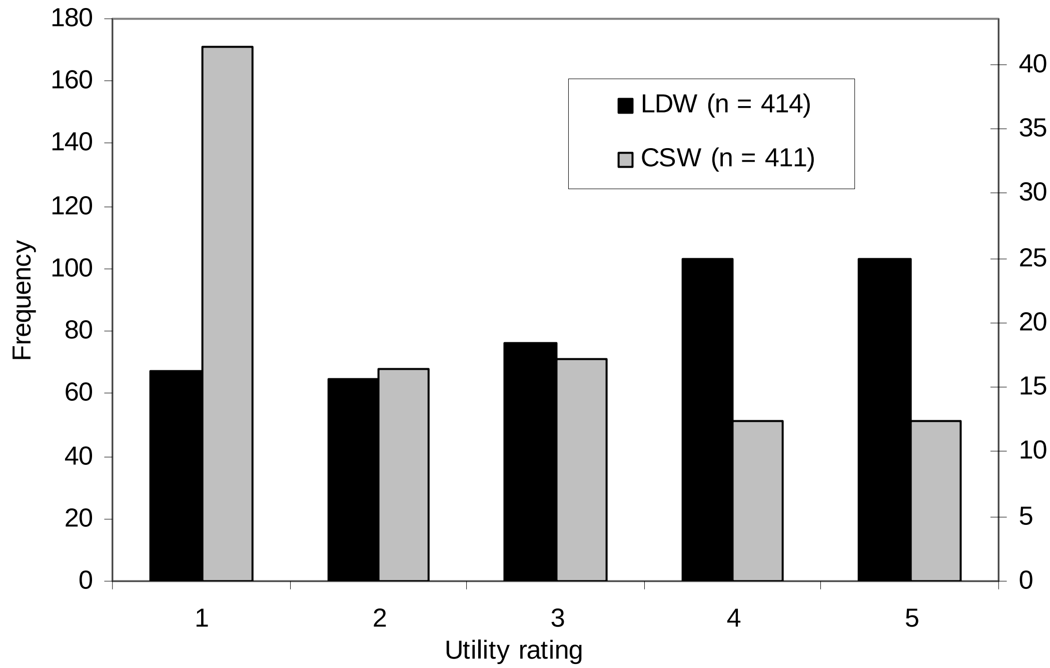


Figure 9.14 Frequencies of utility ratings (collapsed across alert levels) between subsystems

The most notable differences between the LDW and CSW ratings were the higher frequency of *not at all useful* (1) ratings for CSW and the higher frequencies of *fairly useful* (4) and *quite useful* (5) ratings for LDW. Stated another way, just over 40% of the CSW alerts reviewed were rated as *not at all useful* while about 50% of the LDW alerts reviewed were rated as *fairly useful* or *quite useful*.

To further parse these results, the mean utility ratings were broken down by cautionary and imminent alerts for each system (shown in Figure 9.15). The error bars in the figure represent the standard error of the mean. While the mean utility ratings for cautionary and imminent LDW alerts were roughly equivalent, the mean rating for imminent CSW alerts was lower than for cautionary CSW alerts, a finding that was statistically significant, $F(1, 338) = 5.3$, $p < .05$. While 50% of the imminent CSW alerts were rated as *not at all useful* (1), only 33.2% of the cautionary CSW alerts received the same rating. In contrast, 15.2% of the cautionary alerts were rated as *quite useful* (5) while only 9.5% of the imminent alerts received that rating.

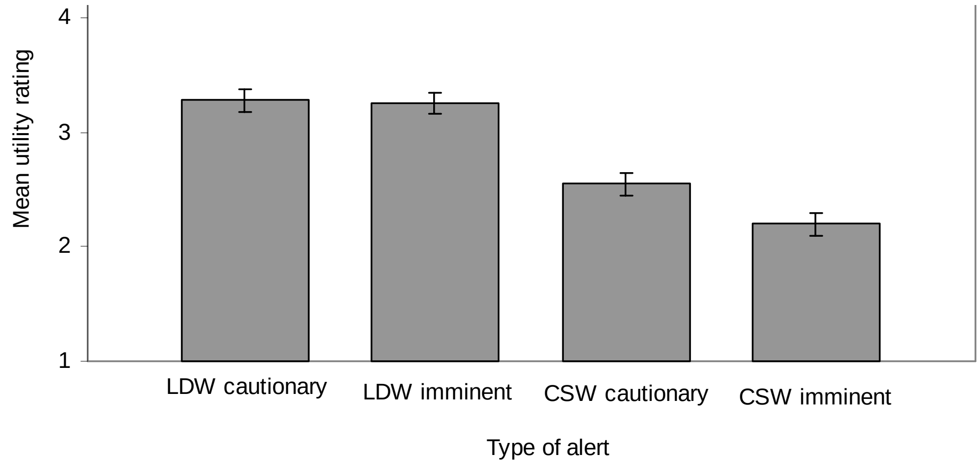


Figure 9.15 Mean ratings of utility for cautionary and imminent LDW and CSW alerts

9.2.2 Utility ratings of LDW by age and gender

In general, ratings of LDW utility increased with age, a finding that was statistically significant, $F(2, 73.5) = 3.3$, $p < .05$. The estimated marginal means were 3.0 in the younger age group ($SE = 0.2$), 3.3 in the middle-age group ($SE = 0.2$), and 3.7 in the older age group ($SE = 0.2$). The relative frequency distributions of ratings among age groups are interesting in that the proportion of alerts that drivers rated as *not at all useful* (1) decreased sharply with age, from about 25% in the youngest age group to about 5.5% in the oldest age group. This is illustrated in Figure 9.16, which compares the rating distributions among age groups.

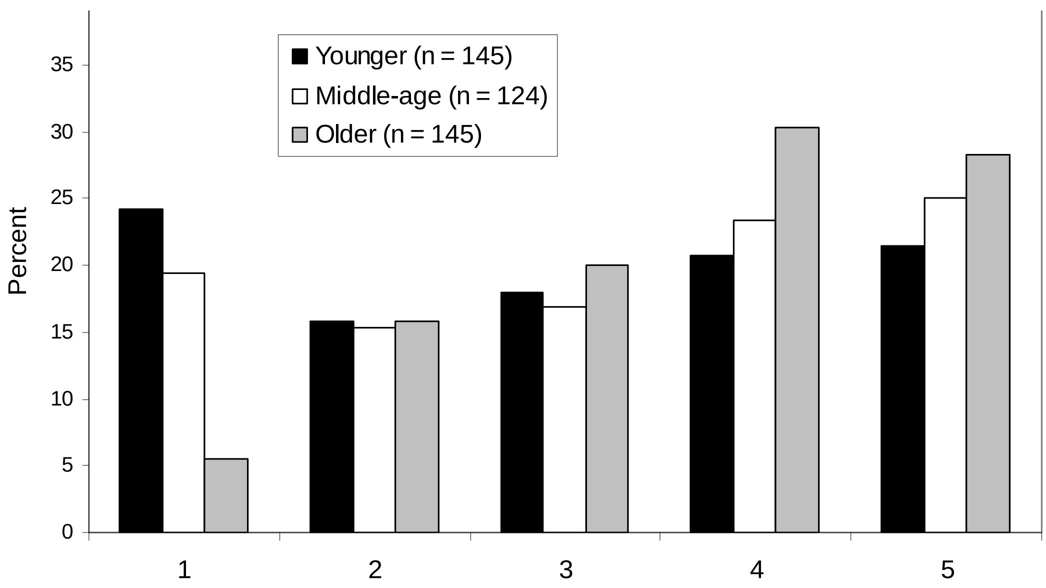


Figure 9.16 Percent distribution of utility for LDW alerts, by age group

Percentages are shown instead of frequencies because there were unequal *n*'s among groups: Drivers 1 and 2 were both middle-age females, and their exclusion from these analyses affected the totals for that age group. Notice from the figure that roughly 60% of the ratings from the older age group consisted of either *fairly useful* (4) or *quite useful* (5).

When comparing LDW utility ratings between males and females, the latter showed a higher (though not statistically significant) overall average rating. The observed mean rating for females was 3.5 (SD = 1.4) compared to 3.1 (SD = 1.4) for males. This is illustrated in Figure 9.17, where it can be seen that females rated roughly 10% more of their reviewed LDW alerts as *quite useful* (5) than did males.

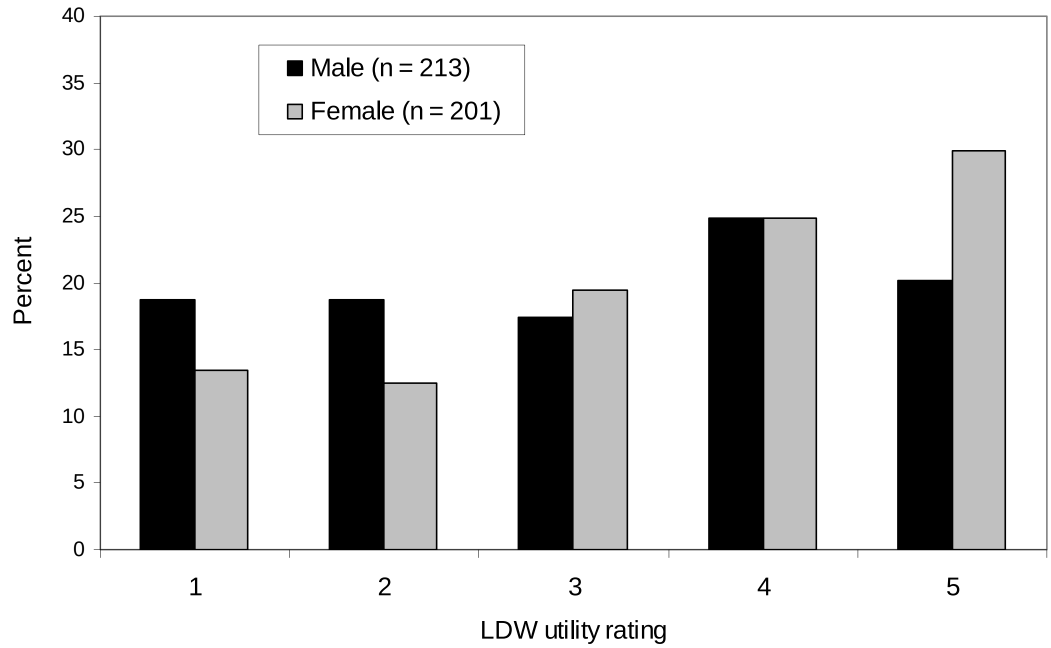


Figure 9.17 Percent distribution of utility for LDW alerts, by gender

9.2.3 Utility ratings of LDW by scenario

During the analysis of FOT data, all of the LDW alerts reviewed by the drivers were also reviewed in detail by researchers in order to classify them into different scenarios (see section 7 for a detailed description of the video coding process and the resulting set of scenarios). Recall that the researchers coded two different samples of LDW alerts: the 414 driver-reviewed alerts (discussed here) and 854 alerts (or 10% of all alerts) randomly selected from the remaining alerts not reviewed by the drivers.

It is useful to compare the distribution of scenarios between these two samples to see whether the driver-reviewed LDW alerts constitute a representative sample. Such a comparison is made in Figure 9.18. The pie chart on the left shows the distribution of the 414 LDW alerts that the drivers reviewed, and the pie chart on the right shows the distribution of the 854 randomly selected LDW alerts that only the researchers reviewed. The most notable differences between the samples are contained within the *unsignaled lane change* and *drifted, did not leave lane, did not respond* categories. For these two scenarios, the driver-reviewed sample contained a smaller percentage than the random sample. While this is unlikely to have an effect on the analysis of drivers' opinions about LDW alerts during unsignaled lane changes, the *drifted, did not leave lane, did not respond* scenario may be under-represented in the following analyses.

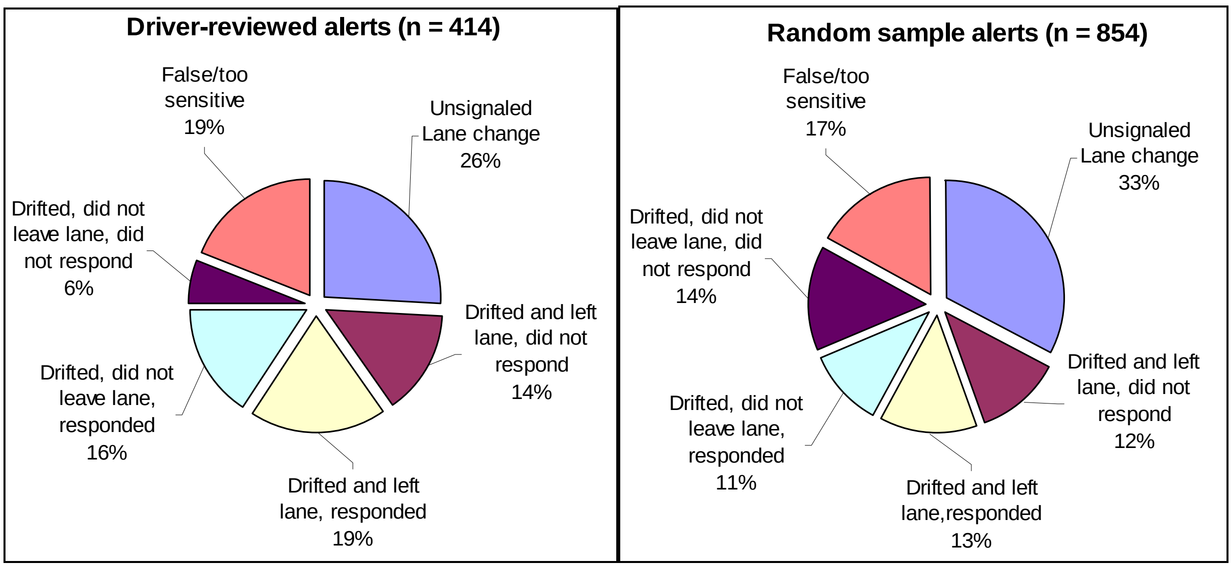


Figure 9.18 Distribution of scenarios in two LDW alert samples

Note that in the driver-reviewed sample, scenarios in which the driver responded to the alert only accounted for 35% of the sample. Additionally, 19% of the driver-reviewed alerts were categorized by the researchers as being false or too sensitive.

Figure 9.19 shows the observed mean utility ratings for each LDW scenario in ascending order. Although there was no significant overall effect of scenario on utility ratings, the scenario *false/too sensitive* had the lowest mean rating while *drifted and left lane*, *responded* had the highest mean rating, which is consistent with what one might expect. Notice also that the two scenarios in which the driver never left the lane received lower ratings than the scenarios in which the driver did leave the lane during the alert. Finally, it is interesting to note that the scenario *unsignaled lane change* received relatively positive ratings of utility. This finding is consistent with results from the post-drive questionnaire and the focus groups, in which drivers commented that LDW's effect on their awareness of turn-signal usage was very positive.

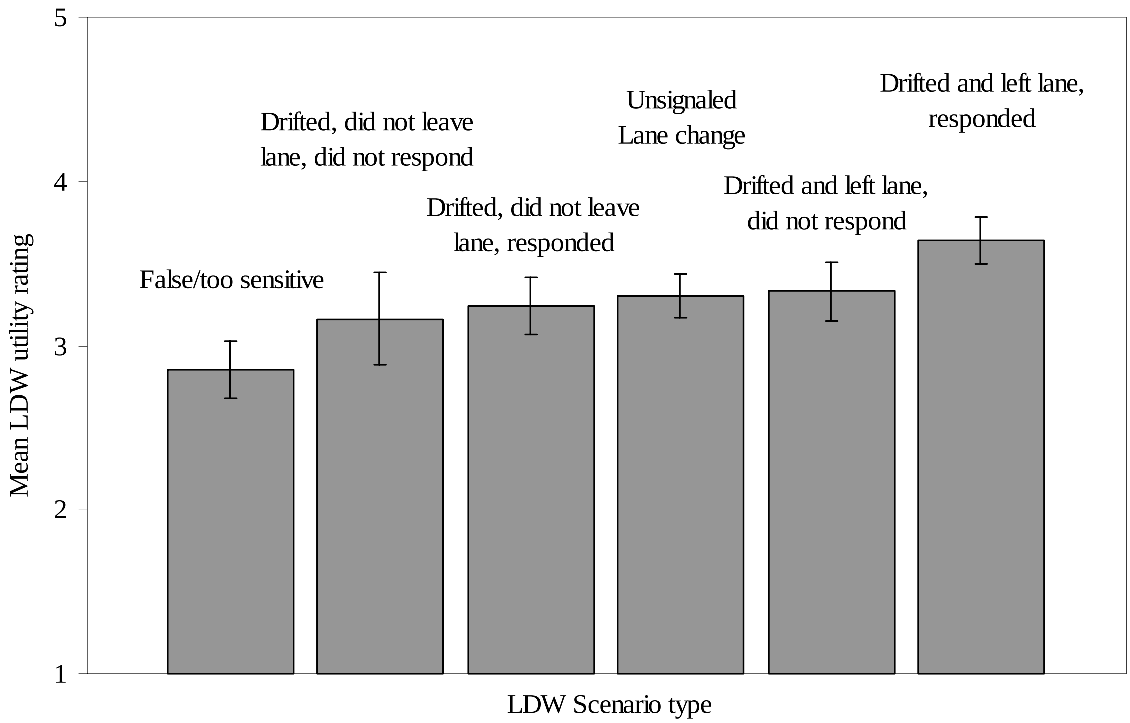


Figure 9.19 Mean LDW utility ratings by scenario

It is also interesting to look at the set of distributions of ratings by scenario, which is shown in Figure 9.20 on the next page. Notice that, although the mean utility ratings are similar among groups, each distribution is different, especially those between the *false/too sensitive* scenario and the *drifted and left lane, responded scenario*.

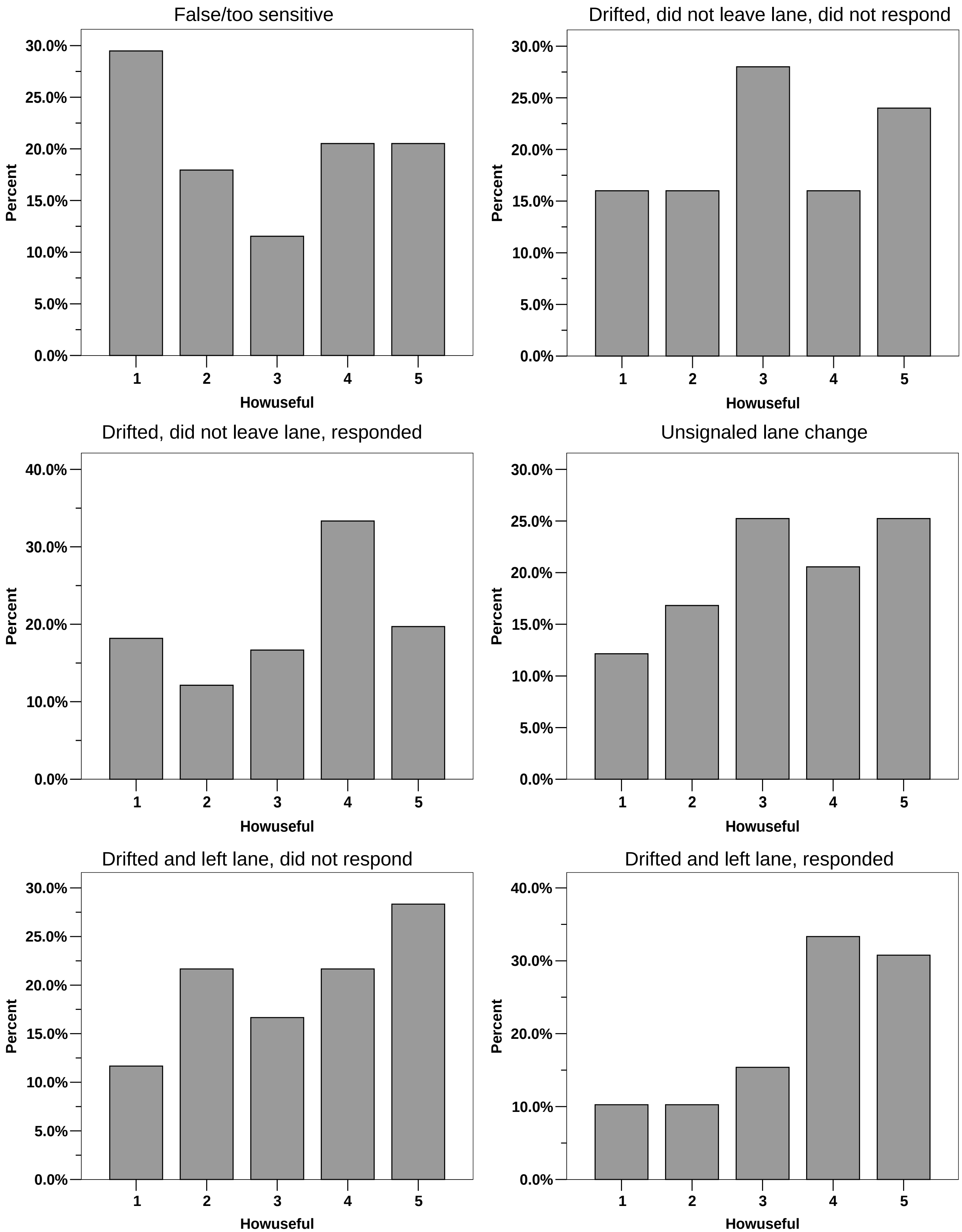


Figure 9.20 Percent distributions of utility ratings by LDW scenario type

9.2.4 Utility ratings of LDW by nondriving behaviors

Table 9.16 displays a frequency count for all the observed nondriving behaviors in the driver-reviewed LDW sample. Notice that the majority of driver-reviewed alerts were not associated with any nondriving behaviors. For those alerts that were associated with nondriving behaviors, several behaviors had relatively low observed frequencies. For example, lighting a cigarette was observed in only one case.

Table 9.16 Frequencies of observed nondriving behaviors in driver-reviewed LDW alerts

Nondriving behavior	N	Percent
None	250	60.4
Conversation	78	18.8
Multiple behaviors	33	8.0
Cellular phone: conversation	24	5.8
Low involvement grooming	15	3.6
In-car system use	7	1.7
Smoking	5	1.2
Low involvement drinking	1	0.2
Lighting a cigarette	1	0.2
Total	414	100.0

To reduce the number of multiple comparisons among groups with low *n*'s, the mixed-effects model included a factor of nondriving behaviors that collapsed all behaviors with an *n* below 30 into an *other* category. Thus, the factor of nondriving behaviors had five levels: *none, conversation, multiple behaviors, cellular phone use*, and *other*. In the case of LDW, this effect was highly significant, $F(4, 386) = 5.6$, $p < .001$. Generally, alerts that were associated with any nondriving behavior were rated as more useful than alerts that were not associated with nondriving behaviors (estimated mean ratings of 3.6 and 3.1 respectively).

In Figure 9.21 on the next page, the estimated mean ratings for specific behaviors are compared in ascending order. The error bars represent the standard error of the mean. Pairwise comparisons revealed that the difference between *multiple behaviors* and *none* was significant, as well as the difference between *cellular phone: conversation* and *none*. However, the differences among the nondriving behavior groups themselves were not significant.

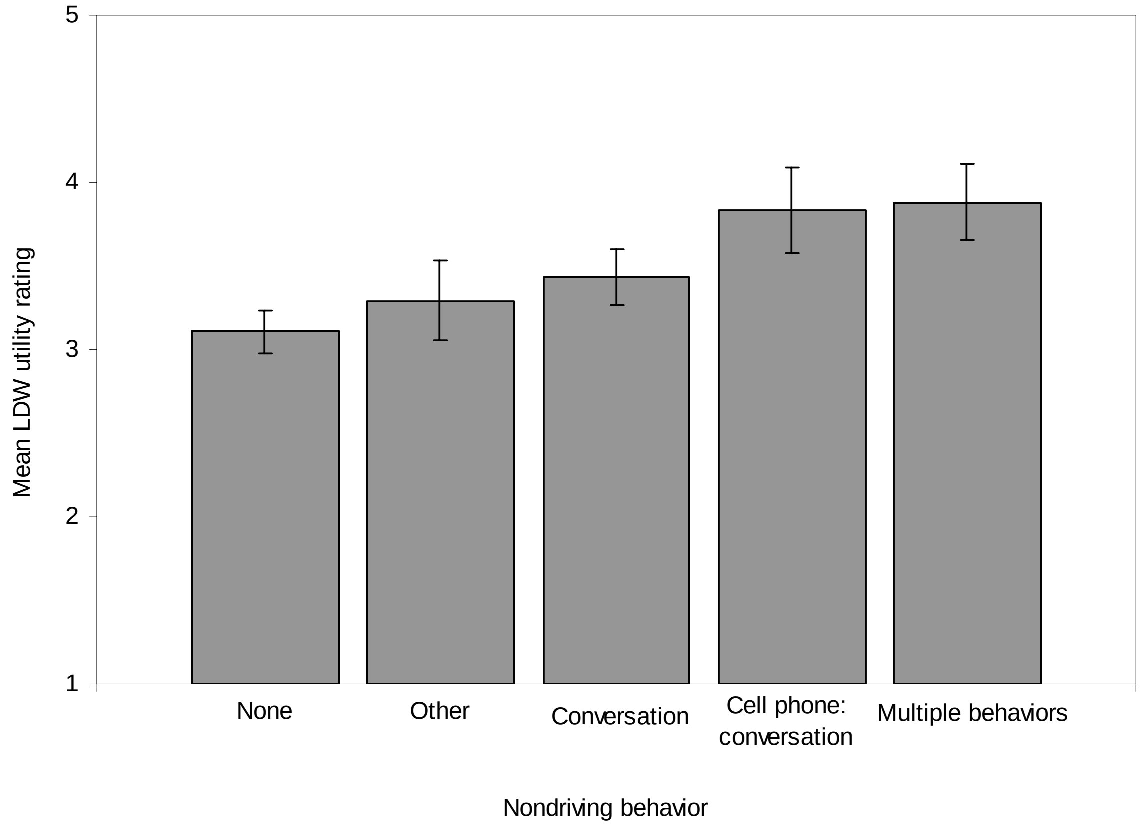


Figure 9.21 Mean LDW utility ratings, by nondriving behaviors

9.2.5 Utility ratings of CSW by age and gender

There was no significant effect of age group on CSW utility ratings. The observed mean ratings followed a u-shaped curve, although the magnitudes of differences were small. The younger age group had a mean rating of 2.4 (*SD* = 1.5), the middle age group had a mean rating of 2.3 (S*D* = 1.4), and the older age group had a mean rating of 2.5 (*SD* = 1.4). The distribution of ratings is shown in Figure 9.22.

Similar to ratings for LDW, females tended to rate CSW utility more positively than males, although this trend failed to reach significance. The observed mean utility rating for females was 2.6 (*SD* = 1.5) compared to 2.2 (*SD* = 1.3) for males. This is illustrated in Figure 9.23. Note that males rated roughly 10% more of their reviewed CSW alerts as *not at all useful* (1) than did females, whereas females rated roughly 10% more of their reviewed CSW alerts as *quite useful* (5) than did males.

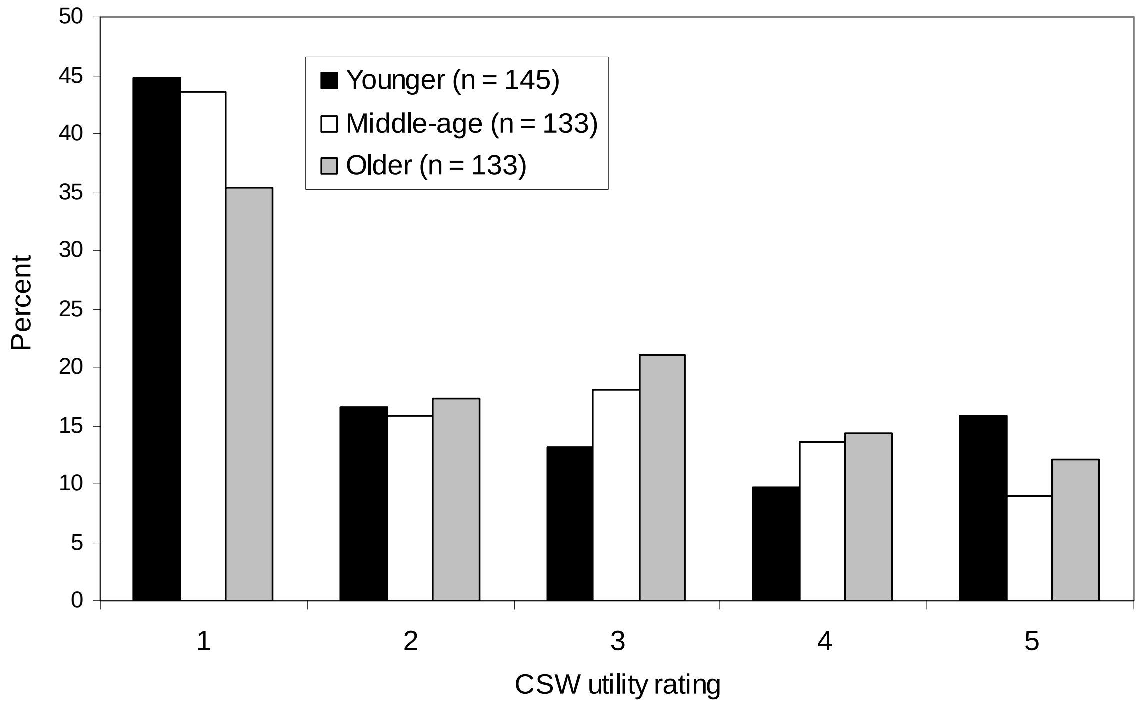


Figure 9.22 Percent distribution of utility for CSW alerts by age group

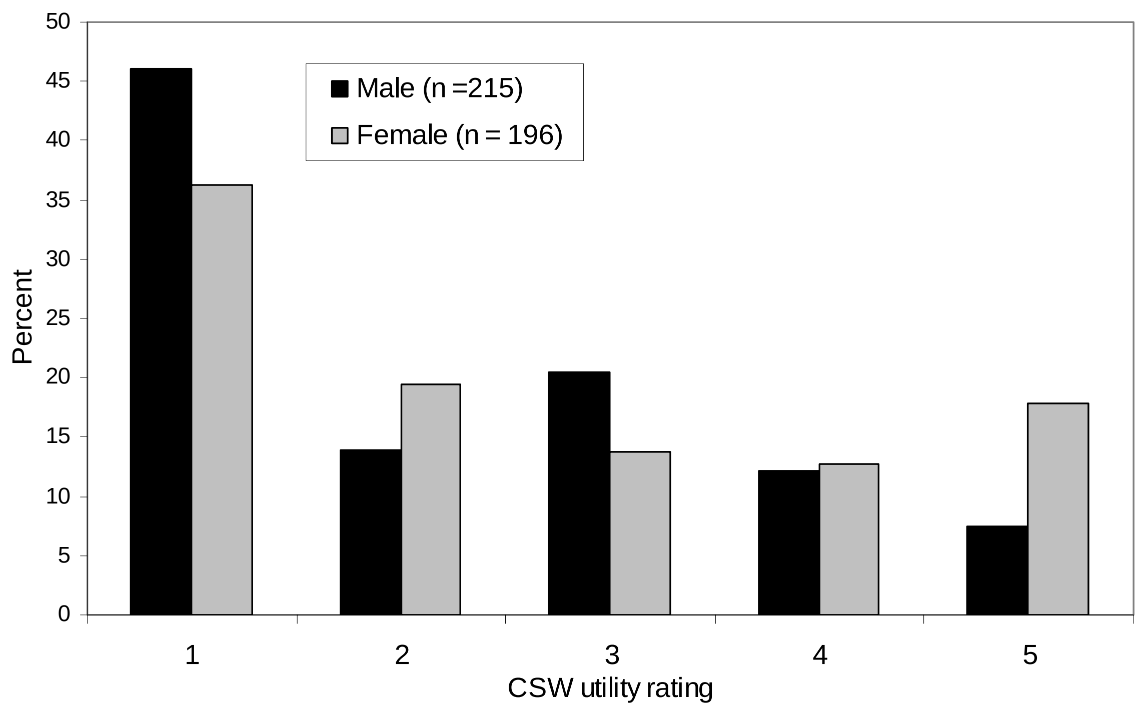


Figure 9.23 Percent distribution of utility for CSW alerts by gender

9.2.6 Utility ratings of CSW by scenario

Recall that CSW scenarios fell into three groups: alerts that were deemed nonfalse by the researchers, alerts that were deemed false due to passing a branching segment, and alerts that were deemed false due to system error (such as reboots, etc.). The analyses that follow examine the utility ratings that drivers gave to CSW alerts in these three different scenarios.

To compare frequency distributions of the driver-reviewed CSW alerts with the random sample of video-coded CSW alerts, Figure 9.24 shows the breakdown of alerts by scenario type for both samples. The most noticeable differences between the two samples include the fact that a higher proportion of nonfalse alerts is contained within the driver-reviewed sample, and that a higher proportion of False-system alerts is contained within the random sample. Note also that nonfalse CSW alerts only account for 50% of the driver-reviewed sample.

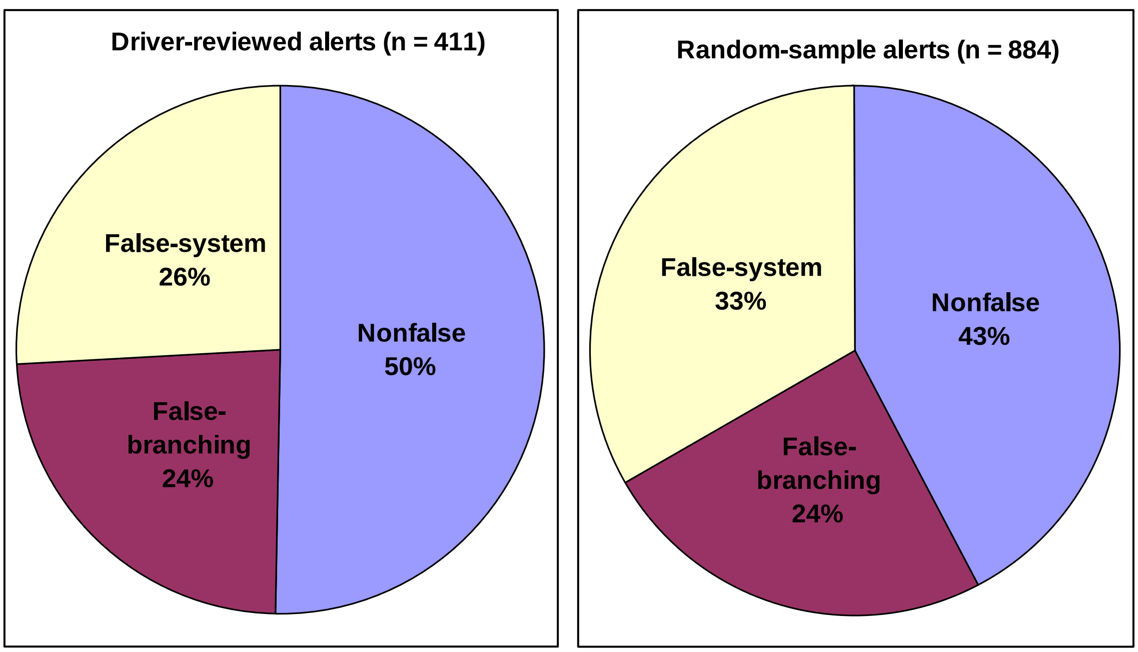


Figure 9.24 Distribution of scenarios in two CSW alert samples

The overall main effect of CSW scenario type on utility ratings was highly significant, $F(2, 365) = 66.9$, $p < .0001$. Figure 9.25 shows a relative frequency distribution of CSW utility ratings by scenario.

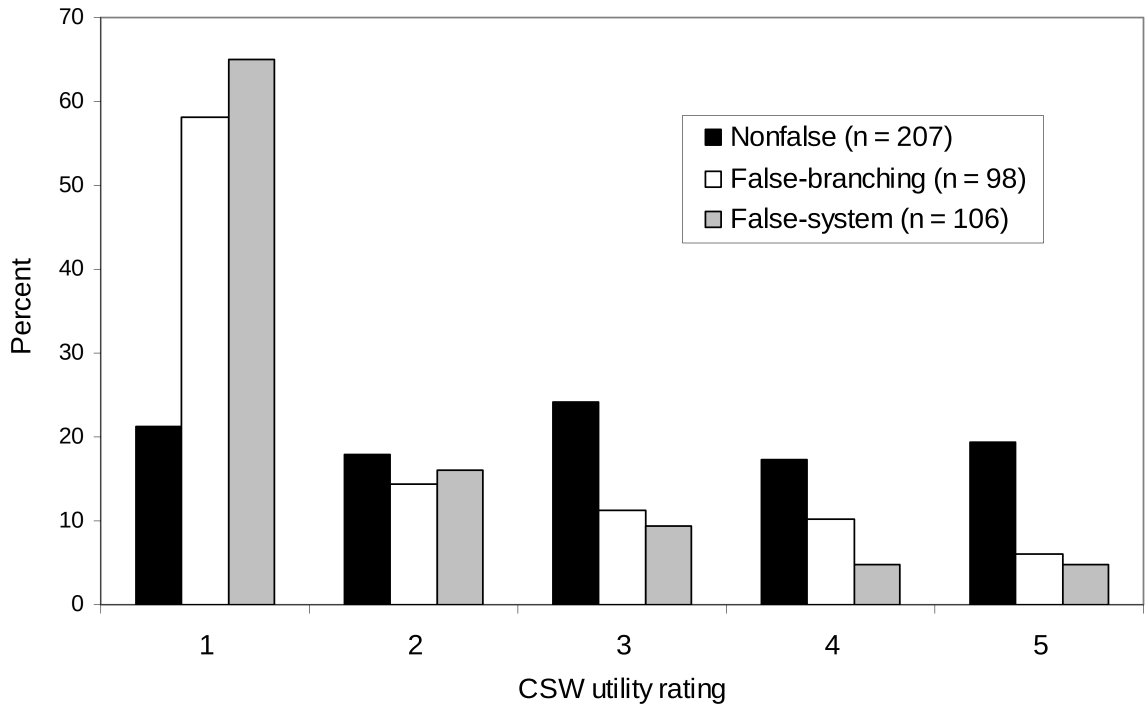


Figure 9.25 Ratings of utility for CSW alerts by scenario

One of the most striking findings is the difference in shapes of distributions between the *nonfalse* scenario and both *false* scenarios. While the *nonfalse* alerts are evenly distributed among low and high ratings, the majority of alerts in both of the *false* scenarios were rated as *not at all useful* (1). This suggests that the drivers' perceptions of what constitutes a false or unnecessary CSW are consistent with how the researchers categorized the alerts. The estimated mean rating for *nonfalse* CSW alerts was 3.0 ($SE = 0.12$), while those of *false-branching* and *false-system* alerts were 1.8 ($SE = 0.15$) and 1.7 ($SE = 0.14$), respectively. Pairwise comparisons showed that the mean ratings between nonfalse and false-branching CSW alerts, as well as between nonfalse and false-system alerts were both significant, although there was no difference between either *false* scenario.

9.2.6.1 Interpreting *nonfalse* CSW utility ratings

While breaking the reviewed alerts into scenario types helped explain much of the variance in the drivers' responses, the results above suggest that drivers varied in their perceptions of the utility of *nonfalse* CSW alerts. That is, the distribution of *nonfalse* ratings show that some *nonfalse* CSW alerts were viewed positively by the drivers, some were viewed neutrally, and some were viewed negatively. This leaves the following question: What are the specific attributes of a given *nonfalse* CSW alert that might cause drivers to rate the alert one way or the other? Or, alternatively, were the drivers rating the *nonfalse* CSW alerts rather arbitrarily? For example, recall that data from the post-drive questionnaire suggested that, to a certain extent, drivers either generally liked or disliked the entire system. It is possible that drivers who generally had a more positive feeling regarding CSW tended to rate all their *nonfalse* CSW alerts positively, and vice versa.

Indeed, this may be the case. Several analyses were conducted on this subset of data in the hopes of finding factors that would predict how a driver might rate a *nonfalse* CSW alert during the debriefing review. A multiple linear regression was performed on *nonfalse* CSW utility ratings that included the following potential predictors: whether the alert occurred during the day or night (as defined by solar zenith angle), the average radius of curvature for the curve that caused the CSW alert, the number of times the driver had received a CSW on that same curve (a proxy for curve familiarity), and peak lateral acceleration through the curve that caused the CSW alert (a proxy for how sharp the curve was). The regression showed no significant results.

Another approach involved a descriptive analysis of the reasons drivers gave for providing the ratings they did. Out of the total sample of 207 *nonfalse* CSW alerts that were reviewed, there were 84 cases in which the drivers rated the alert as *not at all useful* (1), or *quite useful* (5). We examined these 84 cases, looking at the driver's rationale for each rating. These were reduced into a handful of themes that are summarized in Tables 9.17 and 9.18. The first table summarizes the responses of the *not at all useful* ratings, and the second table summaries the *quite useful* ratings.

Notice that a majority in both cases involve the driver's evaluation of their own speed and the degree of curvature in the road. This is consistent with results from the focus groups, in which drivers commented that, while driving, they often made their own evaluation of whether they agreed with each CSW warning they received and hence whether they should slow down. Notice also that, while curve familiarity was mentioned, it was a relatively infrequent response. In addition, there were cases in which being familiar with the curve caused drivers to respond positively to CSW, because they appreciate receiving an alert on a curve that they know to be severe.

Table 9.17 Frequencies of driver rationale for *not at all useful nonfalse* CSW ratings

Category (Rating = "not at all useful")	f	%
Driver was aware of speed or did not think curve was very sharp.	19	43.2
Driver was making an intentional maneuver or just "didn't need" a warning.	9	20.5
Driver was familiar with that particular curve.	9	20.5
Driver said it was a false warning.	4	9.1
The warning was too early or too late.	3	6.8
Total	44	100

Table 9.18 Frequencies of driver rationale for *quite useful nonfalse* CSW ratings

Category (Rating = "quite useful")	f	%
Driver was going too fast or approaching a sharp or dangerous curve.	26	65.0
Driver was unfamiliar with the road or curve.	6	15.0
Driver was familiar with curve, but that is why the warning was useful.	6	15.0
The warning generally increased awareness.	2	5.0
Total	40	100

9.2.7 Utility ratings of CSW by nondriving behaviors

Table 9.19 shows the observed frequencies of nondriving behaviors for the entire sample of driver-reviewed CSW alerts. As was the case for LDW alerts, there were many behaviors with relatively low frequencies. In addition, the same four nondriving behaviors that were most frequently observed for LDW had the highest observed frequencies for CSW alerts. For this reason, they were grouped into five levels: *none, conversation, multiple behaviors, cellular phone use,* and *other*.

Table 9.19 Frequencies of observed nondriving behaviors in driver-reviewed CSW alerts

Nondriving behavior	N	Percent
None	253	61.6
Conversation	73	17.8
Multiple Behaviors	39	9.5
Cellular phone: conversation	14	3.4
Smoking	12	2.9
Low involvement grooming	12	2.9
In-car system use	5	1.2
Low involvement drinking	2	0.5
Dialing phone	1	0.2
Total	411	100

The effect of nondriving behaviors on CSW utility ratings was significant, $F(4, 378) = 2.6$, $p < .05$. The means are displayed in Figure 9.26. An overall trend can be seen here that is similar to that observed for LDW. *Conversation*, *cellular phone*, and *multiple behaviors* were all associated with higher utility ratings than alerts that contained no secondary or nondriving behaviors. This was especially true for the *cellular* phone category, and pairwise comparison tests showed this difference to be highly significant. One will also note that the *other* category was associated with the lowest utility ratings. It is not clear why this was the case, particularly because this category consisted of many different types of behaviors.

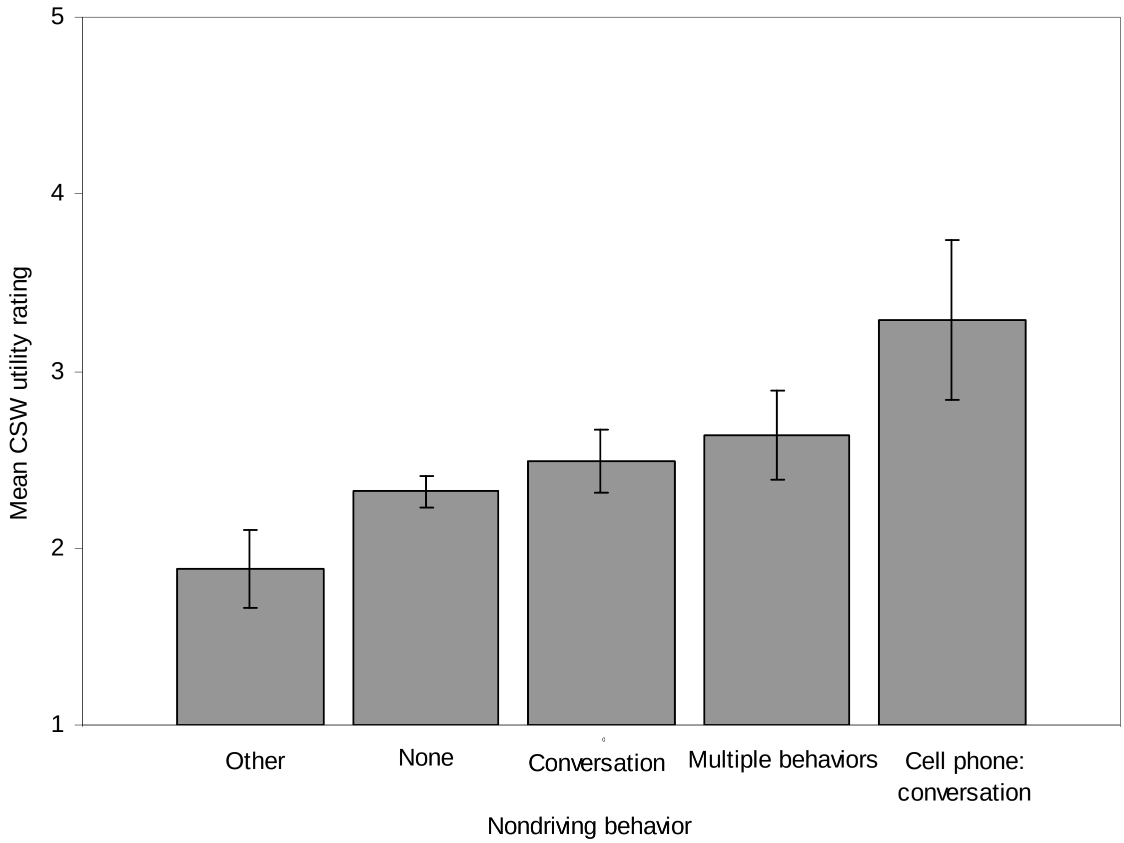


Figure 9.26 Mean CSW utility ratings, by nondriving behaviors

9.3 Synopsis of the responses from the focus groups

Through group discussion and interaction, focus groups are capable of generating data that may not emerge from more structured written questionnaires. They not only provide details about what people think, but often why they think the way they do. However, focus group data do not lend themselves to quantitative analyses for a variety of reasons; rather it is more likely that patterns or themes may emerge. For example, the number of times certain issues are mentioned, the tone of voice that participants use, and even the things that are *not* said can often reveal subtleties of opinion. Thus, the range of information gleaned from the RDCW FOT focus groups provides a partial story concerning system acceptance.

There were four focus groups held in the hopes of obtaining a better understanding of drivers' experiences with the RDCW system. Each focus group involved a small number of drivers (an average of six per session, or 25 drivers total) and consisted of a structured discussion led by a facilitator. Table 9.20 provides a breakdown of age group and gender for all four groups combined. Each of the four groups was asked the same 46 questions in the same order. Discussion was guided by a combination of the facilitator and a PowerPoint presentation that displayed the questions under consideration.

Table 9.20 Number of participants in the RDCW focus groups, by age and gender

	20-30	40-50	60-70	Total
Male	3	2	7	**12**
Female	2	8	3	**13**
	5	**10**	**10**	

A summary of the general findings from the focus groups is presented below. Following this summary, a more detailed analysis of the responses to each individual question is presented. A full list of focus group questions (without their associated responses) can be found in Appendix N.

Overall, focus group participants had generally positive perceptions of LDW and CSW. LDW was largely favored over CSW, although participants appreciated the concept of both systems. That is, most if not all of the participants' negative feedback about RDCW had more to do with specific system performance issues rather than with LDW and CSW as concepts. This is promising because if these findings can be generalized to the larger population, it would suggest that acceptance and willingness to purchase would be high if LDW and CSW functionality can be made more robust and consistent with driver expectations.

For example, when discussing the RDCW system as a whole (both LDW and CSW), 16 of the 25 participants felt more comfortable with RDCW in the vehicle. Participants mentioned that this was primarily because it raised alertness and awareness of their driving habits. In addition, most of the participants found the RDCW system intuitive to use (only one person found it initially confusing). One of the most common critiques of the overall system design concerned the visual display: While the visual display was sometimes used to confirm specific alerts or interpret confusing alerts, many participants mentioned that the visual warnings either needed longer retention or were not necessary at all (12 of the 25 participants). Thus, participants mainly relied on auditory and haptic cues to interpret RDCW warnings. Preferences for either modality were mixed, however. Some participants mentioned that the auditory warnings could sometimes be disruptive, especially with passengers in the car. Additionally, there was some trouble distinguishing the different haptic cues (e.g., left vs. right, and LDW vs. CSW).

When discussing just the LDW component of RDCW, most of the participants who responded found the LDW system useful. Eighteen of the 25 participants recalled receiving LDWs when they were not paying enough attention. One of the most common examples mentioned was cellular phone use, for which LDW was seen as a valuable asset. In more than a few cases, LDW was associated with reports of reduced cellular phone use while driving. In addition, many participants reported using their turn-signals more often as a result of having LDW in the vehicle, a finding that is consistent with the objective turn-signal usage data measured during the FOT (see section 7.3).

Most participants mentioned that they did not rely on LDW, but rather used it as an aid to stay alert about their lane position and their driving in general. When asked what their first response usually was to an LDW alert, most participants said that they would check their lane position and correct if necessary. In terms of alert timing, all 14 participants who responded indicated that they were able to find a sensitivity setting that was just right. While false LDW alerts were reported, there was relatively little annoyance associated with them (with the exception of the specific scenario of rainy nights, when excessive false alerts would occur). Finally, many participants wanted to see increased LDW availability, especially during inclement weather (when warnings are needed the most).

In sum, most of the participants indicated that they would purchase LDW, but they had many qualifications or criteria that LDW would have to meet. These included a relatively low price, higher availability, fewer false alerts, an option to turn the auditory component off when desired, and an on/off switch (to prevent scenarios of excessive false warnings).

When discussing just the CSW component of RDCW, fewer (seven) participants found CSW to be useful. However, no one indicated that the CSW was *never* useful.

Driving at night and on unfamiliar roads were the scenarios in which CSW was reported as most useful. Four participants recalled situations where CSW may have prevented an accident. Interestingly, a number of participants felt that they did not drive on enough unfamiliar roads to adequately test the CSW system.

Participants mentioned that they often responded to CSW alerts by first making their own assessment of the situation; if the CSW was appropriate they would slow down, but they might ignore it otherwise. There was also a large variation in responses to questions of alert timing; some thought CSW alerts were generally too early while others thought they were issued too late. False CSW alerts were a relatively major concern. Eight participants noted annoyance with false CSW alerts; another five reported receiving them but were not particularly annoyed. Many participants viewed CSW as “unreliable;” seven participants noted that drivers might ignore it over time. They commented that CSW did not warn when expected, and it warned too often when there was no curve.

Despite these concerns, very few remarked that they would permanently turn CSW off. In other words, there was perceived value in having CSW present in the vehicle. When asked if they would purchase CSW, however, participants were much less willing to spend money on it. More than a few participants mentioned that the “bugs” needed to be worked out (e.g., fewer false alerts, ability to recognize familiar curves, etc.).

9.3.1 The RDCW system

Overall, did you feel more or less comfortable in a vehicle with the RDCW system?

Participants generally indicated being more comfortable with the RDCW system in the vehicle. Of the 25 participants, 16 explicitly commented that they were more comfortable, one participant was neutral, one participant was comfortable with the LDW system but not CSW, and the remainder did not comment. Many participants gave relatively strong indications of comfort for the system as a whole (using words such as “absolutely,” “definitely,” or “very comfortable”), while some participants indicated that they were comfortable with certain aspects of the system, but uncomfortable with other aspects, such as false alerts.

The reasons most commonly cited for being more comfortable with RDCW included its effect on raising one’s alertness or awareness (e.g., as an aid from “zoning” or being distracted, or letting the participant know how often they unintentionally drift from their lane). Participants indicated a general comfort with having a system that offers feedback about driving performance, particularly during secondary task behavior (e.g., using cellular phones), night driving, or driving in unfamiliar areas. Many participants commented that they had not realized how easy it is to become distracted and drift out of the lane.

While a majority of the participants were more comfortable with RDCW in the vehicle, there were several qualifications that the participants added, such as needing a period of time to get used to having the system in the vehicle before feeling comfortable with it (approximately one week). One participant also indicated that he became comfortable with the system "once I was assured that the RDCW system did not take away control from the driver."

Some typical comments included:

> "I just felt it was a little extra, you know, sometimes if you can't always see the side or others a little bit directly particularly on the right side. I can't see too well. It was, you know, comforting and sometimes curves, if you are not sure about the edge of the curve it was helpful."

> "I mean it was a good system, but I don't think I used it to help me in my driving. But it wasn't until after I was driving home the next day and I was doing something in the car and I was thinking, oh, well, the system will stop me. Because I was doing something down here, picking up my purse or something and I was going off the road and I was thinking, this is going to warn me, but I didn't have the system."

Overall, did you feel more or less safe using the RDCW system?

Responses regarding RDCW's effect on safety were positive overall, but were more variable than comments regarding participants' comfort. While eight participants explicitly indicated a greater feeling of safety with RDCW, three participants felt that RDCW had no effect on feelings of safety, and three other participants felt at least slightly unsafe regarding the operation of CSW (with two of these participants commenting that they received more false warnings than legitimate ones). One participant also commented that, although RDCW did not make her feel safer, she thinks it would make other drivers safer.

Of the eight participants who indicated increased feelings of safety, at least three of these did not respond to the previous question (regarding comfort). Also, some participants who commented that they felt more comfortable with RDCW chose not to comment when asked if they felt more or less safe. Thus, some participants may have felt that they addressed safety issues when they responded to the question regarding comfort, and vice versa.

Reasons for feeling more safe with RDCW were similar to those for feeling more comfortable: RDCW was generally seen as a “safety-net” for times when one might not have been paying attention.

Some comments included:

> “I think it made me feel safer just because it made me think I was paying a little bit more attention than I think I usually do. And it would make me notice the drift thing, make me notice that I ride my lane to one side or not, so it made me shift over to the center, but I never realized in 30 years of driving that I drive to the left side of my lane.”

> “I don’t think it affected my safety factor at all. I don’t think it improved my knowledge of the road or what was going on.”

Was the system intuitive to use?

There were relatively few responses to this question, although most of them were positive. Only one participant found the system initially confusing: “I had to concentrate at first, and I watched that video a couple of times just to reinforce it in my head. But once I got it, I got it, but I don't think that it's intuitive.” Six other participants commented that the RDCW system was intuitive and easy to use. Most of these participants mentioned that they became used to RDCW (and could remember how it functioned) within the first few days of its activation. Two participants (including the one quoted above) indicated that they used the materials UMTRI provided to review how RDCW operated.

An example of a typical comment follows:

> “I thought it was easy to use. It took not even an hour to figure out exactly what was going on. As far as the audio and vibration warnings I don’t think the instrument panel, you aren’t used to having it there and it took a while to get used to spotting that and checking it, but other than that it was real simple, easy to acclimate to.”

Overall, what did you think about how the information was conveyed (e.g., visual display, vibrating seat, audio warnings)?

Participants across focus groups had similar responses to this question. The most frequent (and consistent) observations regarded the visual display; six participants commented that visual warnings needed a longer retention (i.e., the warning arrows were gone by the time the participant looked at the display), and about the same number of participants thought that the RDCW system would be just as effective without a visual component at all. A few participants noted that the visual display caused them to take their eyes off the road, which was seen as a negative outcome. Three participants indicated that they did not notice or use the visual warnings at all. Reaction from the group as a whole to this last sentiment was usually one of several nods of agreement; by and large, participants mainly used the auditory and haptic cues to interpret and respond to RDCW warnings.

Participants were less unanimous, however, when discussing their impressions of the auditory and haptic warnings. Of those who voiced a preference, participants were generally divided evenly between preferring the auditory over haptic or vice versa.

Given this even division, there did appear to be a slightly higher number of negative feelings associated with the auditory component than the haptic. Two participants commented that the auditory warnings in general were sometimes disruptive, especially when passengers were in the vehicle. An additional two participants expressed dissatisfaction with the auditory component of CSW in particular. For both of these participants, the fact that an urgent voice ("Curve! Curve!") would sometimes accompany false alerts was perceived as startling and/or annoying. One participant expressed this sentiment strongly by saying,

> "I hated that. It scared the hell out of me every time it went off. I mean because then when you hear that then I jump, maybe I have bad nerves so then I jump. And then I look down and I try to react. So in the meantime it was three or four seconds I would just hit the wall if I was totally going on a curve. I happened to think it went off wrong, but I don't think that was completely played out in my review of the tapes."

Another participant commented, "It really was the tone of the voice especially when I knew after awhile that it was false. And because it would always go off in the same couple spots on my route home from work."

The haptic warnings also received some critique by participants, but comments were focused more on the left-right distinction than on the nature of the haptic warnings themselves. For example, about four participants commented that they could not distinguish between haptic cues on the left and right portions of the seat pan. An additional participant did not think that a left-right distinction was important to RDCW functionality. When a warning is received, it was argued, the driver could tell what is happening by looking at the road. Less frequent comments about the haptic warnings included the fact that the CSW haptic warning was too long in duration and that the haptic warnings generally could not be felt when one rests one's leg above the seat pan (e.g., on a long trip).

None of the participants voiced an overall dissatisfaction with how RDCW information was conveyed. For the most part, the physical characteristics of the warnings were regarded positively.

Another example of a typical comment follows:

> "The visual display is not in a really bad location for the instrument panel of that particular vehicle, but it does take your eyes off the road. It alarms you and you look down even though you know in your brain different signals are telling you what you -- whether it is lane drift or whatever, you still find yourself taking your eyes off the road tenth of a second."

How easy was it to remember what each warning meant?

Only a small number of participants indicated that they had any problems remembering what each RDCW warning meant. Although this was not always explicitly stated by the participants, some confusion seemed to be caused by not being able to easily differentiate the different haptic warnings. For example, one participant observed that for the first few days of RDCW operation, she had difficulty distinguishing left and right haptic cues and thus could not tell whether she was receiving an LDW or CSW at any given time. A few other participants seemed to indicate a similar phenomenon:

> "I had that propensity to go to the left. So sometimes if it was on a curve I wasn't sure if it was the curve speed or if it was because I was pulling to the left a little bit. And as Jim [another participant] said, by the time I would be correcting everything it would be off the screen so I wasn't quite sure...especially when the seat was vibrating. When it was the audio I knew definitely which one it was, but with vibrating seat I wasn't quite sure."

As illustrated above, when participants did not understand what a particular warning meant, there seemed to be an increased perception of value in having a visual display as a secondary confirmation of the specific warning being issued. However, the retention of visual warnings was not long enough for participants to easily look at the display and confirm the warning. Another example of this sentiment follows:

> "You would hear the sounds and then kind of correct it, but sometimes if it was a false you weren't sure and you looked down and it would be gone or whatever and I could never see, I never once saw any of the arrows for the lateral drift to tell me which side it was on, and so I mean I could tell by looking at the road and could kind of figure out which one it was, but you know, never really at the display."

9.3.2 The LDW system

9.3.2.1 Utility of LDW

How many times a month do you come close to leaving your lane unintentionally?

This question did not generate a lot of discussion. Of those responses that were given, answers varied widely between extremes (e.g., hardly at all, three times a year, once or twice a month, three or four times a month, 50 to 100 times a month, very frequently). The most common observation made by participants was the fact that being in the study made them more aware of just how often they unintentionally leave their lane. Five participants observed that prior to the study they did not think they left their lane very often, but that driving with RDCW altered their opinion substantially.

How often did you encounter situations where you felt the LDW system was useful?

The responses that were given to this question (13 out of 25 participants) fell into two categories: those that indicated LDW was useful in a few situations during their experience, and those that indicated LDW was useful fairly often. The former category was associated with a slightly higher frequency of responses: six participants indicated that LDW was useful about two or three times during their experience, and two participants recalled one specific instance in which LDW was useful. When describing specific experiences of useful LDW warnings, two participants recalled being warned when vehicles in adjacent lanes were overtaking the participant or entering the participant's lane; one participant recalled being warned while intentionally hugging one side of the lane to avoid other vehicles (such as heavy trucks); another example included cutting a curve too close and drifting over the lane marker.

Participants who felt that LDW was useful more often usually observed that they received a total of 10 to 15 useful warnings during their experience. However, some reported receiving useful warnings several times a day, or even several times per trip.

No one explicitly indicated that LDW was not useful at all. Even among those who only found LDW useful a few times, there were no negative sentiments expressed.

One example of a typical comment includes the following:

> "I felt whenever I was slightly distracted talking on the cell phone or things like that or just late at night as well, I felt those were the most, the best times. I felt like I was happy to have it."

Were there situations when you got an alert when you were not paying enough attention?

A majority of participants (about 18) recalled at least one or two examples of this from their own experience. Again (consistent with comments about overall comfort with RDCW), some participants expressed surprise at how easy it is to become distracted, and how LDW increased their awareness of this phenomenon. For example, one participant commented, "not that I relied on the system, but it woke you up to just how easy it was to drift out of your lane when you were just glancing down or thought you were just glancing down." Another participant commented, "I didn't realize that if I have my cell phone to my ear I don't use my signal to change lanes and I got the warning."

Reasons for not paying enough attention were varied, with the most common examples including looking somewhere other than the road and using a cellular phone (five responses each). As will be seen in the responses for other questions, cellular phone usage was a common theme among the focus groups and is of particular interest because many participants indicated that LDW caused them to change their behavior with respect to cellular phones. This is illustrated in part by the following responses:

> "I didn't realize it either because I use my phone as I work quite a bit, and I drive all day and then get in the vehicle at the end of the day and go home and phones are ringing and you know, and I didn't realize. And it taught me a lot about not to do that so much or at least pay attention or, and I pull over more now and stop."

> "[LDW] also alerted me to a problem with [cellular phones] because you, especially when you were trying to dial a number that wasn't loaded in your phone, what it did was it just made you want to pull over to dial a phone or something like that....It woke you up to just how easy it was to drift out of your lane when you were just glancing down or thought you were just glancing down."

Responses to this question mentioned less frequently included receiving warnings while reaching for something (two responses), forgetting to use the turn signal (three responses), adjusting interior vehicle controls (two responses), eating (one response), and "zoning," (one response).

Another typical comment follows:

> "I remember one instance in particular I was on a regular surface street about 35 mile an hour zone and windy, curvy road. There was a lake on the other side. I remember just kind of getting lost in the scenery and all of a sudden, oops, get on over here....I was oh, wow. It actually really did help in that type of situation."

Were there any situations when the LDW system may have prevented an accident?

There were not many responses to this question (a total of eight), and generally discussion was minimal. Three participants responded with a simple "no," one commented that she couldn't really remember, and two participants recalled one specific instance in which they thought LDW did indeed prevent an accident:

> "I had one where somebody was about to hit me and I was fine, but it like beep, beep and it vibrated and it was like I didn't even see him. He was kind of back here, kind of where your blind spot is. I thought I didn't even see he was coming into my lane."

> "I remember going over to the right and it beeped me. I could have hit something, I don't remember all the details, but I think -- but it stuck in my head that, yeah, I could have had an accident in that situation if it hadn't beeped me, so."

In addition to these responses, two participants described events in which LDW did not prevent an accident, but would have had the participant been changing lanes at the time.

When (if ever) did you find false alarms annoying? What false alarm situations did you find most/least annoying? If you received false alarms, how did they affect your driving?

While a fair number of participants indicated that they received some false LDW alerts, there were only a small number of situations that resulted in feelings of annoyance. Most noteworthy were three participants who recalled multiple false warnings while driving during rainy nights. At least in one case, the participant changed his driving in response to this situation:

> "It was rain, snow, pretty much everything came down and in between my drive from work to home I believe the system went off 40 times. That obviously got very annoying....And it got to the point where I'm just like, okay, let me either just get off the freeway so I can just get this thing off my back or just try to zone

> out as best as I can....[It was] to the point where I'm like, what can I do to help remedy this situation. I believe I actually pulled off the freeway and took surface streets which actually didn't have any lines on the road so the system was essentially off if I remember correctly."

While all three participants were annoyed by this kind of experience, these instances were perceived as aberrant behavior of the LDW system. That is, none of the participants indicated that their overall opinion of LDW was substantially altered by these experiences. False warnings due to inclement weather, however, were viewed as particularly annoying/distracting because the driver needs to concentrate on the road during those times.

Other false warning situations that caused some annoyance included snowy conditions in which the participant was forced to drive straddling two lanes, construction areas, and receiving warnings while getting into left-turn lanes. One participant reported this last kind of warning, and was annoyed because he was sure that he was using his turn-signal. Largely, however, the majority of participants indicated that they received minimal or no false LDW alerts, and most participants were not annoyed with the few false warnings they received.

A few participants indicated that receiving false LDW alerts caused them to change certain aspects of their driving. Reactions to false warnings included slowing down, paying more attention to the road, trying to figure out what caused the warning, and turning the sensitivity down. Aside from the participant cited above (regarding a rainy night), no one indicated that they changed routes or drove in different lanes to avoid receiving false LDW alerts.

Were there situations when you did not get an alert when you felt one was required?

A number of participants (five) indicated that this happened at least a couple of times during their experience. In general, however, none of the participants expressed a great concern with this issue. As with false LDW alerts, the relative infrequency of this experience caused at worst some minor confusion for the participants as they were driving. Unlike false LDW alerts, however, no annoyance was associated with not getting an alert when one was expected.

It is interesting to note that the phenomenon of not receiving a warning when one is expected seemed more likely to be noticed when one was trying to test LDW functionality. For example, a few participants noted that this occurred when they were intentionally drifting from their lane to demonstrate LDW operation to a passenger. After receiving no warning, they would look at the DVI display and discover that LDW was unavailable. When asked how often participants engaged in this behavior, some indicated that they tested LDW operation only for the first couple of days of engagement. Others indicated that they did not engage in any testing behavior. No one suggested that he/she continually tried to provoke LDW alerts throughout the study.

Occasionally, the question would also segue into a discussion about why LDW was unavailable in specific circumstances. Although participants remembered being told that LDW would sometimes be unavailable, there were some feelings that LDW availability was inconsistent or nonintuitive. Again, however, no one expressed any major concerns about this. For example, one participant commented, "Again I was really pleased with this system, but I felt that something should be done about that [lack of availability on roads with lane markings only to the left side] because a lot of people drive roads like that."

One participant also commented that he thought the lag for LDW reengagement after turning off the turn-signal was too long and could be slightly shortened.

Overall, did you think LDW warnings were useful? When (if ever) were the LDW warnings useful?

Given that this question was similar to an earlier one, relatively little discussion was generated. Of those who responded (ten participants), all of them expressed positive feelings, with one participant adding that he wished he could have tested LDW on long expressway driving, of 12 or more hours at a time, to give more adequate feedback. Typical comments regarding when LDW was useful are similar to those already noted above (e.g., night-driving, using cellular phones, reminding about turn signal use, raising alertness, etc.) and some examples are provided here:

> "There was one night I had to go to the airport late at night after being at a party and just knowing that the equipment was in the car I did set up the setting higher to be more sensitive. I didn't think that I needed it at the time, but just because it was there thought it would be useful just in case."
>
> "Just generally with cell phones and I can tell you I don't use them anymore when I'm driving, which is great for me and friends of mine."
>
> "It is amazing how this – it forces you to be alert, forces you to use your blinkers because if you don't it will beep you."

Would you have turned LDW off if you could have? If so, when and why?

None of the participants indicated that they would have permanently turned off LDW during their experience, although some qualifications were made by a few participants. For example, four participants would have temporarily turned off LDW during inclement weather (when LDW operation was erratic), but would turn it back on immediately afterwards. Two participants would have liked the option to turn the auditory component off when needed (to avoid disrupting sleeping passengers). An additional participant found herself turning LDW sensitivity down to avoid disrupting passengers.

A total of ten participants indicated that they would have left LDW on 100% of the time had an on/off switch been provided. Typical comments are as follows:

> "I would not have I don't think for a time long-term. I still don't know. My daughter probably would have because she expressed annoyance with the system, she didn't like the tone."

> "For me just aside from that one day of bad weather I would have kept it on. That one day the thing just pretty much failed. I wanted to rip that thing out of there."

> "I would have turned it off in the rainstorm because I don't think it was working properly. I would have turned it right back on the next day because I thought it was useful."

9.3.2.2 Response to LDW alerts

When you got an imminent LDW alert, what did you typically do (e.g., apply the brakes, check the traffic, check your position in the lane or simply ignore the alert)?

Most of the participants responded to this question, and most gave variations of the same response: the typical reaction to imminent LDWs was to visually check lane position by looking through the windshield. Fourteen participants gave this response. Another two participants described slightly different reactions: one would typically release the gas pedal but not necessarily apply the brakes; the second said that she typically repositioned herself in the lane and then checked the DVI to find out what was going on.

When asked if they ever developed enough trust in LDW to automatically adjust lane position after receiving a warning, one participant commented, "No, one month isn't enough [time]." Like this participant, most of them used the imminent LDW as a means of alerting them to a *possible* risk, and still manually checked their lane position to confirm or disconfirm that risk. When participants noticed that the warnings were false (particularly those examples noted in the section on false LDWs), the participants would often try to ignore or tune out the LDW system as much as possible in order to avoid distraction.

As a follow-up to this question, the moderator occasionally asked whether the imminent LDW tone was too loud or startling. Only one participant thought the tone itself was generally too loud, and another participant recalled one instance of being negatively startled by a (false) imminent LDW. By and large, however, there was very little dissatisfaction with imminent LDWs.

Did the way you responded to the alerts change with more LDW experience? If so, how?

This question generated very little discussion, perhaps because most of the participants did not notice any significant change in their response over time. However, a handful of participants (four) indicated that their feelings about LDW changed throughout their experience. Two participants noted that they became more relaxed or comfortable with how the system functioned. Another two participants noted that they came to trust LDW more over time. For example, one commented that he “got used to [LDW] being correct.”

Do you think the LDW cautionary alert (when the seat vibrated) affected how you stayed in your lane? If so, how?

Participants tended to answer this question in terms of an overall evaluation of the effectiveness of cautionary LDW alerts (including, for instance, its effects on getting one’s attention). While a relatively small number of participants specifically mentioned improvements in lane keeping and/or response time associated with cautionary LDW alerts, a greater number of participants rated their overall impression of the cautionary warnings as being effective. This included comments such as “I thought it was very effective...that got my attention more than the sound,” to observations that the seat vibration was “startling” in a good way. Another participant noted that the seat vibration was nice because it was less obvious to passengers than auditory tones.

A handful of participants had difficulty, however, in distinguishing between the left and right components of cautionary LDWs and between the cautionary LDW and CSW warnings (see also the discussion for RDCW above).

Some of the comments included:

> "I thought as soon as the seat vibrated you check your lane position and you correct it and the more often, you know, the longer period of time over the course of 26 days or whatever you would, your response time gets quicker. As soon as you got any type of alert as to how to correct it you could feel exactly what is going on if it was right or left curve speed or whatever warning."

9.3.2.3 LDW alert timing

What did you think of the timing of the LDW imminent alert (when you heard the rumbling sound)? Was it too early, just right, too late?

All 14 participants who responded to this question indicated that they were able to find a sensitivity setting at which imminent LDW timing was just right. Several participants made sensitivity adjustments but ultimately settled back at the middle (four participants), while others kept LDW at either the highest or lowest setting. Two participants mentioned that they would adjust the sensitivity higher when needed, such as during fatigue, and two other participants mentioned that they did not adjust the sensitivity at all (i.e., the timing of alerts was fine the way it was).

Some typical comments included:

> "Because I felt like if I really needed the system to tell me a lot more information I would turn it up, but I found by keeping it down it did allow me a little bit of leeway to just kind of briefly touch a line or something like that, but I'm usually pretty cautious in terms of knowing my surroundings and cars around me and things like that is why I had it down pretty low. Whenever it went off I felt it had a pretty good reason. But I didn't feel it was too late for my personal preference."

> "I was the opposite. I kept it all the way up. At times, I would kind of look and think, boy, I'm just close or on the line, but it kept me in the center. I think if your adjustments, whatever if I felt it was too annoying I could turn it down. I always kept it 3, 4, 5 and it worked very well."

9.3.2.4 LDW and safety

Do you think that LDW will prevent drivers from leaving their lane?

Responses to this and the next question were often closely related, and were almost exclusively positive. While nine participants strongly agreed that LDW has potential to prevent drivers from leaving their lane, there were no participants who expressed the opposite view. In addition, some participants noted the existence of a carryover effect, particularly for turn-signal usage and general awareness of lane position. As one participant commented:

> "I use my blinkers three or four times than I did before I didn't realize how many times I didn't use them. And it alerted you to the fact that you need to use them and so I got in the habit of doing it and so it's carried over."

Two participants emphasized the fact that in order for LDW to actually prevent lane departures, the driver needs to respond to the warnings:

> "Definitely if the driver were to take corrective actions once the warning goes off definitely it would stop people from running off the road and tipping over, so to speak."

> "Yeah, the people who want to be helped will be helped, the people who don't, won't.... Some people don't use their seat belts either. I just think that this system— I tend to not always use my turn signal. It is bad. With this it makes you use your turn signal. I thought I liked the system."

Some other typical comments included the following:

> "I've gotten behind the wheel and stayed behind the wheel 13, 14 hours at a stretch, you know, at a certain point that you are getting a little off kilter and I've been in the car with other people driving back and forth. I've gone there many times and somebody drifted off, dozed off a little bit and the rumble strips on the road made the noise and they corrected themselves and stuff. If they had something like this activated they would never have gotten that close to leaving the road. I think it's very effective."

> "I just thought that it definitely made you pay more attention so that in itself should prevent accidents."

Do you think LDW made you a safer driver (e.g., did you drive more or less aggressively)?

Responses to this question indicate that not all participants interpreted the question in the same way. The behaviors or phenomena that participants associated with safe/aggressive driving ranged from turn-signal usage (three participants noted an increase in this behavior), general awareness of the driving environment/task (three participants noted an increase in awareness), speed (two participants noted changes in their speeding behavior), and level of irritation with other drivers (several participants noted being less irritable after becoming aware of their own driving errors).

Adding a little complexity to this issue was the fact that some participants indicated that changes in driving behavior occurred as a result of driving a new car (with better acceleration) or because they knew that they were involved in a research study. The aforementioned changes in speeding behavior are an example of this; two participants mentioned that they found themselves driving more aggressively (e.g., higher speeds, tighter merges, etc.) because the Nissan Altima handled differently from their own car. In addition, two participants indicated that they thought they might have driven more cautiously as a result of being in the study. For example, one participant commented, “I think you were more cautious. It was competitive. I wanted to drive the thing for a month without a warning going off, so yeah, you are paying better attention.”

Beyond these artifacts, however, a substantial number of participants felt that one of LDW’s effects was to make them safer or less aggressive drivers. While nine participants agreed that LDW made them safer or less aggressive, only one participant commented that he probably wasn’t consciously any safer, but perhaps a little more aware of his surroundings. Some typical comments include the following:

> “I use my turn signals more now than I did. I never felt it was unsafe because if I didn't see anybody close behind me there is nobody to signal so I wouldn’t signal, but I got in the habit of doing it anyway.”

> “I think it made me a safer driver most definitely. I don’t know about the aggressive part though....I think I am more like determined because I drive so much, but I don’t know that it changed that part of my driving.”

> “It makes you realize you do dumb things. You realize that they are doing things that you do that you didn’t even know you do.”

Are there other ways you think LDW may have changed the way you drove?

In response to this follow-up question, only a few participants noted additional changes in their driving. Three participants reiterated their increased awareness of turn signal usage. One participant observed that she found herself using the hands-free cellular phone set more often. One participant noted that he became more sensitive to the potential for oncoming traffic to drift into his lane. One final participant mentioned that he became a "faster driver," though he did not elaborate.

9.3.2.5 LDW as a product

Did LDW perform in the way you would expect it to if you bought this feature? If not, how should LDW perform differently?

What needs to be different before LDW becomes a product?

The first two questions that were asked in this section generated very similar responses, so they are grouped together here. While three participants indicated that LDW functioned exactly how they would have expected, many participants felt that certain aspects of LDW needed to be improved. The availability of LDW was the factor that received the most attention; five participants mentioned that they would have expected LDW to be available more often. As one participant commented, "It was confusing to me a lot of times why it wasn't available when I thought it should be." Another participant said:

> "Maybe just a better sensitivity....During the bad road conditions because I was driving one night in the rain and I know I never got green icons. I was a little bit bothered by how the system worked at that point. I was beginning to rely on the system.....I just wanted it there because I had begun to depend upon it so much."

Less frequent observations included the need to reduce false warnings by about 75%, the need for a greater difference in sensitivity settings (one participant commented that he couldn't detect a difference among settings), and the need to address LDW functionality problems in inclement weather (when, it was added, drivers need the system the most).

In terms of additions or modifications to LDW, five participants thought that LDW should have an on/off switch so that drivers can have the option of temporarily shutting the system off. Somewhat related, six participants thought that there should be an option to either turn the audio component off, or to be able to switch between audio-only and haptic-only. To this end, one participant suggested a headset that drivers could wear. Another four participants thought that the visual display should either be moved more toward the center of the dashboard, or be changed to a heads-up display (HUD).

Would you buy an LDW system? If not, why not? If so, why?

This question was posed twice, once with the preface that "money is not an object," and again by saying, "now money is an object." In response to the former question, all 25 focus group participants said that they would purchase LDW, although four participants added some requirements: Three participants said that LDW would need to come with an on/off switch, and one participant said that he would probably only buy LDW if it came standard on a vehicle. In addition, one participant expressed a little concern about having GPS on the car, as it would allow the possibility of others' tracking his location. Thus, largely, participants perceived at least some value in having LDW in their vehicle.

When prefaced with the fact that money is an object, roughly 25% fewer (or 19 out of 25) participants indicated that they would consider purchasing LDW, and no one explicitly stated that they would *not* purchase LDW. Answers ranged from "definitely" to "it depends." Often, participants indicated that they would weigh many considerations, but that it would depend mainly upon cost. At one focus group, for instance, everyone present (six participants) indicated that they would purchase LDW at a price of $300.00.

Participants generally did not provide many reasons why they would buy LDW, although two participants indicated that they would purchase the system for family members (e.g., children or older parents).

Some typical comments follow:

> "I personally would buy that feature in a heartbeat because I felt that it worked very well for me so I liked that portion of it."

> "Yes, I can visualize this some day, same way as seat belts or the air bags that they mandate something like this. I think it is a fantastic system. Are there some things that have to be tweaked, yeah. Particularly the thing, that warning system on the right as far as the left, but I can see this as something that's very helpful to everyone, it could save lives."

> "It really depends upon like, you know, how I felt about what I was buying at the time, what kind of car and stuff. And if it was a reasonable amount I probably will, but if it was something where it was outrageously priced, which I didn't feel it was reasonable amount for the feature, I probably wouldn't be as likely to get it,

> but if like it all goes back to, if it was standard on a car and didn't have to install it I probably would consider it."

9.3.2.6 Suggested LDW improvements

How would you suggest improving the LDW system?

All of the suggestions that participants gave for improving the LDW system were already mentioned in the previous question regarding necessary changes to LDW.

9.3.3 The CSW system

9.3.3.1 Utility of CSW

How many times a month do you approach a curve too fast (i.e., you are surprised at the sharpness of the curve)?

Though this question did not generate a large amount of discussion, there were a wide range of responses. Two participants said that this happens often (one of them commented that this occurs about five times a day; six participants estimated that it happens an average of a couple times a month; a couple of participants thought it was a fairly rare event (e.g., about once every six months), and one participant mentioned that it never happens.

Several participants observed that it depends on how familiar they are with a given road. That is, unfamiliar roads increase the chance of unintentionally approaching a curve too fast.

Some examples include:

> "Maybe once every six months. But I would imagine it would be different if you are traveling on unfamiliar roads."

> "Mostly on the freeway and freeway speeds moving with the speed of traffic. I'm like, okay, shoot and you feel the car pulling a little bit more than it really should be, so for me I would imagine like five times a day."

How often did you encounter situations where you felt the CSW system was useful?

Seven of the participants recalled one to three situations in which they felt the CSW system was useful, and no one indicated that the CSW system was never useful. Examples included exit ramps there were surprisingly sharp and unfamiliar roads, especially at night. As one driver recalled:

> "I don't remember exactly where I was, but definitely on an unfamiliar road and it helped so just because I didn't know the terrain very well I didn't have a map or navigation system in the car to tell me what was coming up or exactly where I was, but yeah, it definitely helped me in that type of situation and I didn't know what was coming up ahead."

Thus, road familiarity was again emphasized. The most useful CSW situations were on unfamiliar roads, which is somewhat significant given that FOT drivers were at least partially constrained in where they could take the vehicle. During one focus group, a follow-up question was asked that may also offer some unique insights about this phenomenon: When asked approximately how long it might have taken participants to experience CSW enough such that they could develop a sensitive understanding of the range of CSW operation, three participants (out of six) commented that the length and driving constraints of the FOT were not enough to fully experience CSW. As one participant commented, "Yeah, it's not something that was activated that often. Warning-wise and just driving on familiar roads it doesn't seem to be that effective." Another participant observed, "I'm just thinking about where I drive, which is generally around Michigan and Ohio on curves, but I go see my daughter in North Carolina on 77 it is all expressways and curves." This last participant indicated more than once that he wished he could have driven the vehicle on longer, out-of-state drives. Some other examples of comments follow:

> "A few times I was glad it was there on. I was in Ohio and getting off an exit and was surprised how sharp the curve was."

> "I had mentioned that I thought it was really helpful that one time where I got off and it had gone off saying I was going a little too fast and as I approached the curve I found out it was snowy on the curve itself, so that was an extra, you know, incentive to slow down even more."

<u>Were there situations when you got an alert when you were not paying enough attention?</u>

Compared to the same question regarding LDW, there was little discussion on this topic for CSW. Four participants (one per focus group) recalled one or two situations in which they received an alert while not paying enough attention (e.g., ramps, construction, conversing with a passenger, etc.). One participant recalled her experience:

> "I remember a few times, particularly one time I went through the area near me and there is a parkway and I wasn't paying enough attention and the curve was

> pretty sharp and it is pretty hard to see at night. Particularly as you get older and it's harder to see certain things at night and it was helpful particularly at night."

Were there any situations when the CSW system may have prevented an accident?

Similar to the section on LDW, the majority of participants did not respond to this question. However, whereas two participants recalled specific situations where LDW may have prevented an accident, four participants mentioned that this occurred with CSW. Snowy road conditions were mentioned as a salient example by two of the participants. For instance:

> "It was very snowy and it had gone off and I knew the curve was bad, but still going slow as it was and it still went off and I was kind of glad it did because now that I recall I probably would have gone off the road because it was that severe of a curve. And not only that it was, there was ice on the road too and I noticed the car was starting to slide a little bit, so I think probably there it did [prevent an accident]."

One participant also interestingly noted that, at least on a few occasions, he trusted CSW more than his own judgment:

> "Well, several times I was in curve and the system went off directing me that I was traveling too fast and I personally felt that was not the case, but relying on the system I had to believe that it prevented me from having an accident because I did slow down some more."

During one of the focus groups, this question generated a side-discussion regarding the timing of CSW alerts. One participant mentioned that CSWs seemed to come too late: "Now there I'm sorry, but that's to me why I feel that it doesn't work, that it goes off when I'm in the curve. I'm going too fast, it's late. It should warn me before I get in the curve."

When (if ever) did you find false alarms annoying? If you received false alarms, how did they affect your driving? What false alarm situations did you find most/least annoying?

Roughly half of the 25 focus group participants responded to this question. While some participants responded strongly to this question (e.g., "Always."), a more frequent response was to note a general annoyance with false CSW (seven participants). Feelings of annoyance were associated particularly with alerts that occurred while passing exit ramps on freeways or passing so-called Michigan Lefts. Several participants mentioned that false CSWs along common routes were annoying because they would receive them in the same spots every day:

> "Once I thought about it and realized why it was doing it, it became very annoying because I did that turnaround like twice a day every day I went to work, so it became real annoying."

Of those who noted receiving false CSWs but were not necessarily annoyed by them (five participants), a few mentioned that it helped to know what to expect from the CSW system:

> "I eventually came to expect that [false alerts], which made it a little bit less annoying. I would see that I was passing an exit ramp and sometimes it would go off, it wasn't unexpected."

Most participants noted that they did not change the way they drove as a result of receiving false CSWs. The one exception was a participant who mentioned that he found himself driving in the far-left lane of the freeway in order to avoid alerts associated with exit ramps.

Were there situations when you did not get an alert when you felt one was required?

While the majority of participants did not respond to this question, eight participants observed that this phenomenon occurred between one and a few times. Some participants recalled particular curves in which they had expected to get a warning and did not, while others expressed a more general observation of erratic CSW behavior. The latter sentiment is exemplified by the following two comments:

> "It doesn't seem sensitive. Even if you made it sensitive [it wouldn't go off], or then at other times if you made it on the least sensitive, it would go off and you are like, what did I do? It's very off kilter versus the other system was right on the money just about."

> "I wasn't pleased with this system. I felt that it went off at times when it shouldn't, and it didn't go off at times when it should. And I'm not a fast driver, but I would even test it… and I felt uneasy going around these curves at this speed. It wouldn't do anything."

The above participant's comment about "testing" CSW was not unique; three participants noted that they tried to provoke CSWs during their experience, but found the system unresponsive during these times. None of these participants cited this as a frequent experience, however.

<u>Overall, did you think CSW warnings were useful? When (if ever) were the CSW warnings useful?</u>

There was minimal discussion generated from this question (six responses). Participants reiterated some previous feelings, such as finding CSW useful only when driving on unfamiliar roads, or when distracted. While one participant affirmed that he thought CSW was useful overall, two participants reiterated the fact that the false warnings degraded their opinion of the system.

<u>Would you have turned CSW off if you could have? If so, when and why?</u>

Of the 16 participants who responded, very few remarked that they would have permanently turned off CSW. In other words, most participants found some value in having CSW in the vehicle. The extent of this perceived value, however, varied among participants. Although seven participants indicated that they would *not* have utilized an on/off switch to turn CSW off at all, nine participants noted a desire to at least temporarily disable CSW operation. The following four responses, for example, provide a sense of the range of opinion that was expressed:

> "It just wasn't very consistent for me. I didn't feel like I could rely on it to give me accurate information. So I think I might have left it on out of curiosity to see maybe it would straighten itself out. I just didn't find it to be that useful."

> PARTICIPANT: "I wouldn't have [turned CSW off], again just for the same reason if something is available for safety reasons I would have left it on and put up with it. I probably, I probably would turn the sensitivity way down."
> MODERATOR: "But you are still interested in the potential utility of having it?"
> PARTICIPANT: "Right. In theory it seems like a good enough idea to leave it on so I would."

> "If I had the option of turning it on and off, I would definitely have it off during my normal commute. Generally I take the same route every day, I know what is coming up. The thing is I don't necessarily agree with what it is saying to me. It's like okay, you think I'm going too fast, but I know this car a little bit better. I have a good feeling of what it can and cannot do. And I'm still using my eyes and things like that, just way too many incidences where I did not agree with it going off and it just happened so many times on my daily commute that I'm just like, all right, let me switch it off there. But if I were traveling or in areas that I wasn't too familiar with, definitely turn it back on."

> "But if it was, had another sensitivity setting a little bit lower than the ones that were available I probably would never turn it off. But given the sensitivity settings that were on there, yeah, after a while I probably would have turned it off. I thought they were a bit too sensitive."

9.3.3.2 Response to CSW alerts

When you got an imminent CSW alert, what did you typically do (e.g., apply the brakes, check the road geometry, or simply ignore the alert)?

While 13 participants responded, only three of them mentioned that they would automatically slow down when an imminent CSW occurred. Rather, many seemed to use imminent CSWs as a means of bringing their attention back to the road. These latter participants indicated that, when warned, their first response was to visually check to see if a curve was indeed present. They would also manually check their speed and make their own determination whether it was necessary to slow down. If they agreed with the assessment of the CSW system, they would decrease their speed. Three participants mentioned that they began to ignore the imminent warnings altogether because they consistently disagreed with the system.

It is also noteworthy that two participants mentioned that they did not receive many imminent CSWs during their experience. One of these participants felt as though he could not give adequate feedback because of this.

In two of the focus groups, as a follow-up question, it was asked whether imminent CSW alerts were "startling." Few participants responded, but of those who did, two said that they were not startling, one said they were, and two said that they got used to them over time.

Some typical comments included:

> "I got a lot of them, but at a point at first I started like I would hit the brake and try to figure it out and then it was like I would let off the gas and I started ignoring them there were so many false ones."

Did the way you responded to the alerts change with more CSW experience? If so, how?

Three participants mentioned that they began to pay less attention to the CSW system due to the frequency of false alerts. Two participants found themselves engaged in trying to figure out why CSW was giving false alerts. One participant found that he could often predict the location of CSW alerts. One participant began to feel like driving with CSW was "a game" where the goal was to drive to work without receiving a warning. Finally, one participant found that he checked his speedometer more often, and found himself generally slowing down over time.

Do you think the CSW cautionary alert (when the seat vibrated) affected your speed as you approached a curve? If so, how?

Discussion was minimal and similar in content to responses for other CSW questions. A couple drivers commented that they would typically slow down automatically in response to cautionary CSW alerts, but a few drivers also mentioned that they would first make their own assessment of the curve before they decided to slow down. An example of a response follows:

> "I always responded to it. I slowed down. My car wasn't set up as sensitive as it probably could have been so I didn't have false alarms."

9.3.3.3 CSW alert timing

What did you think of the timing of the CSW imminent alert (when you heard "Curve, Curve")? Was it too early, just right, too late?

One of the most interesting sets of responses to this question occurred during one focus group in which the follow-up question was asked: "How many people feel like they didn't drive through enough curves to really experience CSW?" Out of the eight participants who were present, five responded affirmatively. One of them made the following comment:

> "I think the roads that I drive on just didn't lend itself to, most of it was interstate or in town where you were driving too slow for it to react anyway so it didn't lend, I didn't drive it on enough roads that it was useful, let's put it that way....I didn't drive on enough unfamiliar roads."

When considered together with participants' responses concerning false CSW alerts, it would seem that a substantial number of participants felt that, overall, the ratio of useful to nuisance alerts was different between LDW and CSW, and that this may have been caused in part by the participants' level of familiarity with the roads.

Of the participants who commented on the timing of imminent CSW alerts, there was quite a bit of variation among responses: three participants said that the alerts were too early, three said that the timing was just right, and two said that they were too late. An example of opposite opinions follows:

> Participant #1: "I always had mine turned up as sensitive as it would go, the highest.... To me it seemed when it did go off I was already in the curve."

> Participant #2: "I'm almost the opposite. I had it as low as possible. I wish it could have been set even lower. There were a lot of times I felt like I was either, I knew the curve was approaching and I was taking the necessary steps whether just

> kind of coasting or still riding the brake into it and it would just, it felt like it was still telling me way too early that I'm going too fast, even though I am still applying brake pressure into the curve and it just, it just felt like it kept coming off way too quickly for me. To the point where I was never comfortable with it."

9.3.3.4 CSW and safety

Do you think that CSW will prevent drivers from approaching curves too fast?

While a small number of participants agreed that CSW will prevent drivers from approaching curves too fast (one participant affirmed, "absolutely"), most participants who responded voiced concerns about CSW reliability. Two themes that emerged from responses were the familiarity of a given curve (i.e., CSW is only really useful if one is unfamiliar with the curve), and the fact that CSW seemed unreliable. Seven participants observed that people might begin to ignore the system because of false alerts and situations when CSW did not warn when a warning was expected. These sentiments are exemplified by the following comments:

> "I think it was buggy like that and was out there and a lot of false alarms. I think people after a certain point you just probably would ignore it if there was more false alarms than actual curves."

> "I think in terms of preventing drivers from approaching curves too fast I think most of us have our own ingrained curve speeds. We pretty well are programmed in how we approach curves in our familiar areas. Unfamiliar ones no, but familiar ones we know."

Do you think CSW made you a safer driver (e.g., did you drive more or less aggressively)?

Discussion was minimal; a total of four participants responded. All four of them agreed that they were safer or less aggressive as a result of CSW. The participants mentioned that they found themselves either approaching curves more slowly or checking the speedometer more often.

Are there other ways you think CSW may have changed the way you drove?

Again, there were few responses. Of the participants who gave any response, a couple indicated that CSW made them generally more aware of their surroundings: "I think it made me more aware, more cautious so that I wouldn't set it off." Some other participants, however, noted no particular change in their driving, or changes that were motivated by false warnings:

> "I tried to avoid, if I was on Telegraph Road, it has a lot of left turns. I tried to stay out of the left lane as much as possible. It was the lane it usually went off in. It was kind of annoying because I travel down that road a lot."

9.3.3.5 CSW as a product

Did CSW perform in the way you would expect it to if you bought this feature? If not, how should CSW perform differently?

What needs to be different before CSW becomes a product?

Again, the first two questions that were asked in this section generated very similar responses, so they are grouped together here. While the majority of focus group participants responded to these questions (19 out of 25 participants), most of the comments concerned reliability issues (i.e., receiving warnings when warranted, and not receiving warnings when not warranted). Five participants mentioned that the false alarm rate would need to be reduced before CSW could become a product, while another three participants commented that CSW needs to be "more reliable" in general:

> "I think it would have to be more reliable personally. From what little bit I saw I think it has got some flaws whether it is the GPS or just what it is, but to me it seemed like I got a lot of false readings and so I really didn't feel it did much for me."

Another two participants added that CSW would be greatly enhanced by being able to recognize curves that the driver takes often, and being able to better predict the actual speed of the driver. For example, one participant mentioned that he received many false warnings near Michigan Lefts. He suggested that unless the driver had his/her turn signal on (to indicate that he/she intended on making the left turn), CSW should be suppressed.

While critiques such as these dominated the conversation, it is interesting to note that three participants verbally recognized the inherent complexity in trying to predict the driver's path of travel and future speed. As one participant commented:

> "There are so many variables involved, what is a safe speed to enter this curve during the day, it is one speed at night. It is another speed if the roads are wet it's another speed. If they are snowy it's another speed. I see there is so many variables out there for any technology no matter how good it is to tell you what is a safe speed."

Less frequent comments included the fact that the auditory voice warning needs to be changed (i.e., it was grating and annoying to four participants). At the very least, there should be an option to turn the auditory component off. One participant added to this her wish that CSW included more user preference options generally, such as an expansion of the sensitivity settings and switches for audio-only or haptic-only. Finally, one participant mentioned that the CSW warnings generally need to be presented earlier than they were.

Would you buy a CSW system? If not, why not? If so, why?

Responses to this question were complex in that many participants indicated they would only buy a CSW system if certain modifications were made (e.g., fewer false warnings, receiving warnings when they "should" come, a greater range of sensitivity adjustment, etc.). In addition, the question was often framed first with the preface that "money is not an object," and then again with the preface, "now money *is* an object." Consequently, responses varied according to how the question was asked.

For example, while seven participants indicated they would purchase CSW (without modifications) if money weren't an object, only two participants said they would purchase CSW if money were a consideration, and both commented that it would depend on exactly how much money it would cost.

In other words, consistent with responses to other CSW questions, the majority of focus group participants did find some value in CSW, but not enough to want to pay additional money for it. For many of the participants, CSW would need to function more reliably and intuitively before they would consider buying it. As one participant said, "If they were throwing it in for free I would definitely consider it."

9.3.3.6 Suggested CSW improvements

How would you suggest improving the CSW system?

In general, participants did not respond to this question, other than to occasionally refer to suggestions they had made previously during the focus group session.

10 Conclusions

The FOT has succeeded in testing the RDCW system in its intended context of operation by observing laypersons engaged in naturalistic driving in RDCW-equipped vehicles. Objective and subjective data were recorded during the test and analyses of that data were presented in this report. The RDCW system combines lateral drift warning (LDW) and curve speed warning (CSW) functions. An almost-complete capture of data from more than 400 data channels plus forward- and face-oriented video cameras has resulted in a large database that archives approximately 83,000 miles (133,000 km) of driving by laypersons. Each of 78 drivers possessed a RDCW test vehicle for four weeks with a request to use the vehicle as their own personal vehicle. In the first week of a driver's experience, the system did not provide alerts to the driver, but a full set of data was collected. This baseline-driving period serves as an approximation to the driver's natural behavior. The RDCW system was enabled during the subsequent three weeks of the driver's experience, so that LDW and CSW alerts were provided. A rich set of subjective data was also gathered from each driver. Thus, the first conclusion from this project is that a very valuable resource has been added to the state of available information on the naturalistic driving process.

Furthermore, the RDCW system functioned very closely to the design intent throughout the testing. The RDCW system may be viewed as a hybrid system, in that it included functions representative of products that may well be deployed in the near future by the partners of this project team and/or other industrial suppliers of crash avoidance systems. It also employed advanced features such as the use of radar data to influence lateral drift thresholds, which might be more characteristic of a function available in 7 to 10 years when several remote sensors are installed on light vehicles. Therefore, the test system appears to provide a reasonable system for studying road departure functionalities in naturalistic driving.

The suitability of FOT data for supporting conclusions on the safety and acceptance of the RDCW system is based on the extent and nature of the test exposure, as follows:

- Seventy-eight individuals drove RDCW vehicles that each had essentially identical countermeasure systems.
- These persons were distributed across genders equally, as well as equal distributions among three age groups that included younger (20-30 yrs.), middle-aged (40-50 yrs.), and older (60-70 yrs) drivers.
- The typical subject drove 1,062 miles, covering some 750 miles with RDCW enabled.

- The FOT driving conditions varied significantly, thereby exercising the RDCW system and its drivers across a broad range of common driving environments. Mileages were generally distributed as follows:
  - 40 percent on freeways, with the remainder on surface roads or ramps;
  - 80 percent during daytime, 20 percent in the dark;
  - 9 percent with wipers on, 91 percent with wipers off;
  - 80 percent in urban or suburban areas, and 20 percent in rural environments.
- Distributions of the above factors were approximately the same for the first-week baseline segments of the FOT and the subsequent three-week RDCW segment of testing.
- One of the strongest exposure variations within the field test was the differences between individual drivers in terms of their driving styles and travel patterns.
- Since the RDCW system by its nature is so influenced by the roadway setting, key roadway characteristics such as road type, curve geometries, lane boundary characteristics, and seasonal effects such as snow cover, were significant influences on a driver's experience with RDCW. These effects must also be accounted for in analyses, in order to isolate the effects of the RDCW and avoid confounding effects.

The principal conclusions of the FOT are stated below in boxes, with each box followed by observations that either elaborate on the observations or provide a caveat to the boxed topic. This sequence of presentation addresses aspects of driver behavioral changes as if they were attributable solely to either the LDW or the CSW, however, the analysis can only observe changes in the data and then hypothesize about the actual source of any apparent change. Despite this caveat, the following sections address the LDW, CSW, and the combined RDCW system, with conclusions placed within the sections that seem most appropriate. Each subsystem or system is discussed first in terms of observations from the data that address potential safety impacts and system performance, and then by a discussion that draws conclusions from the subjective data that was gathered.

10.1 Conclusions related to LDW safety impacts and system performance

LDW system alerts

> *The LDW system issued no more than one alert for any given lateral drift event – this was either a cautionary or an imminent alert. Imminent alerts accounted for 62 percent of the LDW alerts presented to drivers.*

- Cautionary alerts were provided when the vehicle was crossing a dashed painted lane boundary without use of a turn signal, and when the side radar or side-radar-based lookaside database did not indicate a threatening object alongside the lane edge being crossed. Cautionary alerts were characterized by a haptic cue in the seat pan that emulates a rumble strip, along with a visual icon confirming the nature of the alert.
- Imminent alerts were provided when the vehicle moved across a solid lane boundary without a turn signal, or when it moved across a dashed boundary with a side radar-based observation of an object alongside that lane edge. Imminent alerts were characterized by a directional audio alert within the cabin, along with an accompanying visual display on the instrument panel confirming the nature of the alert.

LDW alert rates

> *The median of the individual drivers' rates of LDW alerts per unit distance was 9.0 alerts per 100 miles (161 km) of travel. The average was 10.6 alerts per 100 miles. This rate varied greatly with road type and among individual drivers.*

- Rates of LDW alerts were greater on ramps than on other road types, with more alerts on surface roads, per unit distance, than on freeways.
- There were almost twice as many alerts on the left side as on the right side on freeways, due to radar-driven alert events. On surface roads, the alert experience was similar on either side.
- Individual driver rates of cautionary alerts varied greatly, so that while the average rate was 4.0 alerts per 100 miles, the median was only 2.1 alerts per 100 miles. This reflects the fact that a minority of drivers had high rates of cautionary alerts, probably due to low usage of turn signals. The average and median rates for imminent alerts were much closer (6.6 and 5.8 alerts per 100 miles, respectively).
- The rate of LDW alerts exceeded the rate of forward crash warning alerts in the ACAS FOT project by an order of magnitude.

LDW cautionary alerts

> *Cautionary alerts are most commonly associated with intentional lane changes, and result in a substantial increase in use of turn signals.*

- When a cautionary alert was given to a driver, six out of ten times the driver continued to execute a lane change in that direction.
- Turn signal use increased when RDCW was enabled, and this is attributable to the system providing LDW alerts when lane changes were executed without using the turn signal.
- The percentage of lane changes in which drivers did not use turn signals decreased by 43 percent on surface roads and 24 percent on freeways. Overall, the rate of turn signal events per unit distance traveled increased 9 percent for the entire driver population, and 23 percent for the quartile of drivers that had the lowest initial rate of turn signal usage per mile in the first (RDCW-disabled) week.
- The rate of cautionary alerts decreased during the drivers' exposure to the system, presumably due to the increase in turn signal use. The rate of cautionary alerts in the final week was 25 percent less than the rate in the first (RDCW-disabled) week.

LDW imminent alert episodes

> *Eighty-five percent of events that triggered an imminent LDW alert ended with the vehicle remaining within the original lane of travel for at least 5 seconds, helping to validate the utility of these alerts.*

- The median response to a lane drift with an LDW alert displayed was to move more rapidly back to the original travel lane than when the LDW alert was not displayed.
- For the middle sensitivity setting of LDW, the most likely position in the lane for an imminent alert that is not radar based was on the edge of the lane. The most likely position for a radar-based imminent alert to be triggered is 0.3 m inside the lane edge for a forward radar-triggered alert and 0.5 m inside the lane for an alert triggered by a side radar or lookaside database.

Influence of RDCW on lane-keeping

> *Lane-keeping measures improved significantly when RDCW was enabled.*

- The standard deviation of lane position decreased when RDCW was enabled. The largest change occurred during the first week in which RDCW was enabled, and standard deviations increased from that value for the following two weeks. The standard deviations in the final week were still less than that in the first week when RDCW was not enabled.
- Drivers spent 63 percent less time outside the lane or within 10 cm of the lane edge when RDCW was enabled, based on an analysis of steady-state lanekeeping periods. There

were 50 percent fewer episodes of intrusion into that space when RDCW was enabled than when it was disabled.

Availability of LDW to provide alerts is a key technical challenge.

LDW was available about half the time that the vehicle was traveling 25 mph or faster. Among the 78 FOT drivers, the median percentage of time that the system was available on both the left and right sides was 46 percent. Median rates of LDW availability were 50 percent for right side availability alone, and 52 percent for availability only on the left side.

- The key technical challenge to the LDW system – or any vision-based lane-tracking system – may be increasing the percentage of time that the system is available to provide alerts. The challenge is achieving greater availability without introducing an excessive number of false alerts that can result from erroneous vision-based tracking of missing or poor-quality lane markers.
- Availability depends in part on the type of road being traveled. On freeways, availability was over 75 percent, and it decreased as the road type moved to major surface roads, as well as decreasing as the road type moved to minor surface roads.
- Some of the lack of availability was by design. The system was not available during or shortly after the driver used the turn signal or brake. The system was not available on very minor surface roads, such as those in subdivisions. This accounted for roughly 10 percent of the travel time.
- Availability was impacted substantially by season, so that the availability measure was lower by 11 percent during the 3-month period in which freezing temperatures were common in the FOT. (Approximately 70 inches of snow fell in this period.) This was presumably due to obscuration of lane edges by snow cover, salt reside, as well as the frequently wet roads that occur in such seasons.
- Availability was also impacted by sun angles, particularly when the sun was between 5 and 10 degrees above the horizon, and further, when the azimuth angle between the vehicle's forward axis and the sun's azimuth angle was less than 5 degrees. Although this is not a common condition, there was only 24 percent availability in this condition, throughout the FOT period.

10.2 Conclusions from subjective feedback on the LDW system

Subscale and Van der Laan results.

Drivers tended to rate LDW rather favorably

- LDW was generally viewed as being comfortable and convenient to use.
- LDW was rated as quite easy to use.

- LDW was generally thought to increase safety.
- Drivers generally stated that they would be willing to purchase LDW.
- LDW was largely judged to be useful.
- LDW was judged to be reasonably satisfying.
- LDW was judged to be almost as useful as adaptive cruise control (ACC), but less satisfying.

Perceived utility of LDW alert events.

Seventy-five percent of LDW alerts reviewed by drivers were deemed to be useful

- Utility ratings of LDW alerts increased with increasing driver age.
- Women were slightly more likely than men to rate LDW alerts as useful.
- Scenarios where the alert resulted from the vehicle leaving the lane, as compared to drifting within the lane without leaving it, were deemed the most useful, regardless of whether the driver actually responded to the alert.
- Generally, LDW alerts that were associated with the driver taking part in a non-driving behavior (e.g., talking on a cell phone) were rated more useful that alerts which were not associated with non-driving behaviors.

Focus group responses.

Focus group respondents provided generally positive feedback regarding LDW

- Negative feedback was generally associated with issues of system performance, and not the concept of LDW.
- Eighteen of 25 participants recalled receiving LDW alerts when they were not paying enough attention to driving.
- In several instances, participants reported that they reduced cellular phone use while driving with LDW.
- Participants were more conscious of using turn signals when LDW it was enabled.
- Three of the 25 participants stated that LDW would have to have an on/off switch in order for them to consider buying the feature.

10.3 Conclusions related to CSW safety impacts and system performance

CSW system alerts

The CSW system was designed to provide one or two levels of driver alerts in most situations that warranted an alert. Seventy percent of CSW alert events involved a single cautionary alert and 29 percent of the events involved a single cautionary alert followed by an imminent alert.

- A CSW alert event included all cautionary and imminent alerts related to a single curve as a set.
- Cautionary alerts were characterized by a haptic cue toward the front of the seat pan, and an accompanying visual icon to confirm the nature of the alert.
- Imminent alerts involved a voice message, "Curve! Curve!" in addition to a visual icon confirming the nature of the alert.
- Imminent alerts typically occurred within 1.4 to 3.5 seconds of the preceding cautionary alert, however, longer time delays occurred occasionally.
- The system would suppress imminent alerts in situations involving possible branching of the vehicle onto another roadway, such as an exit ramp, and only provide a cautionary-level alert. The intent was to reduce nuisances in cases where the vehicle did not take the branch that was expected.

CSW alert rates

The median of the individual drivers' rate of CSW alert events was 5.5 alerts per 100 miles (161 km). The mean rate was 6.1 alerts per 100 miles..

- The median rate of individual drivers' CSW alert events is 39 percent lower than the median of LDW alert rates.
- By distance traveled, the rate of CSW alert events on ramps is six times the rate observed on all road types combined. This may be due to two factors. First, higher lateral accelerations were observed on ramps. Second, drivers are more likely to approach curves on ramps at higher speeds with the intention of slowing shortly before the curve. The CSW system could not perfectly anticipate driver awareness or intentions, and therefore in the interest of protecting drivers, would occasionally issue alerts shortly before drivers began to slow.
- The rate of alerts on surface roads and freeways –except ramps in both cases – were of the same order of magnitude. However, freeway alerts were much less likely to be triggered by a significant curve that the vehicle eventually traversed.

CSW alert events triggered by curves that were traveled

Forty-two percent of CSW alert events within a set of 884 alert events examined in detail were triggered by a curve that was subsequently traveled by the vehicle. This means that approximately half the CSW alert events do not involve the vehicle passing through the curve that triggered the alert. These alerts were distributed as described below.

- Twenty five percent of the total number of alert events were triggered by curves on upcoming roadway branches that the vehicle eventually passed by. It is possible that drivers would consider many of these as unwanted alerts, although some drivers were aware of the cause of some of these alerts.
- Thirty two percent of all of the alert events in the 884-alert set examined in detail could not be classified by the analysts. This includes events that include technical challenges described in a following conclusions, as well as a smaller set of alert events that were simply not classified due to a lack of resources. Some of this latter set may include alerts that were triggered by curves that were indeed traversed.
- Only one in seven CSW alert events are triggered by a significant curve on the same roadway as the vehicle is traveling at the time of alert.

The challenge of handling road branches in CSW design

Over half the CSW alert events were triggered by curves on upcoming road branches, such as exit ramps. In almost half those cases, the vehicle passed by that branch and did not pass through the curve that triggered the alert.

- Anticipating the future path of the vehicle when approaching ramps, turn lanes, and other branches, is a central challenge to CSW.
- Drivers' lateral acceleration on curves on ramps was significantly higher than on other types of curves.
- The CSW was generally successful in predicting whether the vehicle will branch on a roadway. However, the sheer number of potential branches led to a significant number of CSW alerts being caused by occasional errors in predicting the vehicle path.

Technical challenges to implementing CSW systems

Approximately one in four CSW alert events were false alerts associated with aspects of the digital map and/or CSW implementation. Many or most of these errors would be resolved in a next-generation implementation. These false alerts were most common on freeways. The leading causes were are given below.

- Lateral misplacement of roadway geometry shape points within the digital map database, especially:
  - Points near overpasses that occur near gentle freeway curves,
  - Points near merge points of freeway entrances and freeways, and

    - Points near locations where the number of through-lanes changed.

  These occasional issues with shape point placements results from using a map originally built for lower-accuracy applications such as navigation; mitigation of these issues is possible through additional filtering in CSW.
- False alerts caused by occasional reboots of the CSW's navigation subsystem and/or resuming CSW availability before the reboot-induced errors were cleared.
- Map-matching results that misplaced the vehicle on a nearby road.

RDCW influences on broad patterns of curve-taking

No broad change in lateral acceleration behavior in curves was identified in the RDCW-enabled period.

- Although the lateral accelerations were seen to increase in daytime, when the windshield wipers were off, and for travel on ramps, there was no statistically significant change identified when RDCW was made available.
- Studying CSW in the FOT may have been complicated by two facts:
    - First, most curves are traveled at well below the lateral acceleration level of 0.25 g that was the nominal threshold for the CSW to issue alerts, and
    - Most curves traveled by drivers in this experiment had been traversed previously by that same driver within the experiment. Drivers may be less inclined to change their behavior on familiar curves that they are comfortable traveling.

10.4 Conclusions from subjective feedback on the CSW system

Subscale and Van der Laan results.

Drivers tended to rate CSW somewhat favorably

- CSW was reported as being somewhat comfortable and convenient to use, but suffered as a result of what drivers deemed to be unnecessary or false warnings.
- CSW was rated as quite easy to use.
- CSW was generally thought to increase safety.
- Drivers stated that they were somewhat willing to purchase CSW.
- CSW was judged to be useful by some drivers.
- CSW was judged to be marginally satisfying.
- CSW was judged to be almost as useful as forward crash warning (FCW), and equally as satisfying.

Perceived utility of CSW alert events.

Fifty-four percent of CSW alerts reviewed by drivers were deemed to be useful

- Utility ratings of CSW alerts were not affect by driver age.
- Women were slightly more likely than men to rate CSW alerts as useful.
- The type of scenario in which a CSW alert was issued significantly affected utility ratings.
- False-branching and false-system scenarios were rated significantly less useful than alerts in which the vehicle traveled through the curve that triggered the alert. However, even those alerts received a wide range of utility ratings.
- Drivers often commented that when they received a CSW alert, they would make their own evaluation of the situation rather than simply slowing down in response to the alert.
- Generally, CSW alerts that were associated with the driver taking part in a non-driving behavior (e.g., talking on a cell phone) were rated as more useful than alerts which were not associated with non-driving behaviors.

Focus group responses.

Focus group respondents reported that CSW was most useful when driving in unfamiliar surroundings.

- Negative feedback was generally associated with issues of system performance, and not the concept of CSW.
- 4 of 25 participants recalled receiving CSW alerts that may have prevented an accident.
- False alerts were a relatively major concern for participants.
- Reliability, a reduction in the number of false alerts, was the most frequently cited change that would have to be made to CSW in order for participants to consider buying the feature.

10.5 Conclusions related to combined RDCW safety impacts and system performance

Unintended consequences of RDCW deployment

> *There was no evidence of unintended, negative consequences of RDCW during the FOT.*

- No crashes related to lateral drifting occurred during the FOT, as expected.
- No obvious abuse of the RDCW system by drivers was noted.
- Some drivers reported experimenting with LDW and CSW when it was first available to them, but there were no observations of unsafe experimentation.

RDCW influence on drivers' engagement in secondary, non-driving activity

> *The presence of the RDCW driver alerts was not identified as a significant factor in drivers' engagement in non-driving, secondary activity, such as conversing with other passengers or speaking on cellular phones.*

- 1440 four-second video clips taken randomly during the experiment were studied to look for a relationship of secondary activities and the presence of RDCW. No such relationship was identified.

Sensitivity Settings for LDW and CSW

> *Drivers did not change either the LDW or the CSW sensitivity settings often. The most common sensitivity setting for each subsystem was the middle setting. Seventy percent of the drivers went through the final week with the same setting for both system.*

- Two controls were provided to drivers to adjust the LDW and CSW alert sensitivity separately. These settings were intended to influence when the alert was provided, allowing individuals to tune the system to their preferences.
- The middle of five possible settings was the most common setting, with 36 percent and 41 percent of travel time in the final week of testing spent at these settings for the CSW and LDW systems, respectively.
- There was a slight but consistent shift of drivers over time toward less sensitive settings for both the LDW and the CSW.
- Drivers did not adjust settings very often, with an apparent decrease over time in the number of adjustments.
- Drivers tended to settle on the same setting for both the LDW and CSW systems. In the final week, 70 percent of drivers selected the same settings for at least 95 percent of their travel time.

10.6 Conclusions from subjective feedback on the combined RDCW system

Subscale and Van der Laan results.

Drivers tended to rate the integrated RDCW system more favorably than the individual LDW and CSW functions.

- RDCW was reported as being comfortable and convenient to use.
- RDCW was rated as quite easy to use.
- RDCW was thought to increase safety.
- Drivers stated that they were somewhat willing to purchase RDCW.
- RDCW was judged to be useful by most drivers.
- RDCW was judged to be somewhat satisfying.

Focus group responses.

Sixteen of 25 participants stated they were more comfortable with RDCW than without it.

- Participants frequently mentioned that the RDCW system raised their alertness and awareness of their driving habits.
- Participants reported relying on the haptic and auditory displays more so than the visual display.

References

Axelrod, Robert, *The Evolution of Cooperation* , New York: Basic Books, 1984.

American Association of State Highway Transportation Officials (AASHTO). 1984. A policy on geometric design of highways and streets.

Crash Avoidance Metrics Partnership (CAMP). 2004. Enhanced digital mapping project final report. US DOT technical report.

Crash Avoidance Metrics Partnership (CAMP). 2005. Vehicle safety communications project task 3 final report. US DOT technical report.

Emery, L. Srinivasan, G., Bezzina, D., LeBlanc, D., Sayer, J., Bogard, S.,, and Pomerleau, D.: "Status report on USDOT project 'An intelligent vehicle initiative road departure crash warning field operational test.'" Proc. 19th Intl. Technical Conference on the Enhanced Safety of Vehicles, *US DOT HS 809 825*, Washington, D.C., June 2005.

Ervin, R., Sayer, J., LeBlanc, D., Bogard, S., Mefford, M., Hagan, M., Bareket, Z., and Winkler, C.: "Automotive collision avoidance system (ACAS) field operational test methodology and results." *US DOT HS 809 901,* Washington, D.C., September 2005.

Fancher, P.; Ervin, R.; Bareket, Z.; Bogard, S.; Sayer, J.; Haugen, J.; Mefford, M. 2000. Fostering development, evaluation, and deployment of Forward Crash Avoidance Systems (FOCAS). UMTRI report 2000-27.

Fancher, P., Ervin, R., Sayer, J., Hagan, M., Bogard, S., Bareket, Z., Mefford, M., and Haugan, J. 1998. Intelligent cruise control field operational test final report. US DOT report DOT HS 808 849.

Fancher, P.; Bareket, Z.; Peng, H.; Ervin, R. 2003. Research on desirable adaptive cruise control behavior in traffic streams. UMTRI report No. UMTRI-2003-14.

French D.J., West R.J., Elander J., & Wilding J.M. (1993). Decision making style, driving style and self-reported involvement in road traffic accidents. Ergonomics, vol. 36. pp. 627-44.

General Motors (GM). 2005. Automotive collision avoidance system field operational test: Final program report. US DOT report DOT HS 809 886.

Glassco, R., Smith, D., Chang, J., and Cohen, D. (2003). Feasibility of modeling lane-change performance. Society of Automotive Engineers paper 2003-01-0280.

Horst, A.R.A. van der, (1990). A time-based analysis of road user behaviour in normal and critical encounters. TNO Institute for Perception, Soesterberg, the Netherlands.

Janssen, W. H., Brookhuis, K. A., Kuiken, M. (1993). Simulator and field evaluation of in-vehicle collision avoidance systems: Report of first year of research for Nissan (IZF 1993 C-46). Soesterberg, The Netherlands: TNO Institute for Perception.

Jonah, B. A. (1997). Sensation seeking and risky driving: A review and synthesis of the literature. Accident Analysis and Prevention, 5, 651-665.

Kiefer, R., LeBlanc, D., Palmer, M., Salinger, J., Deering, R, and Shulman, M.: "Development and validation of functional definitions and evaluation of procedures for collision warning/ avoidance systems," *US DOT report HS 808 964*, 1999.

Kiefer, R.J., Cassar, M., Flannagan, C., LeBlanc, D., Palmer, M., Deering, R., and Shulman, M.: Forward Collision Warning Requirements Project Final Report – Task 1," US DOT HS 809 574. January 2003.

LeBlanc, D., Kiefer, R., Deering, R., Shulman, M., Palmer, M., and Salinger, J., "Forward Collision Warning: Preliminary Requirements for Crash Alert Timing," *SAE paper 2001-01-0462*. March 2001.

Lee, S., Olsen, E., and Wierwille, W. (2004). A comprehensive examination of naturalistic lane changes. US DOT report DOT HS 809 702.

Najm, Wassim G., Koopmann, Jonathan, Boyle, Linda, and David Smith. (2002). Development of Test Scenarios for Off-Roadway Crash Countermeasures Based on Crash Statistics, September 2002, U.S. DOT technical report DOT-HS-809 505.

NHTSA (2005). Motor vehicle traffic crash fatalities and injuries. US DOT report DOT HS 809 862.

Parker, D., Reason, J. T., Manstead, A. S. R., & Stradling, S. G. (1995). Driving errors, driving violations, and accident involvement. Ergonomics, vol. 38. pp. 1036-1048.

Pomerleau, D., Jochem, T., Thorpe, C., Batavia, P., Pape, D., Hadden, J., McMillan, N., Brown, N., Everson, J. (1999). Run-off-road collision avoidance using IVHS countermeasures. USDOT technical report DOT HS 809-170.

Reason, J., Manstead, A., Stradling, S., Parker, D., & Baxter, J. (1991) The social and cognitive determinants of aberrant driving behaviour. TRRL Contractor Report 253. Crowthorne: Transport and Road Research Laboratory.

Rotter, J. B. (1966). Generalized expectancies for internal versus external control of reinforcement. Psychological Monographs, 80. (Whole No. 609).

Saving lives through advanced safety technology, Intelligent Vehicle Initiative, 2002 Annual Report, US Department of Transportation, Federal Highway Administration, 2002.

Sayer, J. R., Devonshire, J. and Flannagan, C. A. Effects of secondary tasks on driving performance. (Report No. UMTRI-2005-29). The University of Michigan Transportation Research Institute, Ann Arbor, MI.

Subramanian, R. (2005): Motor vehicle traffic crashes as a leading cause of death in the United States, 2002. National Highway Transportation Safety Administration Research Note, DOT HS 809 831.

Szabo, S. and Norcross, R. (2003). Recommendations for objective test procedures for road departure crash warning systems. Memorandum to NHTSA, February 18, 2003.

Szabo, S., Murphy, K., and Juberts, M. (1999). The Autonav/DOT project: baseline measurement system for evaluation of roadway departure warning systems. USDOT technical report DOT HS 808 895.

Talmadge, S., Chu R. Y., and Riney, R.S.: "Description and preliminary data from TRW's lane change collision avoidance testbed," Proc 10th ITSA Annual Meeting, Boston, 2000.

U.S. Department of Transportation. 2005. Intelligent vehicle initiative final report. Technical report FHWA-JPO-05-057.

Van Der Laan, J. D., Heino, A., De Waard, D. (1997). A simple procedure for the assessment of acceptance of advanced transport telematics. *Transportation Researc*h, 5(1), 1-10.

West R.J., Elander J. & French D.J. (1992). Decision making, personality and driving style as correlates of individual accidents risk. Contractor Report 309, Crowthorne: Transport Research Laboratory.

Winkler, C., Sullivan, J., Bogard, S., Goodsell, R., and Hagan, M. (2002). Field operational test of the Freightliner/Meritor WABCO roll stability advisor & control at Praxair. University of Michigan Transportation Research Institute report UMTRI-2002-24.

Zuckerman, M. (1994). Behavioral expressions and biosocial bases of sensation seeking. New York: Cambridge University Press.

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Glossary

A	Amperes
AMR	Available maneuvering room –estimate of the drivable space adjacent to the lane marker, used in LDW threshold computation.
ANOVA	Analysis of variance
APS1	One of two maps used by the CSW system. The APS1 map contained seven southeastern counties of Michigan and was more accurate and contained more attributes than the SDAL map.
Ax	Longitudinal acceleration
Ay	Lateral acceleration
Baseline	A six day period in which LDW/CSW functionality was not available to the driver
CDPD	Cellular Digital Packet Data
CPOI	Curvature point of interest – point in curve that CSW considers as the most-stressing location in an upcoming curve
Cronbach	A test for a model or survey's internal consistency.
CSC	Circuit switched cellular
CSW	Curve speed warning, also called CSWS
CswSensitivity	Driver selected sensitivity level for the CSW system
DAS	Data acquisition system
DB	Database
DBQ	Driver behavior questionnaire
Disabled	A six day period in which LDW/CSW functionality was not available to the driver
Distance-to-edge	Estimated distance from a vehicle tire to the lane edge.
DSQ	Driving style questionnaire
DVI	Driver vehicle interface
EBX	Embedded board expandable
Enabled	Approx. a 20 day period in which the vehicle operated with the RDCW functionality
FOD	Future offset distance
FODT	Future offset distance threshold
FFOV	Forward field of view
First-week	The baseline period of exposure when the RDCW system is disabled
FOT	Field operational test
Freeways	The combination of Interstate and highway road types
FTP	File transfer protocol
GB	Gigabyte

GPS	Global position system
Histogram	A graphical display of tabulated frequencies
Host	The RDCW vehicle
HPMS	Highway performance monitoring system
HURP	Human use review panel
Hz	The unit of frequency
Imminent-alert	The highest level of CSW or LDW alert
IRB	Internal Review Board
K-W	Kruskal-Wallis one-way analyses of variance
LADB	Look-aside database – a component of the LDW system that stores and recalls lateral maneuvering room as a means of modulating alert thresholds.
LAM	Look-ahead module of CSW (considers road branches ahead)
Lane offset	Lateral offset of the vehicle in the lane (left of lane center is negative) also known as vehicle lateral offset
LDW	Lateral drift warning system, also called LDWS
LdwSensitivity	Driver selected sensitivity level for the LDW system
Likert-type	A technique for measuring opinions, attitudes, and beliefs—developed by Rensis Likert
LOC	Locus of control
M	Mean
Manual	The driver is controlling longitudinal headway and speed
Manual-driving	The driver is controlling longitudinal headway and speed
MFI	Median family income
MHI	Median household income
mi	miles
Middle-age	40 to 50 year old participants
MLP	Most likely path of vehicle computed by CSW (predicts branching behavior of the vehicle)
NAVTEQ	A provider of comprehensive digital map information for automotive applications
NHTSA	National Highway Traffic Safety Administration
NPTS	National Personal Transportation Survey
OEM	Original equipment manufacturer
OHP	Out-of-host's path
OHSP	Michigan office of highway safety planning
Older	60 to 70 year old test participants

PC104-plus	a standard PC-compatible modules used to create an embedded computer system
PCI	Per capita income
PDOP	Planar dilution of position metric for GPS position estimates
POM	Position on map – solution of a map-matching operation
PRNDL	Acronym for park, reverse, neutral, drive and low
R	Range, ramp, or correlation coefficient
RDCW	Road departure crash warning
RDCW-enabled	Approx. a 20 day period in which the vehicle operated with the RDCW functionality
Road-type	Road class designation
RMS	Root mean squared
s	seconds
SAM	Situation awareness module within the RDCW system
SDAL	Shared data access library. A standard format for digital map data access.
SEM	Standard error of the mean
Sensitivity	Sensitivity setting; a value from 1 to 5
SPSS©	Statistical package for the social sciences
SQL	Structured query language
SSS	Sensation seeking-scale
Std	Standard deviation
SUVs	Sport utility vehicles
Tr	Driver reaction time
UFOV	Useful field of view
UMTRI	University of Michigan Transportation Institute
USDOT	U.S. Department of Transportation
Veh	Vehicle
VGA	Video Graphics Array
Week1	Days 1 to 6
Week2	Days 7 to 12
Week3	Days 13 to 18
Week4	Days 19 to 24
Young	20 to 30 year-old test participants

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