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16. Abstract
This report presents the results of an independent evaluation of the Road-Departure Crash Warning System (RDCW), which is designed to warn drivers when they are drifting out of their lane or about to enter a curve at an unsafe speed. The RDCW lateral-drift-warning subsystem monitors a vehicle's lane position and lateral speed, and alerts the driver when the vehicle is in danger of departing the road or lane. The RDCW curve-speed-warning subsystem monitors vehicle speed and upcoming road curvature and alerts the driver when the vehicle is in danger of losing control in an upcoming curve. The goal of the RDCW is to improve automotive safety by helping drivers avoid road-departure crashes, but this can only occur if the system is useful and drivers respond to it.

The RDCW Field Operational Test (FOT) collected 130,000 km of driving data from 78 participants to evaluate the performance, driver acceptance, and safety benefits of the RDCW. The University of Michigan Transportation Research Institute conducted the test. Visteon Corporation built the FOT vehicles and Assistware Corporation developed the RDCW lateral-drift-warning subsystem. The National Highway Traffic Safety Administration sponsored the FOT to determine if the RDCW will help reduce road-departure crashes in the United States. The Volpe National Transportation Systems Center of the U.S. DOT's Research and Innovative Technology Administration, under agreement with NHTSA, independently evaluated the RDCW.

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PREFACE

The Volpe National Transportation Systems Center (Volpe Center) of the U.S. Department of Transportation's Research and Innovative Technology Administration, in conjunction with the National Highway Traffic Safety Administration, is conducting independent evaluations of various vehicle crash-avoidance systems. These evaluations support the U.S. DOT's Intelligent Vehicle Initiative (IVI) Program, which focuses on highway crash prevention and the implications of in-vehicle technologies on driver behavior.

The Volpe Center is assessing how crash-avoidance systems benefit safety and if drivers accept these systems. Safety benefits and driver acceptance of a given crash-avoidance system influence both the government and private industry in promoting system deployment of vehicle-based and vehicle infrastructure cooperative crash countermeasures.

This report presents the results of the Roadway Departure Crash Warning System (RDCW) independent evaluation. The RDCW field operational test (FOT), which collected 130,000 km of driving for 78 participants, provided data for this evaluation of the performance, driver acceptance, and safety benefits of the RDCW. The University of Michigan Transportation Research Institute (UMTRI) conducted the FOT. Visteon Corporation built the FOT vehicles, and Assistware Corporation developed the RDCW lateral-drift-warning subsystem. NHTSA sponsored the FOT to determine if systems such as the RDCW will help reduce the over 1.2 million road-departure crashes occurring annually in the United States.

Bruce Wilson, *Mary Stearns*, *Jonathan Koopmann*, and *David Yang* wrote this RDCW evaluation report. We acknowledge the technical contribution and support of many people and organizations: *Ray Resendes*, formerly of the Federal Highway Administration ITS Joint Program Office and currently chief of NHTSA's Intelligent Technologies Research Division, helped initiate the RDCW FOT; *Lloyd Emery*, the NHTSA program manager, provided support and technical guidance; *Wassim Najm* of the Volpe Center was always available for technical and programmatic guidance and deserves special mention; and *John Hitz*, retired from the Volpe Center, helped initiate and develop the evaluation. We also acknowledge the contributions of the following Volpe Center staff members: *Andy Lam* for developing data processing and conflict identification algorithms, *Kevin Green* for programmatic guidance, *Sara Secunda* for developing the GPS/GIS vehicle location algorithm, *Mikio Yanagisawa* and *Kevin Chui* for analyzing video episodes, *Neil Meltzer* for documenting participant debriefs, and *Amy Ricci* and *Jeannie Holtorf* for preparing driver acceptance data files.

We also acknowledge *Raman Sampath* and *Balaji Gopalan* of Computer Sciences Corporation who built and maintained the database, developed the multimedia data analysis tool, programmed various algorithms, and generated analysis reports, and *Sandor Szabo* of the National Institute of Standards and Technology who participated in the characterization tests, providing instrumentation and analyzing lateral-drift alerts. The FOT partners, *UMTRI, Visteon*, and *Assistware*, were always willing to share documents and information. In particular, UMTRI researchers *Dave LeBlanc, Jim Sayer, Scott Bogard, Joel Devonshire, Mary Lynn Mefford, Dillon Funkhouser, Zevi Berekat*, and *Mike Hagan,* who explained data anomalies, provided video processing, time synchronization, and most-likely-path routines; accommodated Volpe Center staff for subject debriefings and focus groups, and supported the system characterization test. *Dean Pomerleau* of Assistware and *Faroog Ibrahim* and *Debbie Bezzina* of Visteon were always willing to explain the lateral-drift-warning and curve-speed-warning subsystems. Finally, we thank *Cassandra Oxley* and *Katherine Blythe*, who edited this report for consistency and readability; and *Barbara Siccone* for her word-processing expertise; all of CASE, LLC.

ACRONYMS

AMR	Available Maneuvering Room
ANOVA	Analysis of Variance
CCD	Charge-Coupled Device
CPOI	Curvature Point of Interest
CPR	Crash Prevention Ratio
CSW	Curve-Speed-Warning
DAS	Data Acquisition System
DVI	Driver-Vehicle Interface
FHWA	Federal Highway Administration
F	Variance Ratio for *F* Test
FOT	Field Operational Test
GES	General Estimates System
GIS	Geographical Information System
IVI	Intelligent Vehicle Initiative
IMS	Independent Measurement System
km	Kilometer
LADB	Look-Aside Database
LDW	Lateral-Drift-Warning
m	Meter
MLP	Most Likely Path
MOP	Measure of Performance
mph	Miles per Hour
MS	Mean Square
NAZD	No Alert Zone Database
NHTS	National Household Travel Survey
NHTSA	National Highway Traffic Safety Administration
NIST	National Institute of Standards and Technology
OEM	Original Equipment Manufacturer
RITA	Research and Innovative Technology Administration
RDCW	Road-Departure Crash Warning
SE	System Effectiveness
SS	Sum of Squares
TAM	Technology Acceptance Model

TTC	Time-To-Collision
U.S. DOT	United States Department of Transportation
UMTRI	University of Michigan Transportation Research Institute
VDT	Vehicle Distance Traveled
VMT	Vehicle Miles Traveled

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EXECUTIVE SUMMARY

From May 2004 to February 2005, 78 drivers participated in a field operational test of a Road-Departure Crash Warning system. The RDCW warned drivers when they were drifting out of their lane or were about to enter a curve at an unsafe speed. A lateral-drift-warning subsystem monitored the vehicle's lane position and lateral speed and alerted the participant when the vehicle was in danger of departing the road or lane. A curve-speed-warning subsystem monitored vehicle speed and upcoming road curvature and alerted the participant when the vehicle was in danger of losing control in the upcoming curve.

THE PROBLEM

Over 1.2 million road-departure crashes occur each year in the United States. Because these crashes often involve collisions with fixed objects or “non-collisions” such as roll-overs, they may be particularly severe. Indeed, according to 2004 United States traffic statistics, although collisions with fixed objects or non-collisions accounted for only 19 percent of all crashes, they accounted for 43 percent of the fatal crashes.

ROAD-DEPARTURE CRASH WARNING SYSTEM

The RDCW warned drivers of impending road departure. The RDCW merged and arbitrated between its LDW and CSW subsystems. The LDW monitored the vehicle’s lane position, lateral speed, and available maneuvering room. The LDW used a video camera to estimate the distances between the vehicle and the left and right lane boundaries and to estimate the lateral speed. The LDW also estimated the AMR and, using a pair of side radars and a pair of forward radars, detected adjacent and upcoming objects. By monitoring the vehicle’s position on the road, the lateral speed, and the AMR, the LDW was able to alert a driver when it appeared the vehicle was likely to depart the lane or the road.

RDCW equipped FOT fleet

The CSW monitored vehicle speed and upcoming road curvature. To estimate the curvature, the CSW used a Global Positioning System receiver to determine the vehicle location and a road database to determine the curvature of the road several seconds in front of the vehicle. The CSW also predicted the most-likely path (MLP) the vehicle would travel. MLP prediction was necessary because freeway on-ramps and off-ramps have much smaller curve radii than the roads these ramps connect to, and a speed that was safe for a road would likely not be safe for a ramp. By monitoring vehicle speed and estimating the upcoming road curvature, the CSW was able to alert a driver when the vehicle was approaching the upcoming curve at an unsafe speed.

FIELD OPERATIONAL TEST

The National Highway Traffic Safety Administration sponsored the FOT to determine if a system such as the RDCW would help prevent road-departure crashes in the United States. Assistware Corporation developed the RDCW lateral-drift-warning and Visteon Corporation built the FOT vehicles. The University of Michigan Transportation Research Institute conducted the RDCW FOT, and collected 130,000 km of driving data from 78 participants. The Volpe National Transportation Systems Center (Volpe Center), under an agreement with NHTSA, evaluated the performance, safety benefits, and driver acceptance of the RDCW.

Under an agreement with NHTSA, UMTRI outfitted 11 identical Nissan Altimas with an RDCW. In addition, FOT vehicles were equipped with two unobtrusive cameras, extra sensors, and data acquisition systems. One camera was aimed forward and showed the lane markings, the road type, nearby vehicles, barriers, the shoulder, and so on. The second camera showed the driver's face and shoulders. The video collected by these cameras supplemented the numerical data provided by the RDCW and extra sensors and enabled video analysts to describe the conditions around alerts. The extra sensors included lateral and longitudinal accelerometers and a yaw rate sensor. These and other variables were used to determine vehicle movements, e.g., a curve or lane change, from the data and to quantify the severity of a given maneuver. The DAS recorded over 300 data channels and saved 8 seconds of buffered video when an alert occurred.

The RDCW display on the left side of the dashboard shows device availability and alert status.

During the FOT, compensated volunteer participants drove FOT vehicles for several weeks. The 78 participants were a balanced mix of males and females in age ranges from 20 to 30, 40 to 50, and 60 to 70. The FOT protocol called for each of the participants to use FOT vehicles in place of their own vehicles for 25 days. During the first six days, the baseline period, the RDCW operated in the background. It sensed the vehicle motion and surroundings and determined when an alert was needed, but it did not issue alerts to the driver. This period provided data for participants' baseline driving, i.e., how participants normally drove. During the final 19 days, the treatment period, the RDCW operated in the foreground. It not only determined when an alert was needed, but also issued alerts. This period provided data for evaluating participants' treatment driving, i.e., how they drove with the collision-avoidance information provided by the device.

The RDCW FOT provided an extensive amount of data to analyze the effectiveness of the device. During the ten-month experiment, participants drove over 130,000 km and over 1,500 hours on public roads. In addition to objective—numerical and video—data, the FOT also collected a considerable amount of subjective data. FOT participants completed surveys before and after their FOT experience. Participants also discussed their opinions of the RDCW. When participants returned their FOT vehicles, UMTRI staff debriefed participants for an average of two hours, discussing their survey responses and reviewing video clips of selected alerts. Finally, 32 of the 78 participants participated in four two-hour focus groups, providing additional subjective data for evaluating the RDCW.

INDEPENDENT EVALUATION

The RDCW evaluation focused on three major areas: performance, safety benefits, and driver acceptance. These three interdependent topics are key to device effectiveness. First, the RDCW must perform reasonably well; i.e., it must detect dangerous situations and alert accordingly. Second, participants must drive more safely with the device than without it. Finally, participants must approve of the RDCW and be willing to use vehicles equipped with it.

PERFORMANCE

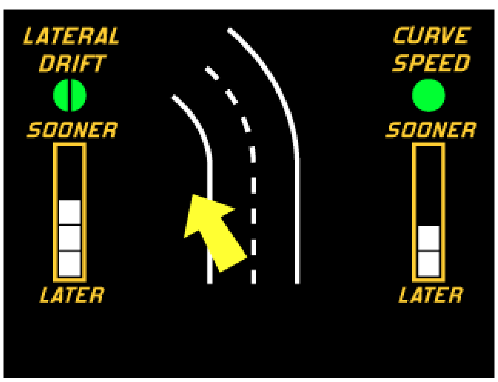
The Volpe Center analyzed 130,000 km of FOT data and 1,300 km of on-road characterization data in evaluating the performance of the RDCW. To perform effectively, the system needs to be "available," i.e., capable of issuing an alert. Poor lane markings, low speeds, a lack of digital road information and other conditions limit LDW or CSW availability, or both. The system also needs to issue an alert when it is necessary and to not issue an alert when it is not necessary. An alert must also be issued in time for a driver to use it effectively to avoid departing the road, but not be issued so early as to be a nuisance. Finally, the system must communicate alerts in a manner that drivers find easy to identify and understand. The performance analysis analyzed all these aspects of the RDCW and its subsystems.

System Availability and Accuracy. The road type and a combination of lighting and precipitation widely influenced LDW availability. On freeways the LDW was 76 percent available (76 of every 100 miles), compared to 36 percent on non-freeways. During dry, daytime conditions the LDW was 56 percent available, compared to 4 percent available during wet, nighttime conditions. CSW availability was consistently high, 99 percent on freeways and 94 percent on non-freeways. A comparison of AMR estimates provided by the LDW against those provided by an independent system revealed that the LDW often overestimated the width of narrow shoulders and underestimated the width of wide shoulders. A comparison of curve-radius estimates and distance-to-curve estimates provided by the CSW against those provided by an independent system revealed inconsistencies, but no clear trend, in these measures.

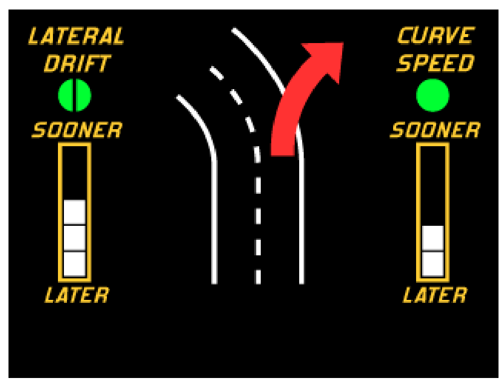
LDW Alerts. A manual video analysis of FOT alerts indicated that one in three alerts was a false positive. Conditions that influenced availability also influenced performance. The odds of an alert being a false positive for nighttime driving were 1.8 times the odds for daytime driving. The odds of an alert being a false positive alert for wet surfaces were 3.0 times the odds for dry surfaces. The odds of an alert being a false positive alert for driving in the rain were 3.6 times the odds for driving under dry conditions. Constructions zones, with barrels, barriers, and poor or no lane markings, also degraded system performance. Of the alerts issued in construction zones, nearly half were false positives. Despite the variation in alert timing, participants commented favorably on it.

CSW Alerts. The system failed to alert in 1 out of every four cases when a vehicle approached a curve with excessive speed. Ninety-three percent of the true positive required alerts provided sufficient time to brake and negotiate the curve safely. Some 10 percent of alerts when approaching curves or passing ramps were false positives.

Driver Vehicle Interface. Eighty-eight percent of the participants readily interpreted the seat vibration alerts, 80 percent readily interpreted the LDW audible alerts, and 86 percent readily interpreted the visual alerts. Participants rated the following favorably: LDW and CSW alert timing; LDW and CSW missed alert frequency; and LDW false-positive alert frequency. Participants' unfavorable responses to certain survey items indicated that they recognized the LDW limitations in poor lighting and road surface conditions.



This RDCW display indicates full lateral-drift and curve-speed availability and a cautionary lateral-drift alert for the left side.



This display indicates full availability and an imminent curve-speed alert.

SAFETY BENEFITS

The 78 FOT participants, their 130,000 km, and 1,500 hours of driving provided data to analyze and estimate safety benefits. The analysis portion refers to how the 78 participants performed. The estimation portion refers to a how a broad deployment of the RDCW would change crash statistics if every vehicle had an RDCW.

Data Processing. FOT data, including lane position, vehicle speed and acceleration, the AMR available on either side of the vehicle, and road information, was sampled 10 10 times per second. From this raw data, *conflicts* (situations likely to result in a collision unless the driver intervenes) corresponding to the dominant road-departure pre-crash scenarios were identified. These scenarios included departing-the-road-while-going-straight, departing-the-road-while-negotiating-a-curve, and losing-control-while-negotiating-a-curve. *Events* (driving situations that the RDCW may influence) were also identified in the FOT data. The event categories included curves, lane changes, turns, and in-lane driving. Because conflicts were used to analyze driving safety and, ultimately, to predict crashes, events were used to analyze unintended consequences.

Results. The analysis of the FOT data showed a net safety benefit and no unintended consequences. The FOT data showed a decrease in road-departure crashes and no degradation in several related situations. With the RDCW activated, a 10- to 60-percent reduction in departure conflict frequency was observed at speeds greater than 55 mph. A modest decrease in conflict severity, the minimum distance from the road edge, was observed over the 35 to 45 mph speed range. With the assumptions of 100 percent deployment and 100 percent device availability, an annual reduction of 9,400 to 74,800 road-departure crashes is forecast. For the 55 percent LDW availability observed in FOT data, this range decreases to 5,200 to 41,200 fewer crashes per year.

Changes in conflict rates, conflict severity, and annual crash forecasts result from changes in driving associated with departure, not control-loss, conflicts. The FOT data indicates that the LDW caused these changes. Conversely, the FOT data do not indicate that the CSW caused any changes in participants' driving. This does not imply that the CSW failed to alert participants or that participants ignored its alerts. It is possible that the FOT location may not have contained a sufficiently diverse collection of curves or a sufficiently long participant exposure to fully demonstrate the potential benefit of the CSW.

The trunk of the FOT vehicles contained RDCW and data-acquisition hardware.

DRIVER ACCEPTANCE

Responses to survey questions, debrief questions, and focus group topics determined driver acceptance of the RDCW and its subsystems. The topics included *ease of use, learning, driver performance, perceived value,* and *advocacy.*

Ease of Use. Participants rated the RDCW as easy to use but rated the LDW more positively than the CSW. The settings and availability indicators were easy to use; the display is

A locked panel hid the hardware, which kept participants unaware of the equipment and helped foster naturalistic driving.

conveniently located; and system operation, including adjusting the sensitivity, was simple.

The alerts did not distract the participants, and a high percentage of LDW alerts were rated as correct.

Although participants knew how to respond to CSW alerts and appreciated them in adverse weather and unfamiliar conditions, the alerts were unnecessary on familiar roads. In particular, participants did not like receiving CSW alerts when they entered or exited freeways.

Learning. Participants learned RDCW operation quickly, but comments at the conclusion of the FOT suggest that some did not fully understand the differences between the LDW and CSW. Participants described the LDW as easy to learn and increased turn-signal use with it. Although participants reported the CSW as easy to learn, focus group comments revealed that many did not fully understand when and why the RDCW issues CSW alerts.

Driver Performance. The RDCW made participants more aware of their vehicle position on the road and of upcoming road challenges. Although the RDCW gave them useful information, participants remained vigilant in their driving and considered themselves responsible for their vehicle. The LDW changed driving performance more than the CSW. The LDW improved vehicle position awareness, enabled participants to relax more while driving, improved lane keeping, and encouraged signaled lane changes. Participants rated the CSW as somewhat useful but did not rely on it to operate their vehicles safely.

Perceived Value. Participants believed the RDCW increased their driving safety because it increased turn-signal use, reduced lane drift, and improved alertness. Participants appreciated the LDW alerts because many helped them to avoid potential safety hazards. Participants rated 75 percent of their LDW alerts as useful, based on a review of selected video clips. There is no relationship between LDW alert frequency and participants' alert tolerance. Participants had mixed comments about the CSW alerts and rated 50 percent as useful. They commented that these alerts, even when false, reminded them to monitor their speed. They rated CSW alerts on unfamiliar roads more positively than alerts on familiar roads.

Advocacy. Most participants wanted to acquire the RDCW and valued it at approximately $725. Those interested in purchasing only the LDW or CSW valued each at $500 and $400, respectively. Participants would not turn off the LDW or CSW, even if given the option. Fifty-three percent expressed an interest in acquiring the LDW and 42 percent wished to purchase it. Forty-seven percent expressed interest in acquiring the CSW and 30 percent wished to purchase it. Participants would like the LDW to work in all weather conditions and the CSW to issue fewer false alerts. The incidence of CSW false alerts is a major concern. Some participants reported that they started ignoring CSW alerts toward the end of the FOT.

CONCLUSIONS

The FOT data collected to evaluate RDCW performance, driver acceptance, and safety benefits show positive results in each of these areas. The device performed reasonably well, but inaccuracies in some of its measures led to some alerting inconsistencies. In particular, the performance test data indicate that the LDW did not measure shoulder width very accurately, resulting in late alerts with narrow shoulders and early alerts with wide shoulders. The performance data also indicate that the CSW occasionally misestimated the distance to a curve or curve radius, causing missed, late, and early alerts.

Participants had fewer departure conflicts with the RDCW enabled, i.e., when it started issuing alerts. Extrapolating the FOT data and assuming comprehensive deployment and function, we project that the observed decrease in conflict rates and changes in conflict severity could result in an annual reduction of 5,200 to 41,200 road-departure crashes with the availability observed in the FOT.

Overall, FOT participants accepted the RDCW and its LDW and CSW subsystems. They rated the system as easy to use and easy to learn, although some did not fully understand the CSW alerts. Participants stated that the RDCW improved their driving and that they would pay $725 to purchase the RDCW.

1. INTRODUCTION

The mission of the National Highway Traffic Safety Administration is to save lives, prevent injuries, and reduce health care and other economic costs associated with motor vehicle crashes.

There are over 1.2 million road-departure crashes in the United States each year, which often involve collisions with fixed objects or a "non-collision" such as a rollover. According to 2004 United States traffic statistics, although collisions with fixed objects or non-collisions accounted for only 19 percent of all crashes, they accounted for 43 percent of the fatal crashes. In 2001, NHTSA signed a two-phased cooperative agreement with the University of Michigan Transportation Research Institute to conduct a field operational test of the Road-Departure Crash Warning System.

HIGHLIGHTS

- Road departure accounts for 19 percent of the crashes and 43 percent of the fatalities annually in the United States.
- NHTSA sponsored a field operational test to evaluate an RDCW using 11 instrumented vehicles.
- Seventy-eight participants drove a test vehicle in place of their own vehicle for 4 weeks.
- The test included a one-week *baseline* period and three-week *treatment* period.
- The Volpe Center evaluated the system's effectiveness in preventing collisions.

In the first phase of the FOT, UMTRI, and its partners, Visteon Corporation and Assistware Technology, developed the RDCW and submitted it to NHTSA. Phase 1 activities included Visteon-led validation testing to check device function and alert timing and a demonstration event for NHTSA that included on-road driving to evaluate device operation, availability, user interface, and readiness for Phase 2, a 10-month data collection effort on public roads.

During the FOT, 78 participants (lay drivers) used an RDCW-equipped and instrumented vehicle in place of their personal vehicles for 25 days. During the first six days, the RDCW performed its usual monitoring and alerting, but the alerts were not presented to the drivers. The vehicle's data acquisition system collected RDCW and other data. This initial block of data described the drivers' *baseline*, i.e., normal, driving. During the final 19 days, the RDCW alerts were presented to the drivers and the DAS continued collecting data. The final block of data described drivers' *treatment*, how they drove with RDCW.

The RDCW warns drivers when they are drifting out of their lane or are about to enter a curve at an unsafe speed. The goal of the RDCW is to improve automotive safety by helping drivers avoid road-departure crashes, but this can only occur if the system is useful and drivers respond to it. The lateral-drift-warning subsystem of the RDCW monitors a vehicle's lane position and lateral speed, and alerts the driver when the vehicle is in danger of departing the road or lane (activating a turn signal silences the alert). The curve-speed-warning subsystem monitors vehicle speed and upcoming road curvature, alerting the driver when the vehicle is in danger of losing control in the upcoming curve.

The Volpe National Transportation Systems Center, under agreement with NHTSA, was the independent evaluator of the RDCW. The Volpe Center compared drivers' baseline and treatment driving. The Volpe Center has prior FOT experience through its evaluation of two other major FOTs: the Intelligent Cruise Control (Koziol et al., 1999) and the Automotive Collision Warning System (Najm et al., 2005). This report presents the results of the RDCW independent evaluation.

1.1 ROAD-DEPARTURE CRASH WARNING SYSTEM

The intention of the RDCW is to warn drivers of impending road departure. In the first warning scenario a combination of lateral drift, available maneuvering room (AMR), and lane position indicate that the vehicle will soon leave the road or collide with an object in the adjacent lane or shoulder. In the second warning scenario, a combination of vehicle speed and upcoming road curvature indicate that the vehicle may lose control (traction) when attempting to negotiate the curve.

The RDCW display on the left side of the dashboard on the FOT-equipped Nissan Altima shows device availability and alert status.

To perform its intended warning function, the RDCW merges and arbitrates between the LDW and CSW (subsystems). In general terms, the LDW uses a video camera to estimate the distances between the vehicle and the left and right lane boundaries and to estimate the lateral speed. The LDW also estimates the AMR and, using a pair of side radars and a pair of forward radars, detects adjacent and upcoming objects. The LDW includes a sensitivity adjustment through which a driver can adjust the timing of alerts. At a high sensitivity setting the RDCW issues LDW alerts sooner than it does at a low setting.

The CSW monitors vehicle speed and upcoming road curvature. The CSW estimates upcoming road curvature using a GPS receiver to determine the vehicle location and a road database to determine the curvature of the road several seconds in front of the vehicle. The CSW must also predict the "most-likely path" the vehicle will travel. MLP prediction is necessary because freeway on-ramps and off-ramps have much smaller curve radii than the roads these ramps connect to, and a speed that is safe for a road may not be safe for a ramp. These differences in safe speeds require the CSW to predict if the vehicle is going to continue on a road or turn onto a ramp. When there is no ramp nearby, MLP prediction is straightforward–there is essentially only a single road (path) for the vehicle to take. When there is a ramp nearby, the system uses turn signals and other cues to increase the likelihood that the MLP and the path the vehicle actually takes coincide. By monitoring vehicle speed and estimating the upcoming road curvature, the CSW is able to alert a driver when the vehicle is approaching the upcoming curve at an unsafe speed.

The RDCW arbitrates between conflicting and repeated alerts. When both the LDW and CSW determine that an alert is required, the system will issue only the alert that it deems the most safety-critical. This prevents the system from confusing or overloading the driver. Furthermore, RDCW designers took care to ensure that the system would not issue alerts too frequently. The system uses “lockouts” that require a brief no-alert period after an alert. Lockouts also help avoid confusing or frustrating RDCW users. For more details on the RDCW and its subsystems refer to Appendix A.

1.2 FOT METHODOLOGY

For the FOT, UMTRI equipped 11 passenger vehicles with RDCWs, extra sensors, and data acquisition hardware. Assistware Corporation developed the LDW and was a principal participant in developing the RDCW. Visteon Corporation developed the CSW, the driver-vehicle interface, and the overall alert logic for integrating LDW and CSW. Visteon also outfitted the FOT vehicles (2004 Nissan Altimas) with warning system sensors and processors. UMTRI instrumented each FOT vehicle with sensors, such as accelerometers, to measure lateral and longitudinal motion, and with a data acquisition system. UMTRI also recruited the FOT drivers, familiarized them with the vehicles, surveyed them before and after the FOT, debriefed them, and led four participant focus groups.

The FOT and evaluation are usually conducted before deploying a system to provide an independent and objective assessment of a device’s operational capabilities and characteristics (Stevens, 1986; Reynolds, 1996). The test produces data from the operational environment under realistic operating conditions, on a production-representative system (or nearly so), using typical users who have the same characteristics as anticipated users. For the RDCW FOT this means that the system needed to appear to be part of its original equipment. In addition, the FOT participants selected (the drivers) were intended to be representative of a large class of drivers, as opposed to a special subgroup.
Characteristics of a typical FOT and its evaluation include: natural operating environment, a wide range of typical users, realistic operating conditions where drivers use the device as part of their normal driving, and a focus on operational measures

UMTRI conducted the RDCW FOT, instrumenting 11 FOT vehicles: 10 for participants and 1 spare, and collecting road data from May 2004 to February 2005. The FOT driving occurred primarily on Michigan roads. The FOT participant pool included three age groups (younger, middle-aged, and older) with equal numbers of male and female drivers in each group. Table 1-1 lists participants by age and gender.

Table 1-1. FOT Participant Pool

Gender	Younger	Middle-Aged	Older	Total
Female	13	13	13	**39**
Male	13	13	13	**39**
All Groups	26	26	26	**78**

UMTRI researchers familiarized FOT participants with the RDCW and the vehicles before releasing the FOT vehicles. After arriving at UMTRI at a scheduled time, each participant filled out a background and driving-habit questionnaire and a consent form, watched a 20-minute video on RDCW operation and functions, and was then assigned an RDCW test vehicle. The UMTRI researcher demonstrated various vehicles and the RDCW controls and explained that certain road conditions, driving speeds, and GPS coverage would limit RDCW availability. The researcher then demonstrated the RDCW graphic displays and accompanied the participant on a 30-minute drive on a predefined route so the participant could become familiar with the vehicle and RDCW operation.

The FOT provided *baseline* and *treatment* data. Each FOT participant drove an RDCW (equipped) vehicle for 26 days. During the first six days, the baseline period, the RDCW was *disabled:* it performed all the normal sensing and processing functions but did not issue alerts. This baseline period provided data for the independent evaluation to understand drivers' baseline behavior. After the sixth day, the RDCW was automatically *enabled*, which started the treatment period. During the treatment period, the RDCW performed normal sensing and processing functions and issued LDW or CSW alerts when its sensors and processors indicated they were needed.

The FOT provided extensive sub-objective and objective data. Participants filled out surveys both before and after their FOT experience. In addition, participants were interviewed when they returned the FOT, and 25 participants returned to take part in 1 of 4 focus groups. Data acquisition hardware recorded participant face and forward scene video, vehicle motion and lane position, GPS coordinates, extensive internal RDCW channels and alert levels, and brake, steering, and accelerator positions.

The DAS recorded non-video channels every 0.1 second (10 Hz) and continuously buffered 8 seconds of video. An imminent CSW or LDW alert acted as a trigger to save the video on the DAS hard drive. In addition to the FOT, system performance testing also provided objective data.

1.3 INDEPENDENT EVALUATION

1.3.1. Goals

The Volpe Center team, the RDCW independent evaluator, has three goals: *understand RDCW safety benefits, assess driver acceptance of the device,* and *characterize its per-*

formance and capability. These goals determine the numerical and video data collected and how it is processed and analyzed. They also determine the number of participants, the duration of the FOT, the duration of the baseline and treatment periods, the survey questions asked, and how the vehicle was tested.

Safety Benefits

We examined associations between conflicts and the RDCW and between certain unintended consequences and the RDCW. In this study, conflicts involve near or actual road-departures and near or actual control-loss on a curve. We examined both conflict *exposure* and *severity*. The exposure analysis estimated RDCW effectiveness in reducing the conflict frequency, i.e., conflicts per 100 km. We quantified this effectiveness by comparing the difference in conflict rates from the baseline period to the treatment period. The analysis includes overall conflict rates as well as separate analyses by speed, light level, population density, and road type. The conflict-severity analysis examines the peak excursion and the distance to road-edge of departure conflicts and the peak lateral acceleration of control-loss conflicts. A decrease in conflict exposure or conflict severity indicates a positive safety benefit associated with RDCW use.

A collision-avoidance system such as the RDCW could have unintended consequences. For example, drivers could start to drive more aggressively, relying less on their own judgment and more on the device to determine when they should negotiate a curve more slowly. Or drivers may pay less attention to the road, relying on the device to warn them of impending road departure. We analyzed driving performance to determine if the RDCW resulted in any unintended consequences during the treatment period. Performance categories include curve approach and negotiation, lane keeping, signaling during lane changes, and turns.

System Performance

The independent evaluation included a thorough assessment of RDCW performance and capability, providing objective measures of system performance on real roads, as opposed to a test track. The objective measures use an independent set of calibrated equipment that provides lane position, lateral speed, distance to road edge, and vehicle location information. They enabled us to determine how well the system alerts drivers to potential road-departure and potential control loss, in terms of:

- False-positive and true-positive alert rates;
- Variation in alert timing with sensitivity adjustments;
- Consistency of alert timing; and
- LDW and CSW availability and which conditions reduce availability.

In collecting the performance data, we drove one of the spare FOT vehicles for nearly 1,300 km and 18 hours during several visits to the UMTRI facility. In addition to on-road test data, we used objective and subjective FOT data to assess system performance. The objective FOT data provides overall availability information for the LDW and CSW. For example, we analyzed availability under different road and lighting conditions. Participant surveys provided the subjective FOT data. Numerous survey questions relate to system performance; we analyzed participants' responses to these questions in the context of objective performance test measures.

Driver Acceptance

The RDCW is expected to benefit traffic safety by reducing road-departure crashes, but this depends on driver acceptance and use. If drivers accept the RDCW, they will be more inclined to use it and heed its warnings. If they reject it, they are more likely to ignore it or its warnings.

We assessed RDCW acceptance by analyzing drivers' opinions obtained through pre-drive questionnaires, post-drive surveys, post-drive debriefing sessions, focus groups, and trip statistics to determine whether FOT participants liked the RDCW, used it, and expressed a willingness to obtain it.

Driver acceptance has five major themes:

1. Compatibility between drivers' understanding and expectations of the device.
2. Degree to which drivers use its output to improve vehicle handling and driving safety.
3. Comfort and safety from using the RDCW.
4. Interest drivers show in acquiring the RDCW.
5. Perceptions of drivers relating to system setup and adjustments.

1.3.2. Data Processing

The RDCW FOT and its evaluation generated a considerable quantity of data. Figure 1-1 illustrates the principal data categories associated with the FOT DAS and independent evaluation, and also the order-of-magnitude size of these categories. The figure does not include survey data, essential to the independent evaluation, but not part of the computer-based data processing.

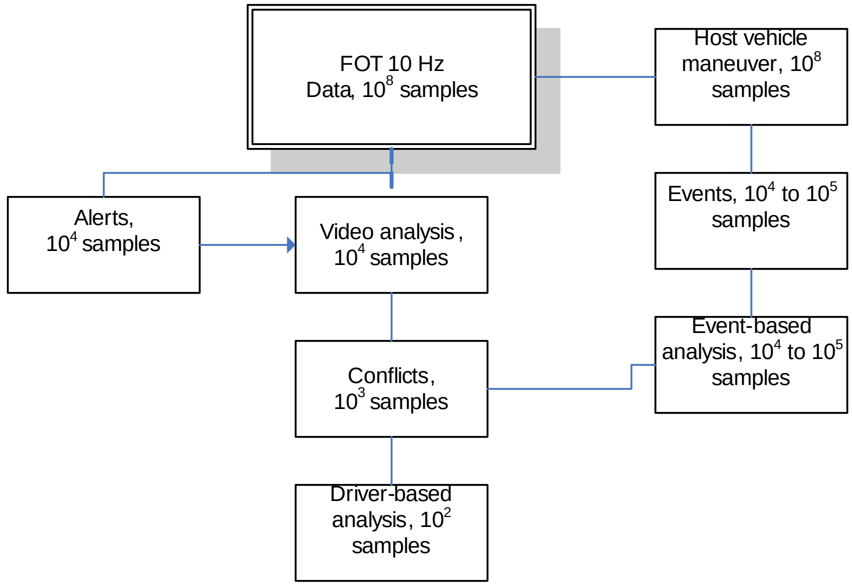


Figure 1-1. Orders of Magnitude Sizes for FOT DAS and Analysis Data

Data categories in Figure 1-1 range in size (order of magnitude) from 10^2 samples for driver-based analyses to 10^8 samples for raw FOT 10 Hz DAS data. In a spreadsheet analogy, the main database has 10^8 rows. The host vehicle maneuver algorithm operates on FOT data row by row and produces the same number of samples contained in the main database. The FOT produced 10^4 alerts (again, order of magnitude), and video analysts analyzed the majority of these alerts. We identified several 10^3 conflicts in the FOT data and created 10^2 rows of participant performance data from these conflicts. We also identified various *events*, e.g., a curve, in the FOT data. Event counts ranged from 10^4 to 10^5, producing the same quantity of event data for subsequent analysis.

Conceptually, we divided data processing into the FOT database and the *subsequent* processing of the FOT data stored on a Volpe Center server. Figure 1-2 illustrates the immediate processing of FOT data. After receiving the raw data (on portable hard drives) from UMTRI (the FOT conductor), we backed it up on tape drives and inserted it into a temporary database. We then checked the data quality. If the data passes the quality check, we input it into the database. The right side of Figure 1-2 illustrates the extraction of JPEG images from the video data, the synchronizing of these images with the analog data (measured data such as speed and lane position), and the uploading of these images into the FOT database.

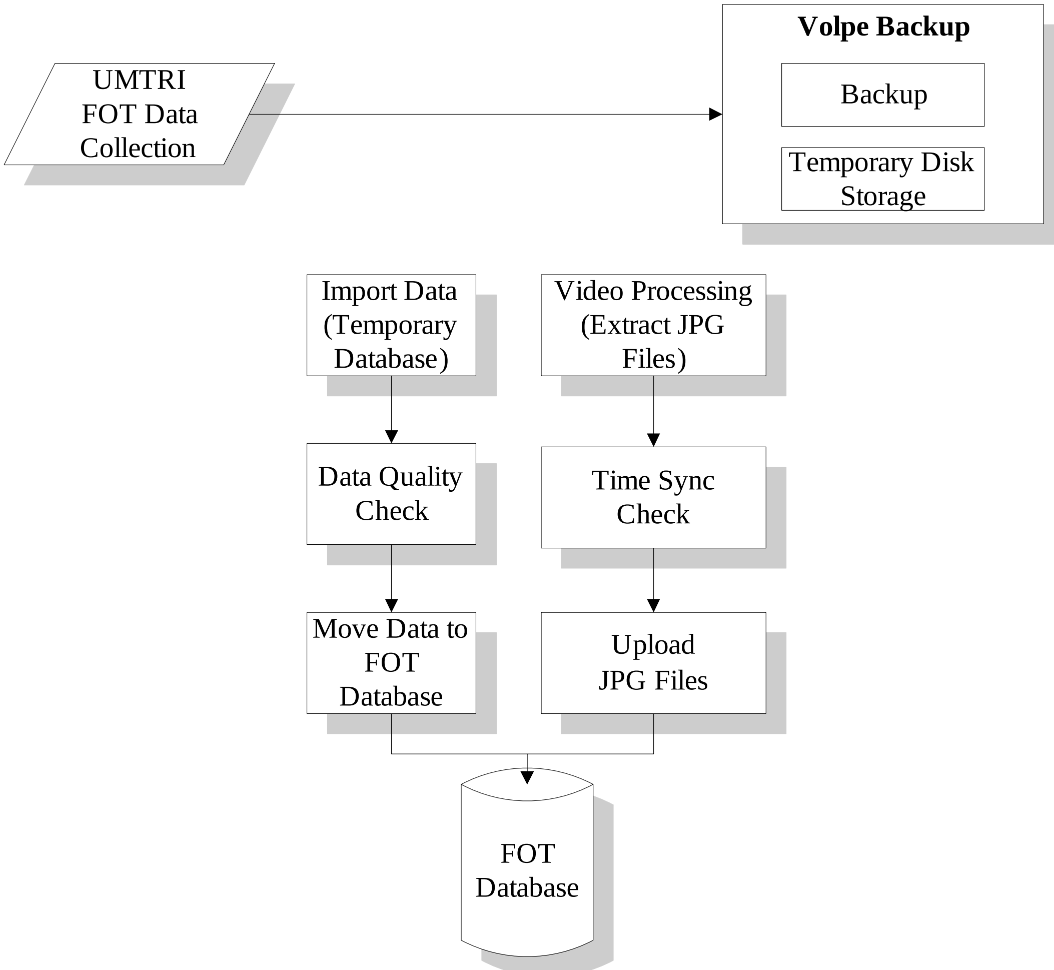


Figure 1-2. Immediate Processing of FOT Data

As shown in Figure 1-3, once the raw FOT data were input into the FOT database, we processed it using Matlab programs, SQL routines, XML file generation, and geographical information system (GIS processing), and create a number of analysis tables. We exported comma-separated-variables (CSV) files from the database and used Matlab to identify curve, in-lane, lane-change and turning events in the FOT data. A set of variables including the participant information, vehicle speed, trip number, and other event-specific data described each event.

The FOT database contained 10^4 to 10^5 instances of each event. We identified control-loss conflicts as within curve events then stored the event and control-loss conflict data in new database tables that are part of the FOT database. On the right side of Figure 1-3, we show the creation of XML files from the FOT database. These files contain both analog and video data; an analyst used a video logger tool to load and play these files. We used analog and video FOT data to identify departure conflicts, which we stored in a new database table. Finally, on the far right in Figure 1-3, we show the processing of GIS data to identify road type and population density associated with the FOT data.

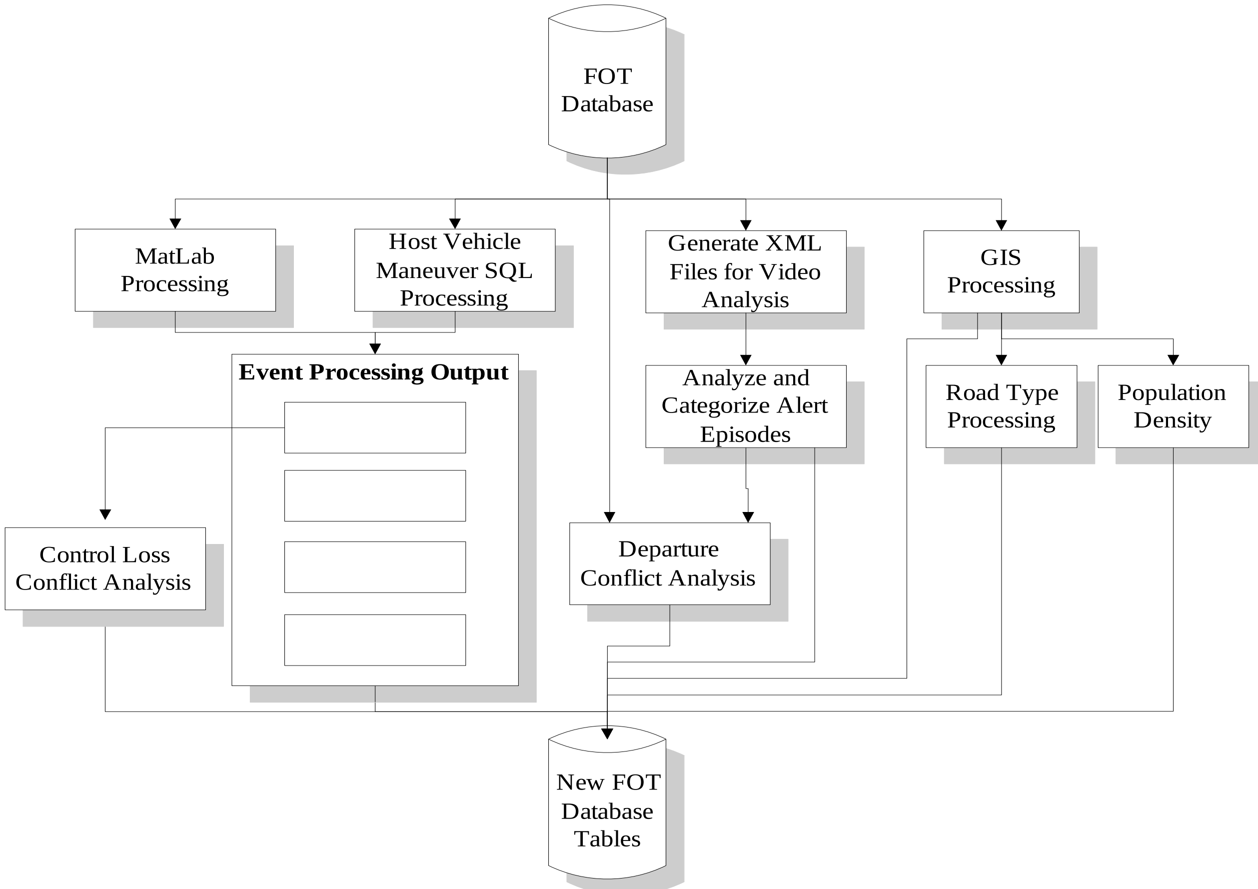


Figure 1-3. Subsequent Processing of FOT Data

1.3.3. Analysis Tools

The *routines* used to analyze FOT data consist of an internal (to the database) SQL program, an external interactive program, and an external non-interactive program. They generate intermediate tables in the database, indirectly and directly populating the "New FOT Database Tables" icon shown in Figure 1-3.

The host-vehicle maneuver algorithm (Ayres and Wilson, 2003) parses FOT data and determines if drivers are going straight, negotiating curves, turning, or changing lanes. The HVM is also used to isolate events in the FOT data. A GPS/GIS location program locates FOT vehicles within a database of roads and assigns road and population attributes to each FOT data sample. A video logger tool integrates numerical data with video clips from alert-triggered episodes captured during the FOT. As shown in Figure 1-4, the tool synchronizes two sets of video (forward scene and participant face) and 10 Hz FOT data and includes a DVI window and a path window. The latter plots both the MLP (the one the RDCW anticipated the vehicle taking) and the actual path, derived from FOT data.[1]

[1] The Volpe Center acknowledges UMTRI's development and sharing of an algorithm and Visual Basic code for this routine.

The tool also includes a logger window (an Access database) that allows video analysts to comprehensively and systematically describe alert episodes.

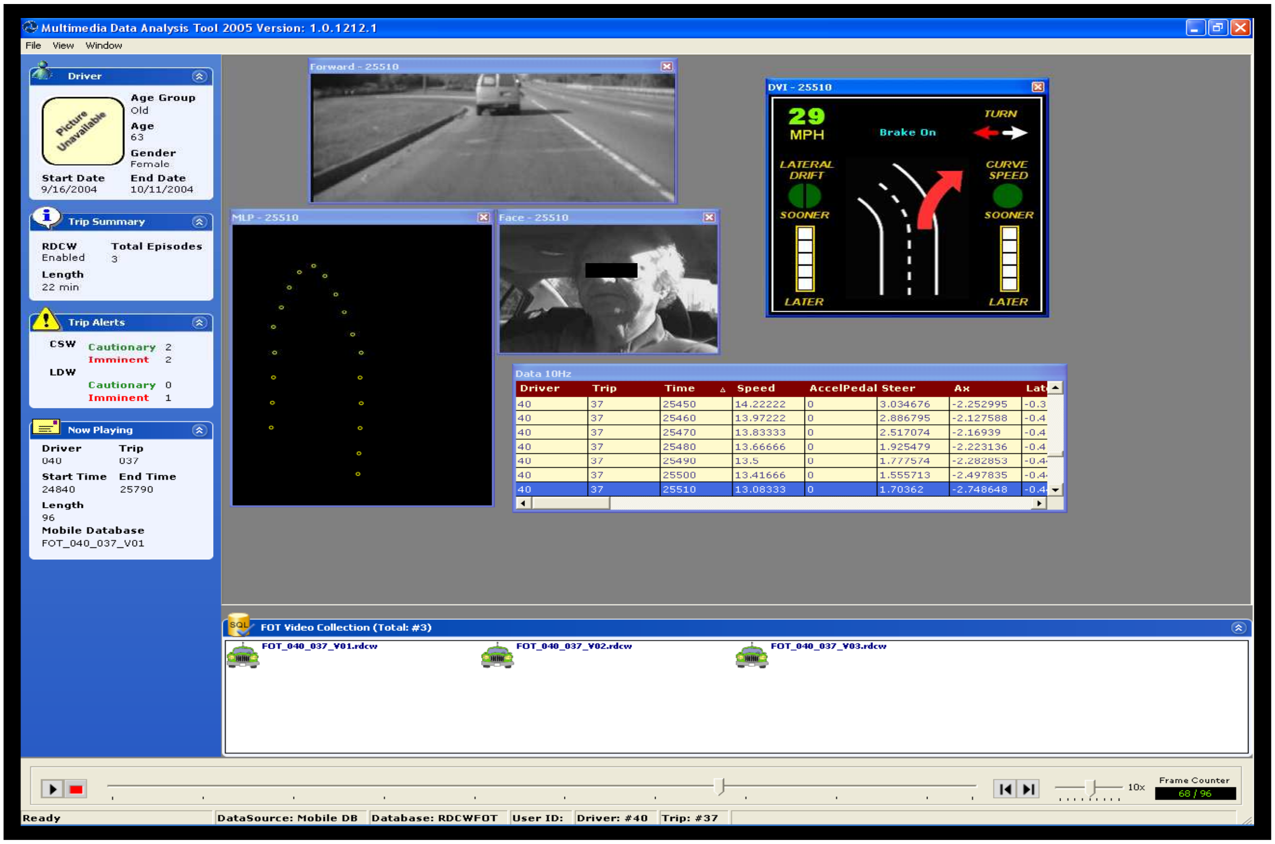


Figure 1-4. Video Logger Screenshot

The National Institute of Standards and Technology (Szabo and Norcross, 2006) has also developed a tool for analyzing performance-test data. The tool integrates calibrated video cameras, alert data, GPS data, lane position data, and vehicle motion data. Figure 1-5 illustrates the NIST tool user interface. The principal use of the NIST is to measure the LDW validity, timing, and AMR.

Using these LDW analysis tools with FOT data processing allows us to generate numerous analysis tables through querying the FOT database.

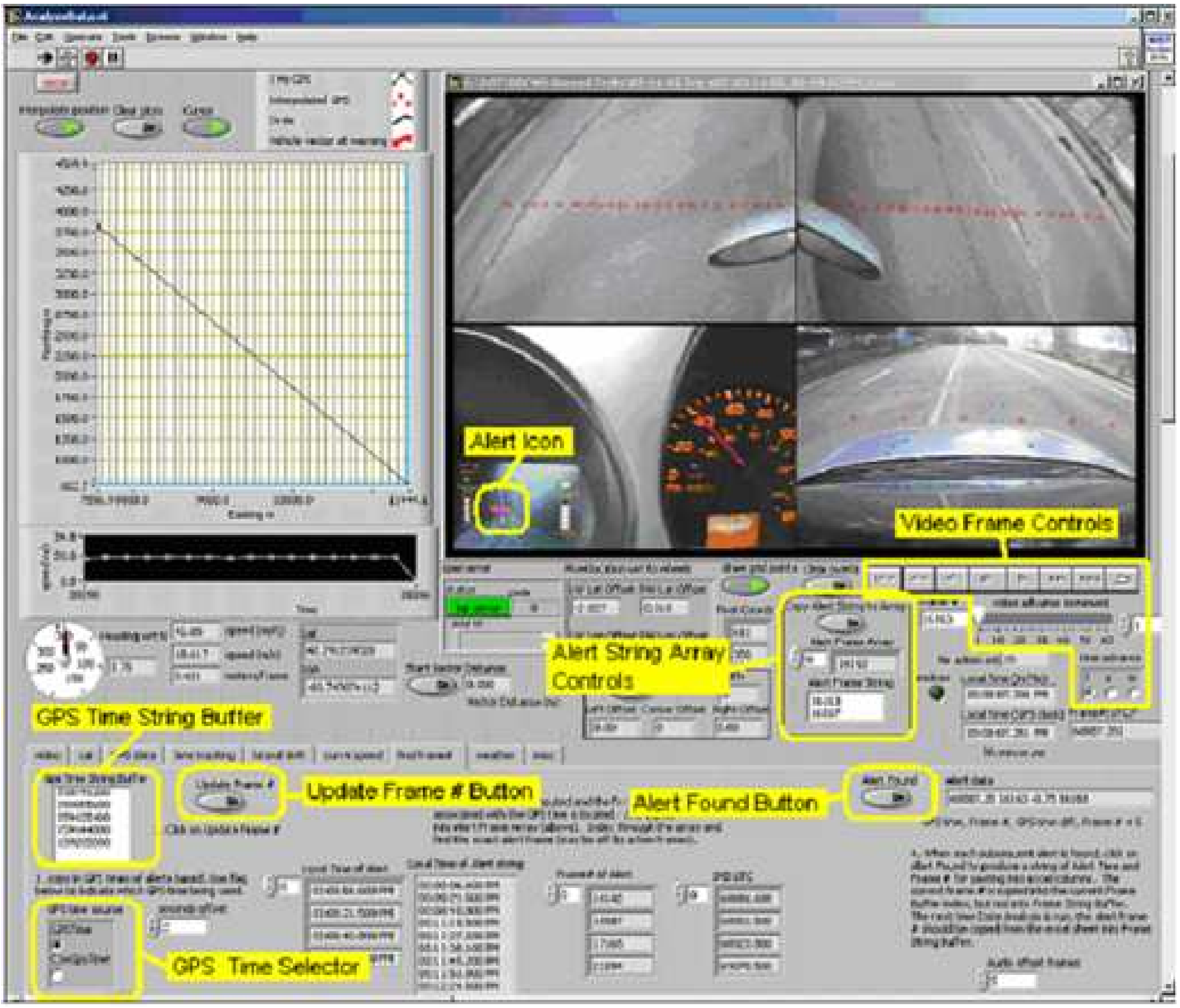


Figure 1-5. LDW Analysis Tool Interface

1.4 REPORT OVERVIEW

This document consists of 6 chapters and 10 appendices.

Chapter 2: RDCW Exposure describes the exposure of FOT drivers—how much and where they drove.

Chapter 3: System Capability evaluates RDCW performance given the influence of RDCW on both drivers' perceptions of the device and the safety benefits associated with the device.

Chapter 4: Safety Benefits presents the results of safety analyses we performed using baseline and treatment period data from the FOT participants, and the safety benefit associated with using the RDCW.

Chapter 5: Driver Acceptance is a comprehensive analysis of the degree to which FOT participants approved of the RDCW.

Chapter 6: Conclusions summarizes findings related to system performance, safety benefits, and driver acceptance.

The report also includes the following appendices:

A) Road-Departure Crash Warning System details
B) Overview of On-Road System Characterization Testing
C) RDCW Data Analysis Tool and Logger Instruction Manual
D) Driver Acceptance Goals and Objectives
E) Driver Acceptance Methodology
F) Questions Used in Focus Group Discussion
G) Driving Statistics of the FOT Participants
H) Summary of RDCW Alerts Issued to the FOT Participants
I) Description of Simulator Experiment
J) Driver Acceptance Survey Results

Note: Most of this document uses SI units such as meter (m) for short distances, meters per second (m/s) for speed, and meters per second per second (m/s^2) for acceleration. Kilometer (km) is used for longer distances and “per 100 km” to normalize by distance. One exception is the speed ranges in Chapter 4, where miles per hour (mph) is used.

2. RDCW EXPOSURE

The RDCW FOT goals included analyzing safety benefits, driver acceptance, performance, and capability. The amount that FOT participants used the RDCW, i.e., their *exposure* to the device, under different conditions influences the analyses associated with these goals. In general, we examined if FOT participants had sufficient exposure under a variety of conditions, so that:

- Sufficient data was available to analyze driving under a variety of conditions;
- Survey answers and comments were informed by driving under various conditions; and
- The device's performance could be broadly assessed.

This chapter discusses FOT participant exposure by conditions such as vehicle speed, light level, population density, road type, and weather.

HIGHLIGHTS

- Seventy-eight FOT participants were divided into six groups, balanced by gender and age.
- Participants drove over 130,000 km and 1,500 hours.
- Participants had more alerts early in the treatment period, suggesting experimentation with the RDCW.
- During the baseline and treatment periods, younger participants averaged 660 km, middle-aged participants 580 km, and older participants 440 km.
- Males drove more than females during the treatment period.

2.1 INTRODUCTION

The 25-day FOT had two periods: a 6-day *Baseline* period and a 19-day *Treatment* period. During the baseline period the RDCW sensed its surroundings but did not issue alerts to the participants. The device, however, did issue internal alerts in response to sensors and processing algorithms, and the DAS recorded these. Data generated during this period represents normal (or baseline) driving behavior. During the treatment period the RDCW issued audible, visual, and haptic alerts, including lateral-drift and curve-speed warnings. Properly analyzed, data collected during this period provides an understanding of participant behavior in response to warnings.

Baseline- and treatment-period data were further subdivided using each participant's travel distance, or vehicle distance traveled (VDT). Figure 2-1 illustrates the FOT data division. Each "trip" (ignition cycle) in the FOT has an associated VDT. In partitioning the FOT data for the baseline period, the VDT for all the trips in that period are summed. The first trip where associated cumulative VDT exceeds half of the VDT for the baseline period is the first trip of Period 2. For example, if we had trips of 10, 20, 30, and 5 km, the sum is 65 km and the respective cumulative sums after the 20 and 30 km trips are 30 and 60 km. The 30 km trip is therefore the first trip of the second period. Earlier trips are labeled as Period 1. The same procedure divides data into Periods 3 and 4 for the treatment period.

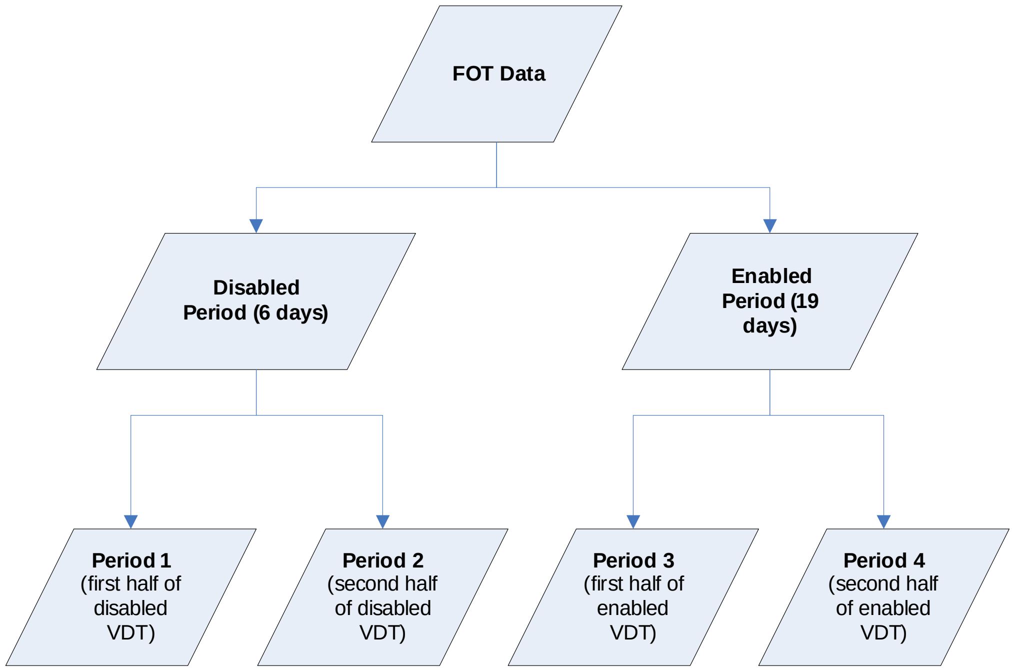


Figure 2-1. FOT Data Partition

2.2 OVERALL EXPOSURE OF PARTICIPANTS

There were 78 participants in the original RDCW participant pool, equally divided by male and female gender and age ranges: 20 to 30 years old ("younger"), 40 to 50 ("middle-aged"), and 60 to 70 ("older"). As shown in Table 2-1, FOT participants drove a total of 130,630 km, with 72 percent of the driving occurring during the treatment period. The percentage is approximately equal to the time percentage of the treatment period, 76 percent, of the overall FOT.

Table 2-1. Summary FOT Driving Statistics by Period (km)

Period	Mean	Median	Sum	Min	Max	Percentile 10	Percentile 90
1	225.3	186.8	17,124	2.0	625.3	92.3	387.3
2	263.9	244.6	20,060	40.5	846.3	112.8	435.6
3	596.3	539.7	45,316	139.3	1,081.8	210.4	980.9
4	633.3	608.2	48,130	143.2	1,129.2	236.2	999.8
Total			**130,630**				

For the analyses in this chapter and the safety benefits analyses in Chapter 4, two participants from the original pool of 78 were removed. Participant 56, an older female, had only taken a single trip with 10.4 km of recorded driving exposure in the entire 6-day baseline period. As the independent evaluation relies on sufficient exposure in both the baseline and treatment periods to perform meaningful comparisons, 10 km of exposure was inadequate. The alert data for Participant 34, a younger female, suggested she was intentionally causing LDW and CSW alerts during both the third and fourth periods. Table I-1 illustrates the increase in her alert rates from the baseline to the treatment period and a further increase from Period 3 to 4. The CSW alert rate follows a similar pattern.

Removing Participants 34 and 56 resulted in a final FOT participant pool with 76 participants: 37 females and 39 males, summarized in Table 2-2.

Table 2-2. Final FOT Participant Pool

Gender	Younger	Middle-aged	Older	Total
Female	12	13	12	37
Male	13	13	13	39
All Groups	**25**	**26**	**25**	**76**

Prior to analyzing the exposure data for the FOT participants, it was necessary to determine:

- If data from both Periods 1 and 2 or Period 2 only should be used to analyze participant behavior from the baseline period.
- If data from both Periods 3 and 4 or Period 4 only should be used to analyze participant behavior from the treatment period.

For the baseline period, the issue was participant lack of familiarity with the vehicles during Period 1. If driving data showed significant changes from Period 1 to Period 2, the assumption would be participants were becoming familiar with the vehicles in Period 1. Data from this period, therefore, would not represent how participants would actually drive the vehicles during an extended baseline period, once they were familiar with the vehicles.

For the treatment period, the issue was participants experimenting with the vehicles during Period 3. If driving data showed significant changes from Period 3 to Period 4, the assumption would be participants were experimenting with the vehicles in Period 3. Data from this period, therefore, would not represent how participants would actually drive the vehicles during an extended treatment period, once they were familiar with the RDCW.

2.2.1. Baseline Period

Two measures assessed the influence of participant familiarity with FOT data during the baseline period: LDW alert rate and CSW alert rate. The rates were analyzed separately, using a repeated-measures analysis of variance, to determine if there was a statistically significant difference in alert rates between Periods 1 and 2. The repeated-measures ANOVA was used because each driver provides the same measure twice, once in Period 1 and once in Period 2. The resulting analyses, presented in Tables I-1 and I-2 in Appendix I, show that for both the LDW and CSW there is no statistically significant association between the alert rate and period. These measures thus show no evidence of participants becoming adapted to the vehicle during the baseline period.

The analyses in this section determined *there was no statistically significant difference in alert rates between Periods 1 and 2*. This allows the FOT data from Periods 1 and 2 to be combined into a single category of baseline data.

2.2.2. Treatment Period

The same measures used for the baseline period, LDW and CSW alert rates, were used to assess participant experimentation during the treatment period. Table 2-3 presents the ANOVA results for the LDW alert rates during the two halves of the treatment period. The data shows a statistically significant association between the period and the alert rate.

Table 2-3. ANOVA Results for LDW Alert Rates During Treatment Period

	SS	DOF	MS	F	p
Intercept	2048.7	1	2048.7	153.7	<0.001
Gender	23.9	1	23.9	1.8	0.185
Age Group	7.1	2	3.6	0.3	0.766
Gender*Age Group	54.9	2	27.5	2.1	0.135
Error	933.0	70	13.3		
Period	15.4	1	15.4	4.4	0.041
Period*Gender	0.0	1	0.0	0.0	0.939
Period*Age Group	1.0	2	0.5	0.1	0.863
Period*Gender*Age Group	13.9	2	7.0	2.0	0.148
Error	247.5	70	3.5		

Figure 2-2 plots the LDW alert rates. There is a statistically significant difference in the mean LDW alert rate between Periods 3 and 4, and the alert rates decreased from Period 3 to 4. This measure shows evidence of participants experimenting with the LDW subsystem during the treatment period. It is likely, therefore, that data from this period does not represent how participants used the device once they became familiar with it. Consequently, *data from Period 3, the first half of the treatment period, will not be used for subsequent exposure and safety benefits analyses.*

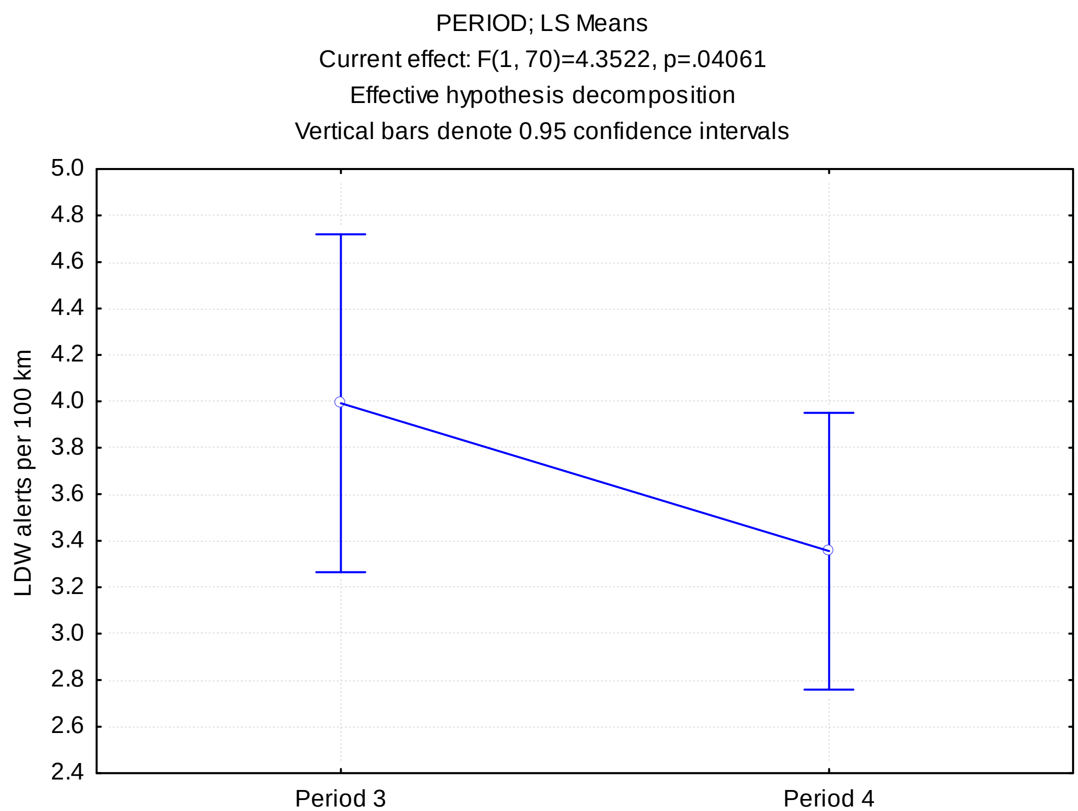


Figure 2-2. LDW Alert Rates During Periods 3 and 4

Table 2-4 presents the ANOVA results for the CSW alert rates during the two halves of the treatment period. The analysis shows a statistically significant association between age group and the alert rate but no association between period and the alert rate. The actual means for the different age groups reflect data from both Periods 3 and 4. Since data from Period 3 will not be used in subsequent analyses, the means associated with this period are not presented.

Table 2-4. ANOVA Results for CSW Alert Rates During Treatment Period

	SS	DOF	MS	F	p
Intercept	188.5	1	188.5	181.5	<0.001
Gender	0.6	1	0.6	0.6	0.438
Age Group	6.7	2	3.4	3.2	0.045
Gender*Age Group	1.9	2	1.0	0.9	0.402
Error	72.7	70	1.0		
Period	0.5	1	0.5	1.1	0.294
Period*Gender	0.1	1	0.1	0.3	0.579
Period*Age Group	0.0	2	0.0	0.0	0.984

	SS	DOF	MS	F	p
Period*Gender*Age Group	0.0	2	0.0	0.1	0.947
Error	29.4	70	0.4		

2.2.3. Final Exposure

Having determined which periods to include in the safety benefits analyses, we next analyzed the exposure associated with these periods. Table 2-5 presents the ANOVA results for VDT during baseline and treatment periods, with gender and age group as the additional independent variables.

Table 2-5. ANOVA Results for VDT

	SS	DOF	MS	F	p
Intercept	4.8E+07	1	4.8E+07	489.7	<0.001
Gender	2.5E+05	1	2.5E+05	2.6	0.113
Age Group	1.3E+06	2	6.3E+05	6.5	0.003
Gender*Age Group	7.7E+03	2	3.8E+03	0.0	0.961
Error	6.8E+06	70	9.7E+04		
Period	7.5E+05	1	7.5E+05	28.5	<0.001
Period*Gender	1.8E+05	1	1.8E+05	6.8	0.011
Period*Age Group	4.5E+05	2	2.2E+05	8.6	<0.001
Period*Gender*Age Group	1.8E+04	2	9.1E+03	0.3	0.708
Error	1.8E+06	70	2.6E+04		

Analysis of the exposure data provides the following statistically significant findings:

- *Mean VDT varies with age:* younger participants averaged 659 km, middle-aged participants averaged 583 km, and older participants averaged 438 km. A post-hoc analysis of the data showed a statistically significant difference between the VDT of older participants and the other two groups, but no difference (statistically significant) between the VDT of younger and middle-aged participants.
- *Mean VDT varies with period:* with a mean of 490 km during the baseline period and 630 km during the treatment period.
- *Gender and period interact:* males and females had approximately the same VDT during the baseline period (496 versus 483 km), but males had a larger increase during the treatment period (209 versus 72 additional km).
- *Age and period interact:* younger participants had the same VDT during the baseline and treatment periods, but middle-aged and older participants drove more during the treatment period. This last finding is presented in

Figure 2-3, which plots the mean exposure of the FOT participants by period and age.

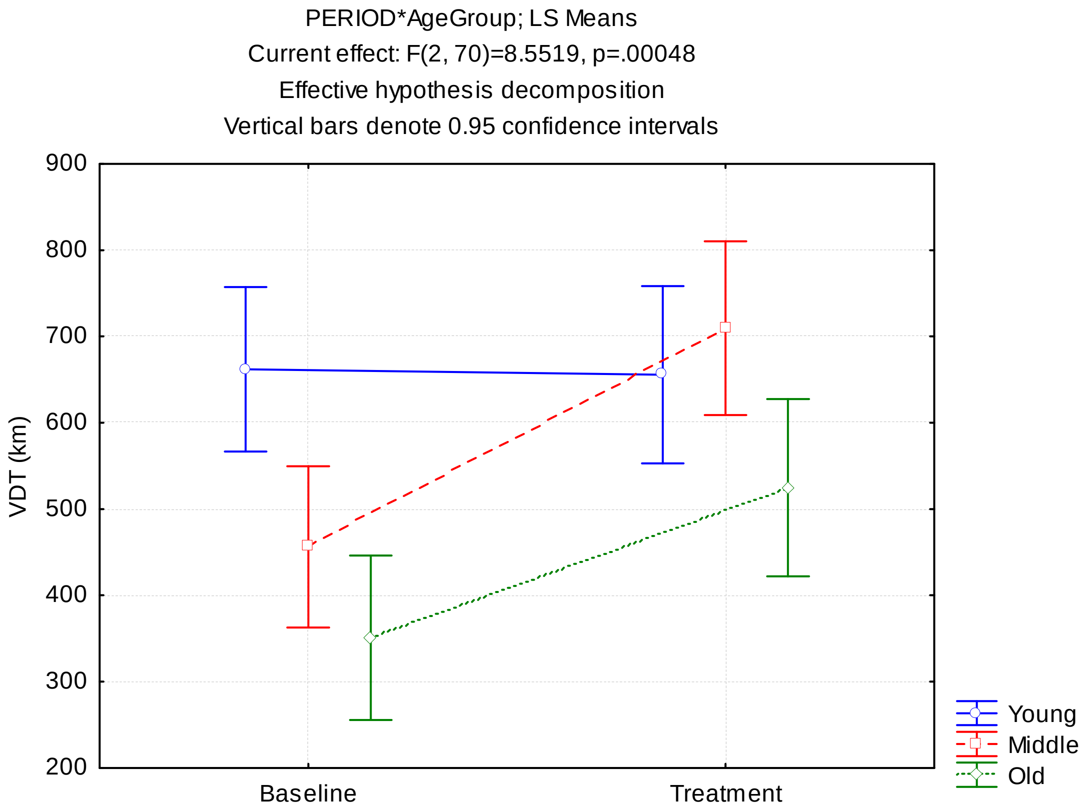


Figure 2-3. Final Exposure by Age and Period

Table 2-6 presents the VDT data by age and gender during the baseline and treatment periods. The mean VDT (km) had the following ranges:

- Baseline period—339 for older females to 671 for younger females; and
- Treatment period—436 for older females to 764 for middle-aged males.

Table 2-6. Exposure Age, Gender, and Period (units in km)

Gender	Age	Period	Mean VDT	Std. Error	-95%	95%	N
Female	Younger	Baseline	671	69	533	808	12
Female	Younger	Treatment	574	74	426	723	
Female	Middle-aged	Baseline	441	66	309	573	13
Female	Middle-aged	Treatment	655	71	513	798	

Gender	Age	Period	Mean VDT	Std. Error	-95%	95%	N
Female	Older	Baseline	339	69	201	476	12
Female	Older	Treatment	436	74	287	584	
Male	Younger	Baseline	653	66	521	785	13
Male	Younger	Treatment	737	71	595	879	
Male	Middle-aged	Baseline	472	66	339	604	13
Male	Middle-aged	Treatment	764	71	621	906	
Male	Older	Baseline	363	66	231	495	13
Male	Older	Treatment	614	71	471	756	

2.3 EXPOSURE BY VEHICLE SPEED

To analyze exposure by vehicle speed, FOT data was separated into six speed bins:

0–18 mph (0–28.99 kph)
18–25 mph (28.99–40.23 kph)
25–35 mph (40.23–56.33 kph)
35–45 mph (56.33–72.42 kph)
45–55 mph (72.42–88.51 kph)
>55 mph (>88.51 kph)

Baseline and treatment periods were analyzed separately because VDT differences between these periods are expected and are not particularly important. Since exposure in each speed bin is important, it was necessary to determine if any group was underrepresented. If this was the case, we would need to ensure that low VDT in a given speed range did not result in artificially high alert or conflict rates when analyzing this group.

The analysis focused on the four speed bins above 25 mph. The first two speed bins were used only to facilitate device performance analyses. Since these speed ranges include VDT from parking lots and driveways, they were not combined with road data at higher speeds.

2.3.1. Baseline Period

Table 2-7 presents the repeated-measures ANOVA results for participants' baseline VDT over four speed bins. The rightmost column in the table indicates that there are statistically significant associations between the outcome measure and (1) the age group and (2) the speed bin. In addition, the data shows an interaction between speed bin and age group.

Table 2-7. ANOVA Results for Baseline Period VDT by Speed Bin

	SS	DOF	MS	F	p
Intercept	3.8E+06	1	3.8E+06	286.0	<0.001
Gender	6.7E+02	1	6.7E+02	0.0	8.2E-01
Age Group	2.9E+05	2	1.4E+05	10.8	<0.001
Gender*Age Group	2.3E+03	2	1.1E+03	0.1	9.2E-01
Error	9.4E+05	70	1.3E+04		
Bin	1.5E+06	3	5.1E+05	49.4	<0.001
Bin*Gender	1.1E+04	3	3.8E+03	0.4	7.8E-01
Bin*Age Group	4.9E+05	6	8.2E+04	7.9	<0.001
Bin*Gender*Age Group	1.9E+04	6	3.2E+03	0.3	9.3E-01
Error	2.2E+06	210	1.0E+04		

A summary of the statistically significant associations follows:

- *Mean VDT per bin during the baseline period varies with age*: younger participants had the highest VDT, followed by middle-aged and older participants (153, 105, and 78 km). Statistically, the younger participants had more VDT than a combined middle-aged and older group.
- *Mean VDT varies by speed bin*: the 55+ speed bin had the highest VDT. The actual respective mean values over the four bins are 52, 87, 76, and 234 km. A post-hoc analysis shows that each of these mean values is statistically distinct.
- *Speed bin and age interact*: younger participants had significantly[2] more VDT at the highest speed range than middle-aged and older participants. A separate analysis of participants' VDT for the three lower-speed bins showed only a single statistically significant association: speed bin and VDT (i.e., no association with age group). An analysis of participants VDT at the highest speed bin showed younger participants had significantly more VDT than the other two groups.

Figure 2-4 illustrates the interaction between speed bin and age group. The three age groups tracked each other fairly closely over the first three speed bins. Mean VDT ranged from 50 to 100 km. In the fourth bin, younger participants traveled approximately 75 percent farther than middle-aged participants, who traveled approximately 60 percent farther than older participants. All age groups showed a mean VDT increase at high speeds, but younger participants had significantly more than the other age groups.

[2] Here and throughout, *significantly* implies statistical significance.

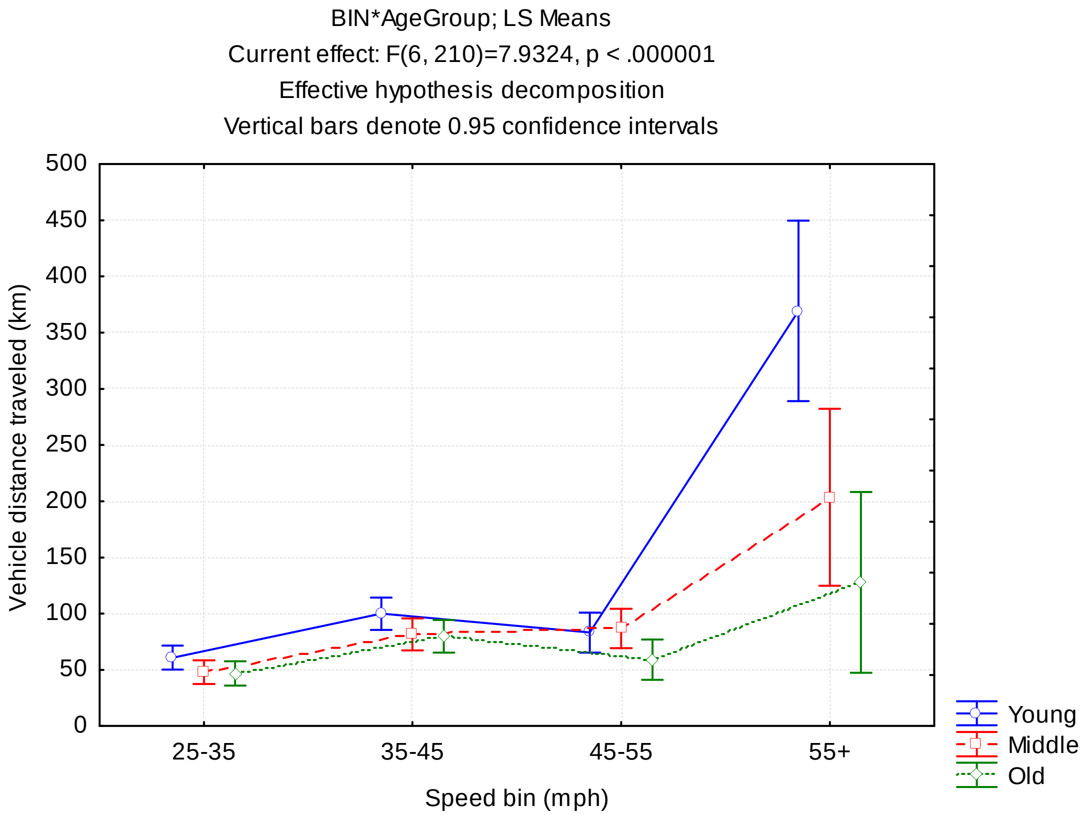


Figure 2-4. Baseline Period Exposure by Age and Speed Bin

2.3.2. Treatment Period

Table 2-8 presents the repeated-measures ANOVA results for participants' VDT over four speed bins during the treatment period. The rightmost column in the table indicates that there are statistically significant associations between (1) the gender, (2) the age group, and (3) the speed bin and the VDT. In addition, the data shows an interaction between speed bin and age group.

Table 2-8. ANOVA Results for Treatment Period VDT by Speed Bin

	SS	DOF	MS	F	p
Intercept	6.4E+06	1	6.4E+06	416.1	<0.001
Gender	9.8E+04	1	9.8E+04	6.4	1.4E-02
Age Group	1.1E+05	2	5.7E+04	3.7	3.0E-02
Gender*Age Group	4.6E+03	2	2.3E+03	0.1	8.6E-01
Error	1.1E+06	70	1.5E+04		
Bin	2.7E+06	3	8.9E+05	85.1	<0.001
Bin*Gender	3.3E+04	3	1.1E+04	1.1	3.7E-01

	SS	DOF	MS	F	p
Bin*Age Group	1.5E+05	6	2.5E+04	2.4	2.7E-02
Bin*Gender*Age Group	4.2E+04	6	7.1E+03	0.7	6.7E-01
Error	2.2E+06	210	1.0E+04		

A summary of the statistically significant associations follows:

- *Mean VDT per bin during the treatment period varies with gender*: males averaged more VDT than females (163 versus 127 km).
- *Mean VDT per bin during the treatment period varies with age*: younger and middle-aged participants had significantly more VDT than older participants (151, 165, and 119 km). A post-hoc contrast analysis confirmed that the mean VDT for younger and middle-aged participants was statistically equal.
- *Mean VDT varies by speed bin*: the 55+ speed bin had significantly more VDT. The actual respective mean values, which are statistically distinct, are 62, 112, 103, 304 km.
- *Speed bin and age group interact:* younger and middle-aged participants had significantly more VDT than older participants at the highest speed range.

The speed bin and age data is important for subsequent analyses. Figure 2-5 plots treatment-period VDT versus speed bin for each age group. Similar to findings from the baseline period in Figure 2-4, the three age groups tracked each other fairly closely over the first three speed bins. Mean VDT in these bins ranged from approximately 60 to 130 km. In the fourth bin, VDT increased markedly. Younger and middle-aged participants had approximately 50 percent more VDT than older participants, a smaller increase compared to the baseline period.

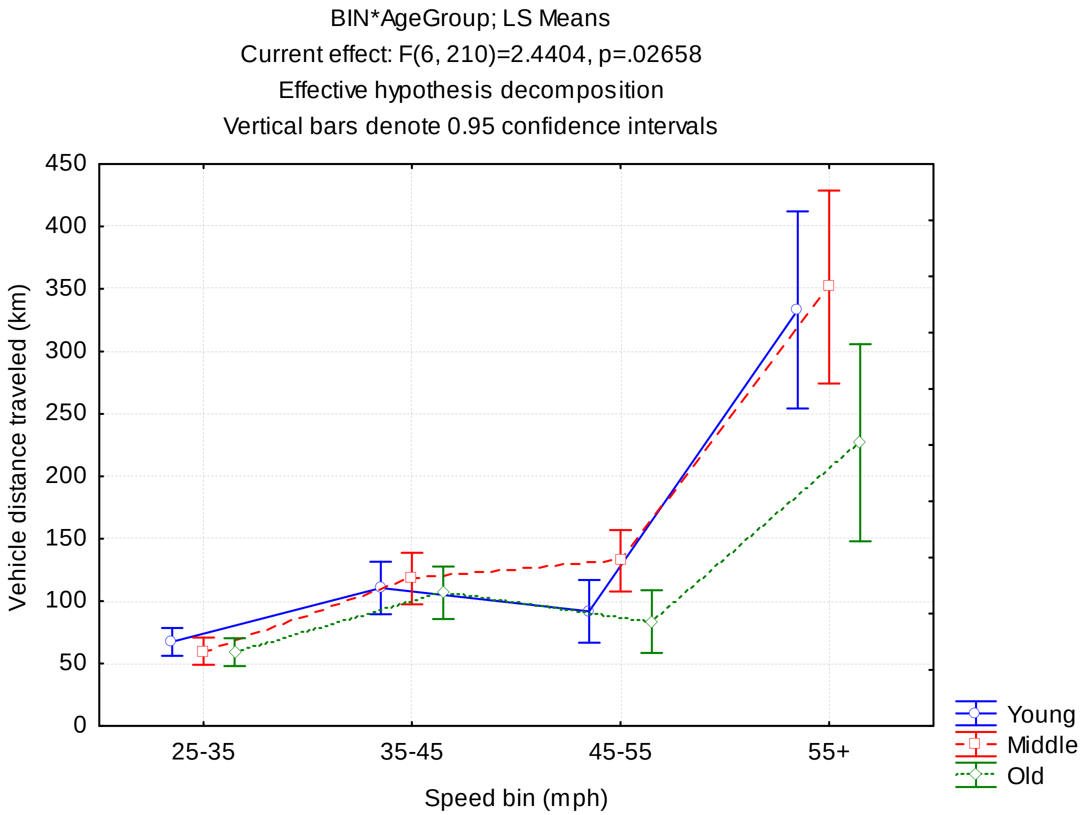


Figure 2-5. Treatment Period Exposure by Age and Speed Bin

These treatment-period findings differ from baseline-period findings. Table 2-9 summarizes these differences.

Table 2-9. Summary of Differences in VDT - Explanatory Variables for Speed-Bin Analysis During Baseline and Treatment Periods

Explanatory Variable(s)	Baseline Period	Treatment Period
Gender	No difference	Males have more VDT than females
Age	Younger participants have highest VDT	Older participants have lowest VDT
Speed Bin and Age	Younger participants have highest VDT at highest speed	Younger and middle-aged participants have highest VDT at highest speed

2.4 EXPOSURE BY LIGHT LEVEL

Because the light level influences RDCW performance and safety benefits, exposure by light level was analyzed. Once again, baseline and treatment periods are analyzed separately. Provided that each combination of period and light level has sufficient VDT, VDT differences between these periods are irrelevant to safety benefits.

2.4.1. Baseline Period

Table 2-10 presents the ANOVA results for baseline period VDT by light level. The rightmost column in the table indicates that there are statistically significant associations between (1) the age group and (2) the light level and the VDT.

Table 2-10. ANOVA Results for Baseline Period VDT by Light Level

	SS	DOF	MS	F	p
Intercept	9.1E+06	1	9.1E+06	318.9	<0.001
Gender	1.5E+03	1	1.5E+03	0.1	8.2E-01
Age Group	6.2E+05	2	3.1E+05	11.0	<0.001
Gender*Age Group	4.3E+03	2	2.2E+03	0.1	9.3E-01
Error	2.0E+06	70	2.9E+04		
Light	2.8E+06	1	2.8E+06	146.3	<0.001
Light*Gender	1.0E+04	1	1.0E+04	0.5	4.7E-01
Light*Age Group	3.2E+04	2	1.6E+04	0.8	4.4E-01
Light*Gender*Age Group	4.4E+04	2	2.2E+04	1.2	3.2E-01
Error	1.3E+06	70	1.9E+04		

The specific differences behind these associations are:

- Participants averaged 109 km at night and 380 km during the day.
- Younger, middle-aged, and older participants averaged 331, 228, and 175 km, respectively, over night and day driving. A post-hoc analysis using contrasts showed only the difference between younger and the combined middle-aged and older participants to be statistically significant.

2.4.2. Treatment Period

Table 2-11 presents the ANOVA results for treatment period VDT by light level. The rightmost column in the table indicates that there are statistically significant associations between (1) the age group and (2) the light level and the VDT.

Table 2-11. ANOVA Results for Treatment Period VDT by Light Level

	SS	DOF	MS	F	p
Intercept	1.5E+07	1	1.5E+07	454.4	<0.001

	SS	DOF	MS	F	p
Gender	2.1E+05	1	2.1E+05	6.4	0.014
Age Group	2.3E+05	2	1.1E+05	3.5	0.037
Gender*Age Group	8.6E+03	2	4.3E+03	0.1	0.878
Error	2.3E+06	70	3.3E+04		
Light	5.1E+06	1	5.1E+06	148.4	<0.001
Light*Gender	1.8E+04	1	1.8E+04	0.5	0.477
Light*Age Group	2.6E+05	2	1.3E+05	3.7	0.029
Light*Gender*Age Group	7.9E+04	2	4.0E+04	1.1	0.326
Error	2.4E+06	70	3.5E+04		

The specific statistically significant differences behind these associations are:

- Males drove more than females: 352 km versus 278 km averaged between night and day driving.
- Younger and middle-aged participants drove more than older participants, 328, 355, and 262 km, respectively, averaged between night and day driving. Of the three age groups, only the middle-aged and older participants had significantly different VDT.
- Mean daytime VDT exceeds nighttime VDT: 499 versus 131 km.
- Day and nighttime VDT interacts with age: younger participants tended to do more night driving and exhibited a smaller increase from day to night driving than middle-aged and older participants.

This last finding in particular highlights a difference in driving patterns among this study's participants. Figure 2-6 presents VDT by light level and age group. Roughly, the younger participants averaged 200 km at night and 250 km more than this value during the day. Older participants averaged 65 km at night and 385 km more than this during the day. Middle-aged participants averaged 125 km at night (between the other age groups) and 450 km more than this during the day. The differential increase in VDT from night to day driving by age group accounts for the interaction. Some low exposures to night driving for older participants suggest caution when interpreting alert- and conflict-rate data from these participants.

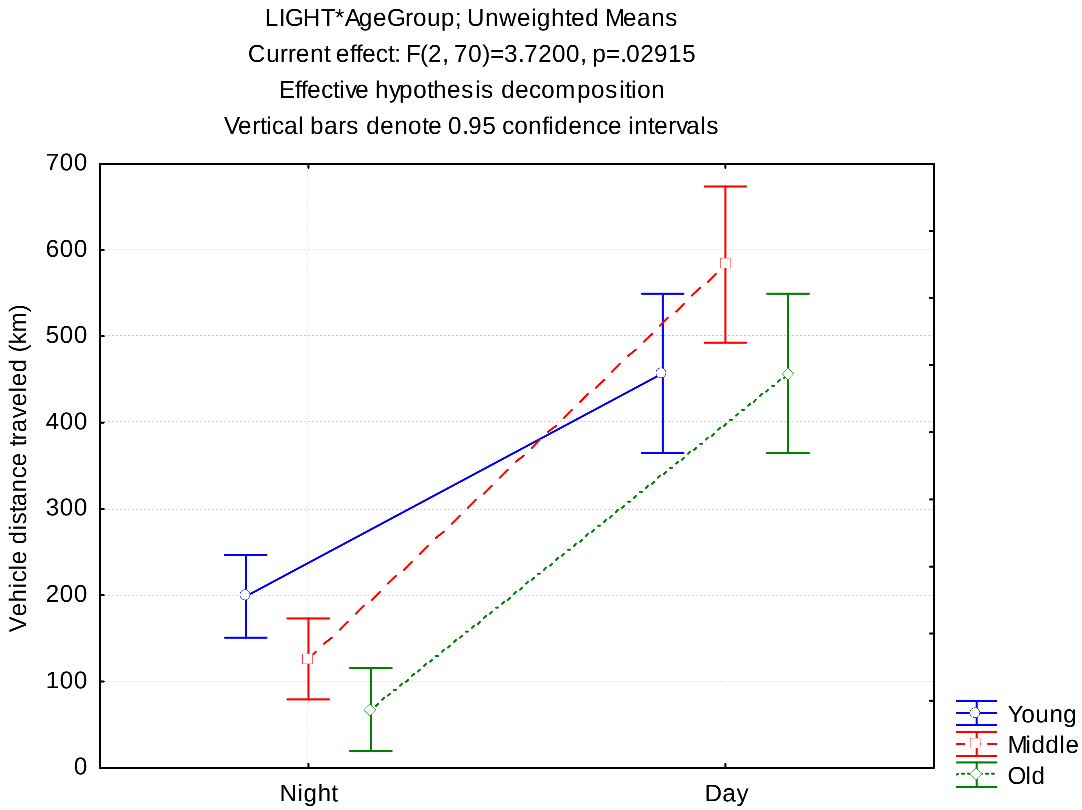


Figure 2-6. Treatment Period Interaction Between Age and Light Level

2.5 EXPOSURE BY POPULATION DENSITY

General Estimates System crash statistics show that a significant number of road-departure crashes occur in rural areas. Since population density may influence safety benefits, exposure using this variable was analyzed.

Figure 2-7 illustrates the urban-rural classification for southeastern Michigan, where most FOT driving occurred. A GPS/GIS location algorithm assigned road attributes to the GPS points associated with FOT data. One of the attributes defines whether or not a RDCW vehicle—at each decisecond sample—was located in an urban area. To populate this attribute, the location algorithm intersects the U.S. Census Bureau's boundary file with the GPS points layer to determine which GPS points fall within an urban area. We analyzed baseline and treatment periods separately.

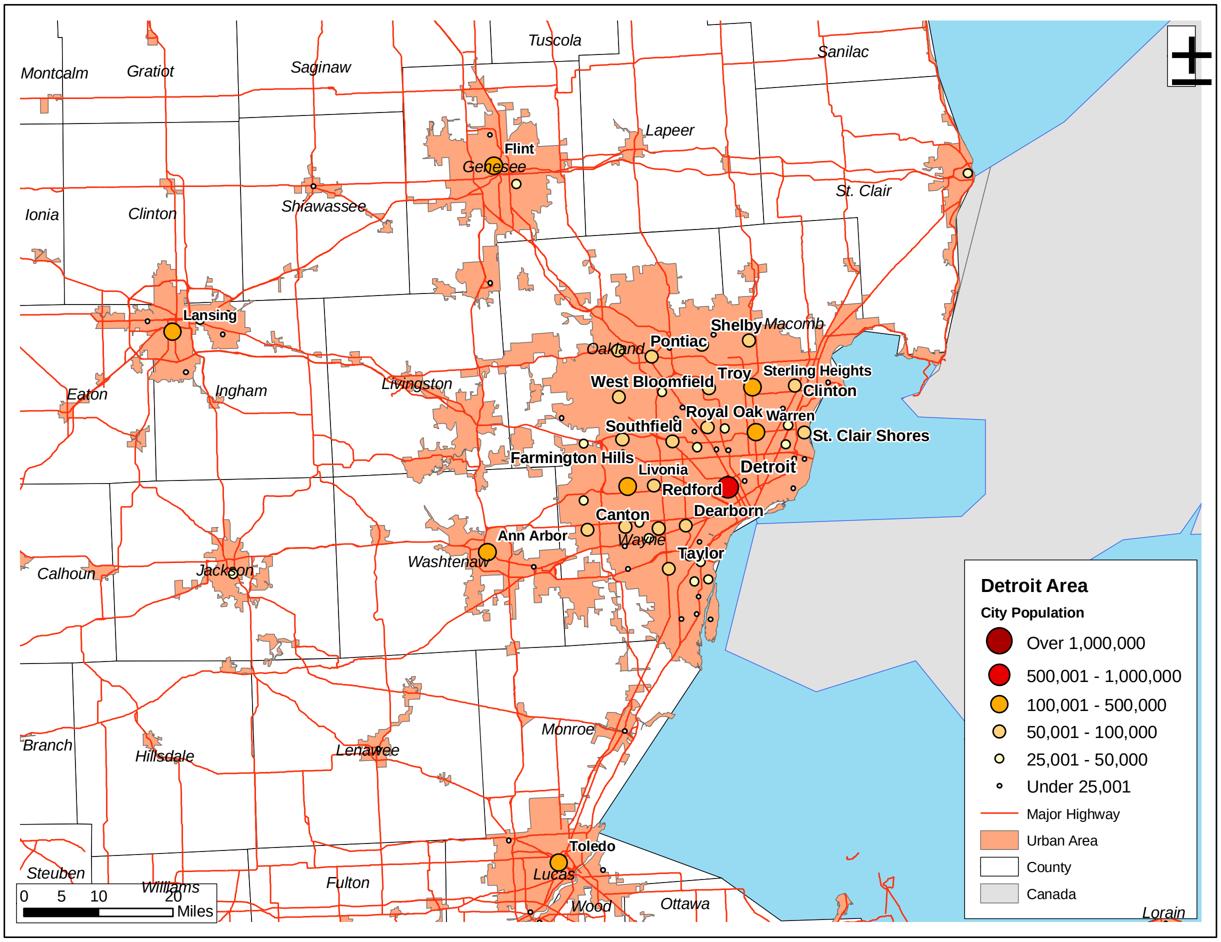


Figure 2-7. Urban and Rural Classification for FOT Data

2.5.1. Baseline Period

Table 2-12 presents the ANOVA results for baseline period VDT by population density. The rightmost column in the table indicates the usual statistically significant association between the age group and the VDT and a statistically significant association between the population density and the VDT.

Table 2-12. ANOVA Results for Baseline Period VDT by Population Density

	SS	DOF	MS	F	p
Intercept	8.6E+06	1	8.6E+06	324.2	<0.001
Gender	2.8E+03	1	2.8E+03	0.1	7.48E-01
Age Group	6.1E+05	2	3.1E+05	11.5	<0.001
Gender*Age Group	5.9E+03	2	3.0E+03	0.1	8.95E-01
Error	1.9E+06	70	2.7E+04		

	SS	DOF	MS	F	p
Density	2.0E+06	1	2.0E+06	69.6	<0.001
Density*Gender	4.9E+03	1	4.9E+03	0.2	6.84E-01
Density*Age Group	9.5E+04	2	4.8E+04	1.6	2.04E-01
Density*Gender*Age Group	3.5E+04	2	1.8E+04	0.6	5.52E-01
Error	2.0E+06	70	2.9E+04		

The specific means of these associations are:

- During the baseline period, younger, middle-aged, and older participants averaged 324, 220, and 171 km, respectively, averaged over urban and rural driving. These numbers differ slightly from the values in Section 2.4.1 because of an "unknown" category for population density. The VDT in this category, which is very low, is not included in the ANOVA. An analysis using contrasts showed only the difference between younger and the combined middle-aged and older participants to be statistically significant.
- During the baseline period, participants averaged 123 km in rural areas and 354 km in urban areas.

2.5.2. Treatment Period

Table 2-13 presents the ANOVA results for treatment period VDT by population density. The rightmost column in the table indicates that, in addition to the statistically significant associations between gender and VDT and age group and VDT, there is a statistically significant association between the population density and the VDT. Based on the clear association between population density and the VDT observed in the baseline period data, this association is expected.

Table 2-13. ANOVA Results for Treatment Period VDT by Population Density

	SS	DOF	MS	F	p
Intercept	1.4E+07	1	1.4E+07	443.7	<0.001
Gender	2.2E+05	1	2.2E+05	6.7	1.2E-02
Age Group	2.4E+05	2	1.2E+05	3.7	2.9E-02
Gender*Age Group	6.3E+03	2	3.2E+03	0.1	9.1E-01
Error	2.3E+06	70	3.2E+04		
Density	3.6E+06	1	3.6E+06	71.5	<0.001
Density*Gender	1.3E+05	1	1.3E+05	2.6	1.1E-01
Density*Age Group	1.4E+05	2	7.1E+04	1.4	2.5E-01
Density*Gender*Age Group	9.3E+04	2	4.6E+04	0.9	4.1E-01

	SS	DOF	MS	F	p
Error	3.6E+06	70	5.1E+04		

The specific significant differences behind these associations are:

- Males drove more than females: 345 versus 269 km, averaged over urban and rural driving.
- Younger, middle-aged, and older participants averaged 321, 347, and 253 km, respectively, averaged over urban and rural driving. However, only the difference between middle-aged and older participants was statistically significant.
- Participants averaged 152 km in rural areas and 462 km in urban areas.

2.6 EXPOSURE BY ROAD TYPE

GES crash statistics show a significant number of road-departure crashes occur on roads other than high-speed freeways. Corresponding differences in alert and conflict rates between freeways and non-freeways are anticipated. As in the previous sections, baseline and treatment periods are analyzed separately.

2.6.1. Baseline Period

Table 2-14 presents the ANOVA results for baseline period VDT by road type. The rightmost column in the table indicates that there is the usual statistically significant association between the age group and the VDT and a statistically significant interaction between the age group, road type, and VDT.

Table 2-14. ANOVA Results for Baseline Period VDT by Road Type

	SS	DOF	MS	F	p
Intercept	8.7E+06	1	8.7E+06	325.4	<0.001
Gender	2.7E+03	1	2.7E+03	0.1	7.5E-01
Age Group	6.1E+05	2	3.1E+05	11.4	<0.001
Gender*Age Group	5.6E+03	2	2.8E+03	0.1	9.0E-01
Error	1.9E+06	70	2.7E+04		
Road type	5.1E+04	1	5.1E+04	2.2	1.5E-01
Road type*Gender	7.8E+04	1	7.8E+04	3.3	7.5E-02
Road type*Age Group	1.9E+05	2	9.3E+04	3.9	2.5E-02
Road type*Gender*Age Group	2.6E+04	2	1.3E+04	0.5	5.8E-01
Error	1.7E+06	70	2.4E+04		

The specific means behind these associations are:

- During the baseline period, younger, middle-aged, and older participants averaged 325, 220, and 172 km, respectively, averaged over non-freeway and freeway driving. A post-hoc analysis showed only the difference between younger and the combined middle-aged and older participants to be statistically significant.
- Figure 2-8 illustrates the interaction between age group and road type. Younger participants averaged 62 km more exposure to freeways than non-freeways, and middle-aged and older participants had less exposure to freeways, 72 km and 99 km, respectively.

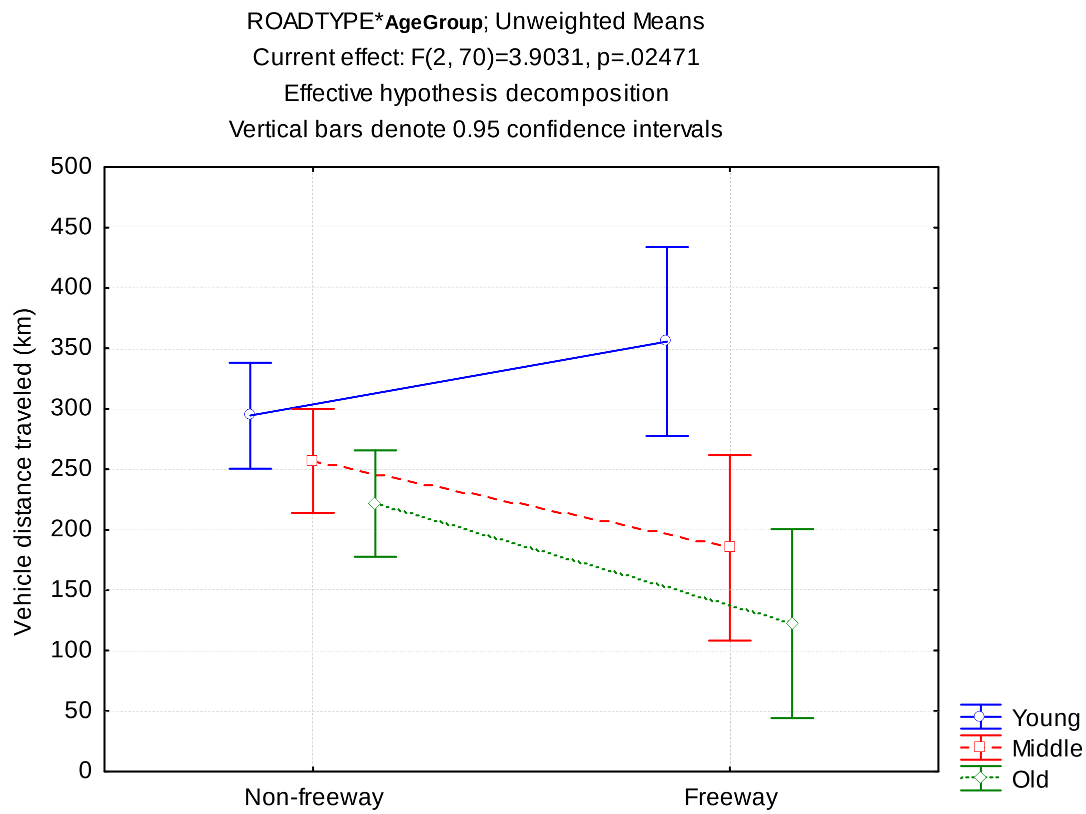


Figure 2-8. Baseline Period Exposure by Age and Road Type

2.6.2. Treatment Period

Table 2-15 presents the ANOVA results for treatment period VDT by road type. Only gender and VDT and age group and VDT have statistically significant associations.

Table 2-15. ANOVA Results for Treatment Period VDT by Road Type

	SS	DOF	MS	F	p
Intercept	1.4E+07	1	1.4E+07	449.9	<0.001
Gender	2.1E+05	1	2.1E+05	6.7	1.2E-02
Age Group	2.4E+05	2	1.2E+05	3.8	2.8E-02
Gender*Age Group	7.2E+03	2	3.6E+03	0.1	8.9E-01
Error	2.2E+06	70	3.2E+04		
Road	7.4E+04	1	7.4E+04	2.3	1.3E-01
Road*Gender	2.4E+04	1	2.4E+04	0.7	3.9E-01
Road*Age Group	5.9E+04	2	2.9E+04	0.9	4.0E-01
Road*Gender*Age Group	3.0E+04	2	1.5E+04	0.5	6.2E-01
Error	2.2E+06	70	3.2E+04		

The specific means behind these associations are:

- Males drove more than females: 346 versus 271 km, averaged over freeways and non-freeways.
- Younger, middle-aged, and older participants averaged 322, 349, and 255 km, respectively, averaged over freeways and non-freeways. Only the difference between middle-aged and older participants was statistically significant.

Of the 12 means available when crossing gender by age group by road type, older females had the lowest mean VDT, 156 km on freeways. While this number is greater than some of the other mean VDT discussed in this section, it still suggests caution in analyzing and interpreting subsequent findings in this category.

2.7 EXPOSURE BY WEATHER

Weather may influence device performance and safety benefits. For this analysis, weather has two levels: wet and dry. Four weather levels (wet or dry crossed with warm or cold) were considered initially, but approximately half of the FOT participants did not drive in cold weather. Thus, FOT data was not categorized by temperature. The wiper switch setting in the FOT data served as a proxy for weather, where the off position was interpreted as dry and any on position was interpreted as wet.

2.7.1. Baseline Period

Table 2-16 presents the ANOVA results for baseline period VDT by weather. The results show statistically significant associations between VDT and (1) weather and (2) the age group. The results also show an interaction between the age group and weather.

Table 2-16. ANOVA Results for Baseline Period VDT by Weather

	SS	DOF	MS	F	p
Intercept	9.1E+06	1	9.1E+06	318.9	<0.001
Gender	1.5E+03	1	1.5E+03	0.1	8.2E-01
Age Group	6.2E+05	2	3.1E+05	11.0	<0.001
Gender*Age Group	4.3E+03	2	2.2E+03	0.1	9.3E-01
Error	2.0E+06	70	2.9E+04		
Weather	7.1E+06	1	7.1E+06	221.8	<0.001
Weather*Gender	2.5E+04	1	2.5E+04	0.8	3.8E-01
Weather*Age Group	6.2E+05	2	3.1E+05	9.7	<0.001
Weather*Gender*Age Group	2.5E+03	2	1.3E+03	0.0	9.6E-01
Error	2.2E+06	70	3.2E+04		

The specific means behind these associations are:

- During the baseline period, younger, middle-aged, and older participants averaged 331, 228, and 175 km, respectively, averaged over dry and wet weather. As discussed in earlier sections, only the difference between middle-aged and older participants was statistically significant.
- Participants averaged 461 km during dry weather and only 29 km during wet weather. The low exposure to wet weather suggests particular caution and the likelihood of limited findings with this data.
- The interaction between age group, weather, and VDT is best understood by viewing the data, presented in Figure 2-9. All the age groups had similar low exposure to wet weather (35, 17, and 37 km means for respective younger, middle-aged, and older participants), but the differential increase for exposure to dry weather varied with the age group. Younger participants had the largest increase, followed by middle-aged and older participants (591, 427, and 277 km, respectively).

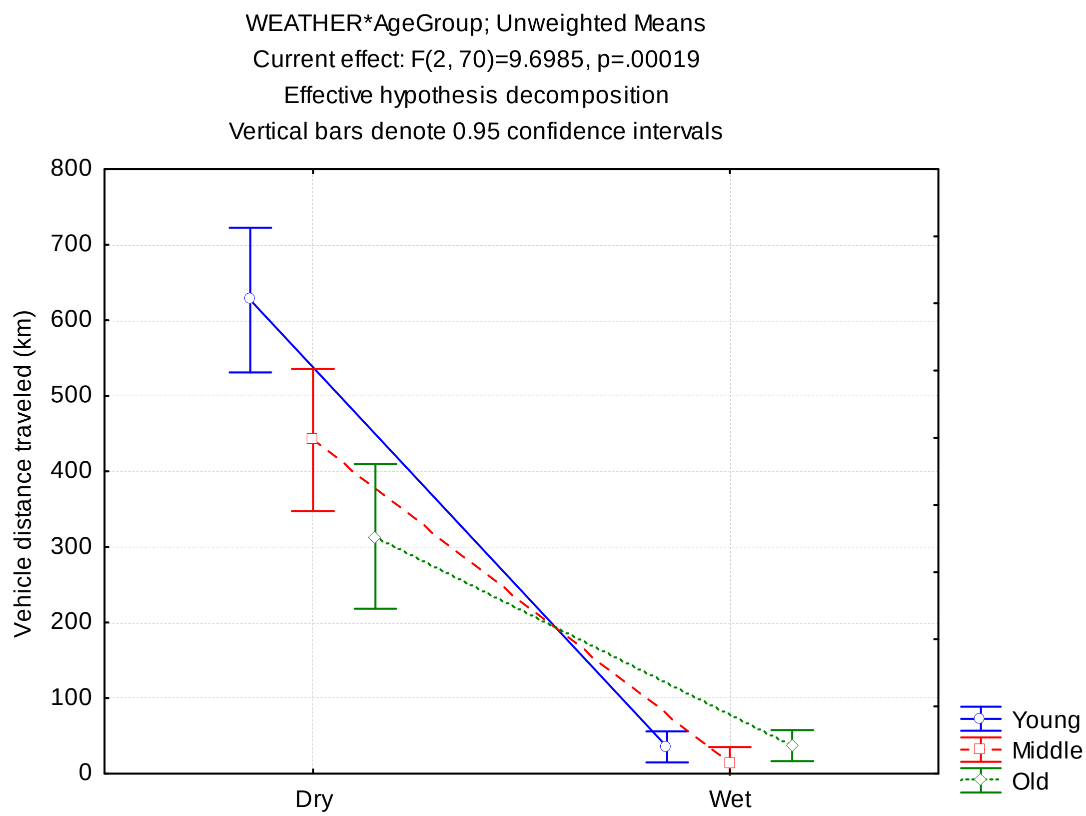


Figure 2-9. Baseline Period Exposure by Age and Weather

2.7.2. Treatment Period

Table 2-17 presents the ANOVA results for treatment period VDT by weather. The results show statistically significant associations between VDT and (1) gender, (2) the age group, and (3) the weather. The results also show an interaction between weather and age group.

Table 2-17. ANOVA Results for Treatment Period VDT by Weather

	SS	DOF	MS	F	p
Intercept	1.5E+07	1	1.5E+07	454.4	<0.001
Gender	2.1E+05	1	2.1E+05	6.4	1.4E-02
Age Group	2.3E+05	2	1.1E+05	3.5	3.7E-02
Gender*Age Group	8.6E+03	2	4.3E+03	0.1	8.8E-01
Error	2.3E+06	70	3.3E+04		
Weather	1.2E+07	1	1.2E+07	365.6	<0.001
Weather*Gender	2.3E+05	1	2.3E+05	7.0	1.0E-02
Weather*Age Group	1.9E+05	2	9.4E+04	2.8	6.6E-02

	SS	DOF	MS	F	p
Weather*Gender*Age Group	1.0E+04	2	5.2E+03	0.2	8.5E-01
Error	2.3E+06	70	3.3E+04		

The specific means behind these associations are:

- Males drove more than females: 352 versus 278 km, averaged over wet and dry weather.
- Younger, middle-aged, and older participants averaged 328, 355, and 262 km, respectively, averaged over wet and dry weather. A contrast analysis shows that only the difference between middle-aged and older participants is statistically significant.
- Participants had much higher average exposure to dry weather, 598 km, than wet weather, 32 km.
- The data showed a small interaction between gender and weather. Females and males had roughly the same exposure to wet weather, 30 and 34 km, respectively. Females had a smaller differential increase in exposure to dry weather than males, 491 and 640 km, respectively.

2.8 EXPOSURE BY SENSITIVITY LEVELS

FOT participants could select LDW and CSW alert sensitivity independently.

To assess how participants adjusted the RDCW, exposure by sensitivity level was analyzed for both LDW and CSW subsystems. Analysis by sensitivity level differed from previous exposure analyses in three ways.

First, the VDT for each participant at each sensitivity level was divided by each participant's VDT, which normalized his or her sensitivity data. This normalization assigned the same weight to each participant's data in the usage-pattern analysis. Without it, participants' VDT would weigh their data in this analysis, whereas the intent in this section is to have each participant's data weigh equally. Second, data from the baseline period was omitted because sensitivity had no relevance for this period. Finally, data from Period 3 was included in these analyses to track changes in sensitivity preferences over time. Using the normalized data from Periods 3 and 4, we performed the usual repeated-measures ANOVA categorized by age and gender and determined if the preferred sensitivity levels varied with age, gender, or time (Period 3 to 4).

2.8.1. Lateral-Drift-Warning Adaptation

LDW adaptation was analyzed by focusing solely on the *changes* in the percentage use at each sensitivity level. Exposure to, i.e., use of LDW sensitivity settings over different quantities of VDT map into the *change in percent* variable, which was the dependent variable used to analyze adaptation. For example, if a participant set the LDW sensitivity at Level 3 for 10 percent of Period 3 and 50 percent of Period 4, the change in percent for Level 3 would be +40 percent. The factors of interest include Delta Sensitivity, the change in sensitivity at each level, and the statistically significant interactions (if any) between this factor and the age group or gender.

The changes in percent over the five sensitivity levels sum to 0. For a given driver, the increases in usage at one or more levels were balanced by decreases in usage at one or more other levels. Thus, the ANOVA results in Table 2-18 have entries of 0 for the sum of square terms in the first five rows, and there is no significance test associated with any of these rows.

Table 2-18. ANOVA Results for LDW Sensitivity Preference

	SS	DOF	MS	F	p
Intercept	0.0	1	0.000		
Gender	0.0	1	0.000		
Age Group	0.0	2	0.000		
Gender*Age Group	0.0	2	0.000		
Error	0.0	70	0.000		
Delta Sensitivity	2.0E+04	4	5.1E+03	6.134	<0.001
Delta Sensitivity*Gender	7.7E+02	4	1.9E+02	0.232	9.2E-01
Delta Sensitivity*Age Group	1.2E+04	8	1.5E+03	1.819	7.3E-02
Delta Sensitivity*Gender*Age Group	1.3E+04	8	1.7E+03	2.001	4.6E-02
Error	2.3E+05	280	8.3E+02		

The ANOVA results indicate that one or more sensitivity levels changed from Period 3 to Period 4 and that an interaction existed between the sensitivity levels, age group, and gender. The means behind these findings include:

- Participants increased their use of the lowest sensitivity (Level 1) setting by 11 percent and decreased their use of the middle setting (Level 3) by the same amount. They made smaller changes at the other levels. A separate contrast analysis showed that the changes in these levels were the only statistically significant changes. As Figure 2-10 shows, the percentage use at Levels 2, 4, and 5 did not change from Period 3 to 4.

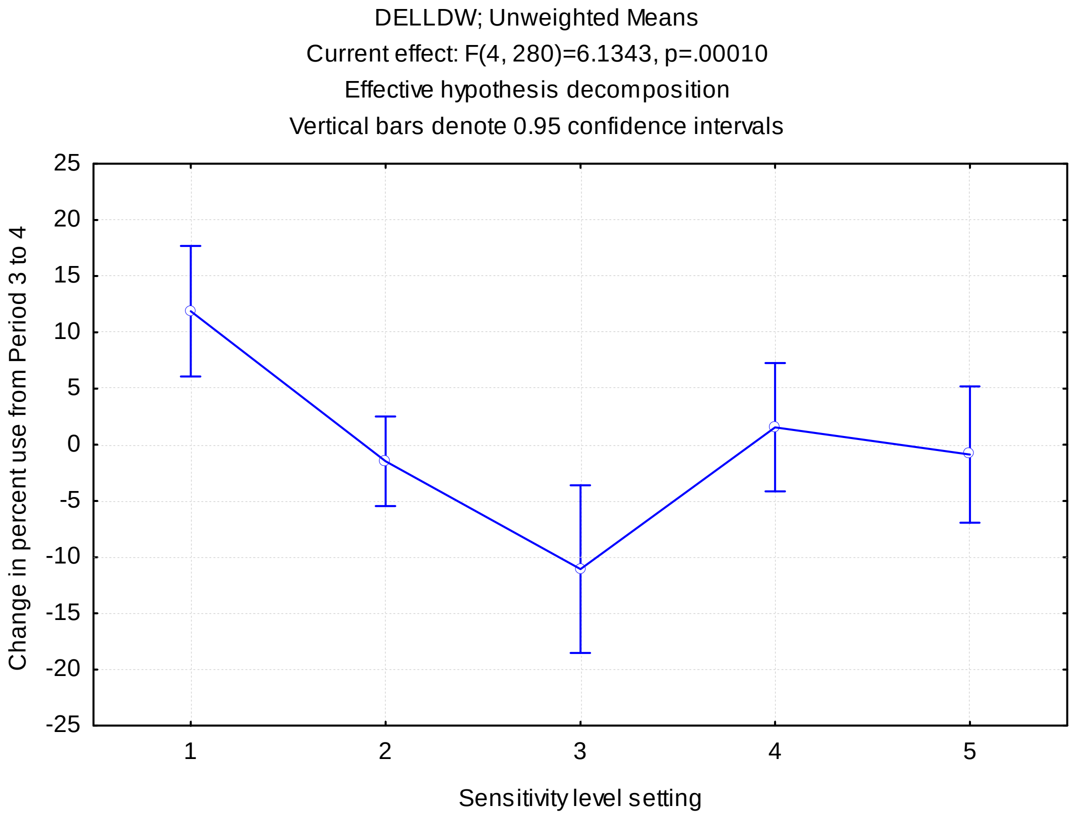


Figure 2-10. Change in LDW Sensitivity Use From Period 3 to 4

The remaining statistically significant finding, the interaction between age, gender, and sensitivity level, is presented in Figure 2-11. The interaction results because participants' changes in LDW sensitivity settings varied by age and gender. Specifically:

- Younger females switched from Levels 2 and 3 to Level 1 (least sensitivity, latest alerts).
- Middle-aged males switched from Levels 3 and 5 (earliest warnings) to Levels 1 and 4.
- Older males switched from Level 3 to Levels 2 and 5.

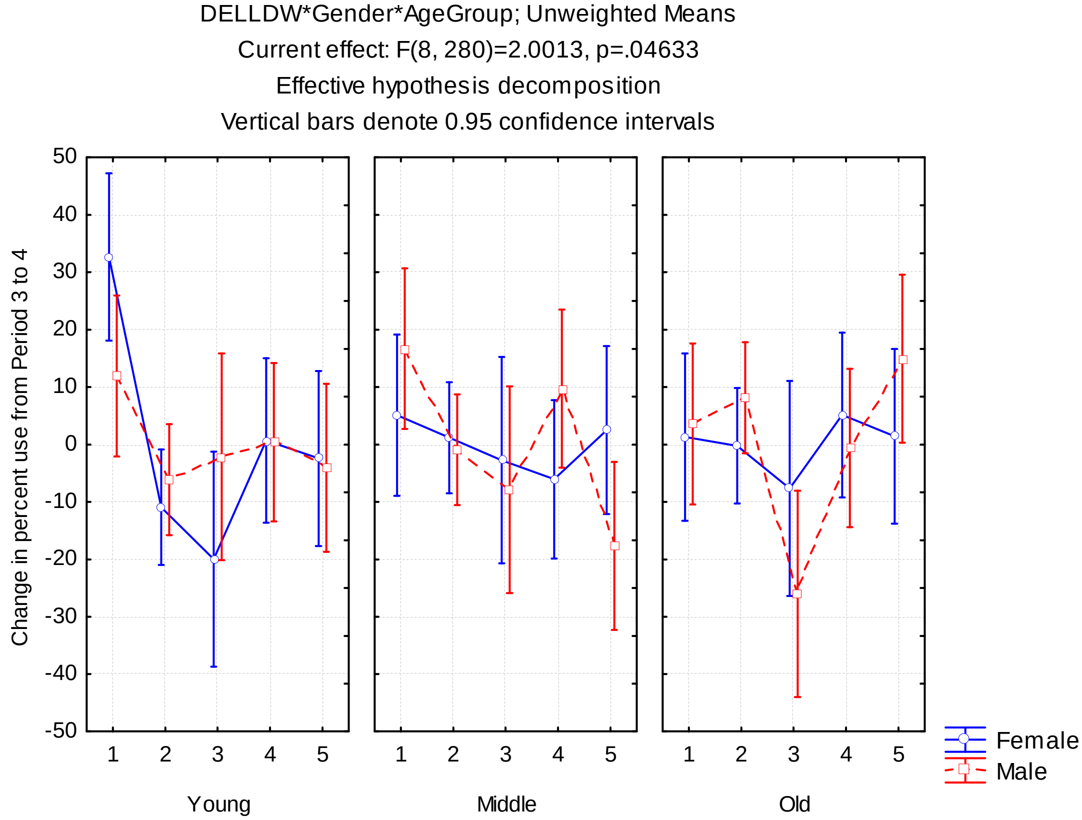


Figure 2-11. Changes in LDW Sensitivity From Period 3 to 4 Versus Sensitivity Level, Categorized by Age and Gender

2.8.2. Curve-Speed Warning Adaptation

CSW adaptation, like LDW adaptation, was analyzed using the changes in the percentage use at each sensitivity level as the outcome measure. Once again, the changes in percent over the five sensitivity levels sum to 0, and the increases in usage at one or more levels are balanced by decreases in usage at one or more other levels. The ANOVA results in Table 2-19 thus have entries of 0 for the sum of square terms in the first five rows.

Table 2-19. ANOVA Results for Changes in CSW Sensitivity

	SS	DOF	MS	F	p
Intercept	0.0	1	0.000		
Gender	0.0	1	0.000		
Age Group	0.0	2	0.000		
Gender*Age Group	0.0	2	0.000		
Error	0.0	70	0.000		
Delta Sensitivity	1.2E+04	4	3.0E+03	3.574	7.3E-03

	SS	DOF	MS	F	p
Delta Sensitivity*Gender	2.2E+03	4	5.4E+02	0.643	6.3E-01
Delta Sensitivity*Age Group	5.7E+03	8	7.1E+02	0.847	5.6E-01
Delta Sensitivity*Gender*Age Group	9.0E+03	8	1.1E+03	1.334	2.3E-01
Error	2.4E+05	280	8.4E+02		

The only statistically significant finding in the ANOVA results is the change in the sensitivity levels. Illustrated in Figure 2-12, the mean changes in percentage use show an increase at the lowest sensitivity setting (7.4%) and a corresponding decrease at the medium setting (-8.2%). A separate contrast analysis showed that the changes in these levels were the only statistically significant changes. The percentage use at Levels 2, 4, and 5 did not change from Period 3 to 4.

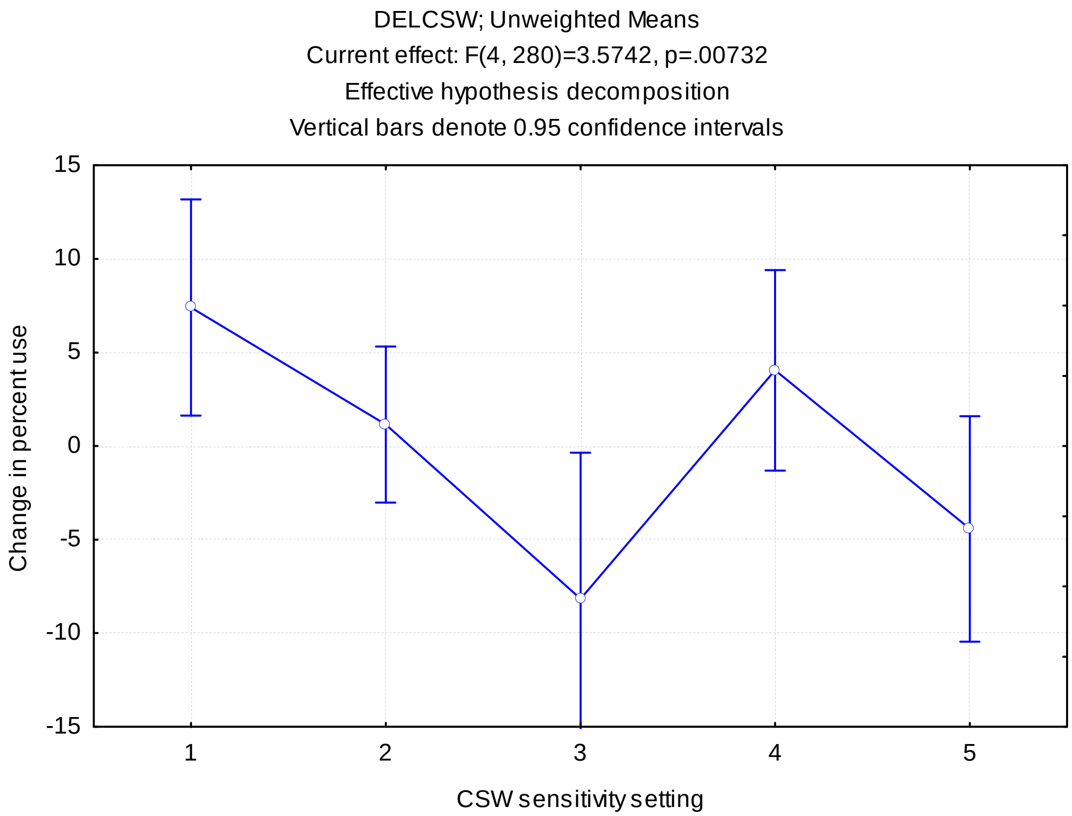


Figure 2-12. Changes in CSW Sensitivity From Period 3 to 4

2.8.3. Lateral-Drift-Warning Sensitivity Settings in Period 4

The LDW sensitivity settings in Period 4, the second half of the treatment period, presumably reflect participants' ultimate preference for LDW sensitivity settings. Table 2-20 presents the ANOVA results for these settings in Period 4. Since each participant's percent use totals 100 and the mean use over each setting is thus 20, neither gender nor age group can be associated in a statistically significant way with the sensitivity setting. Thus, the FOT ratios and p-values for the first five rows in the table are blank. The remaining rows indicate that participants preferred some LDW sensitivity levels over others and that the different age groups differed in these preferences.

Table 2-20. ANOVA Results for Period 4 LDW Sensitivity

	SS	DOF	MS	F	p
Intercept	1.5E+05	1	1.5E+05		
Gender	1.4E-12	1	1.4E-12		
Age Group	-2.5E-12	2	-1.2E-12		
Gender*Age Group	3.2E-12	2	1.6E-12		
Error	-1.4E-11	70	-1.9E-13		
Sensitivity	4.2E+04	4	1.1E+04	9.068	<0.001
Sensitivity*Gender	3.6E+03	4	8.9E+02	0.765	5.5E-01
Sensitivity*Age Group	3.1E+04	8	3.9E+03	3.325	1.2E-03
Sensitivity*Gender*Age Group	7.8E+03	8	9.7E+02	0.830	5.8E-01
Error	3.3E+05	280	1.2E+03		

Figure 2-13 illustrates the first of these findings. Participants preferred the middle LDW sensitivity setting over the others. A post-hoc comparison using contrasts showed that the means for sensitivity settings 1, 2, 4, and 5 are statistically equal. A second comparison showed the expected result that the percentage use at setting 3 exceeded the use at the other settings.

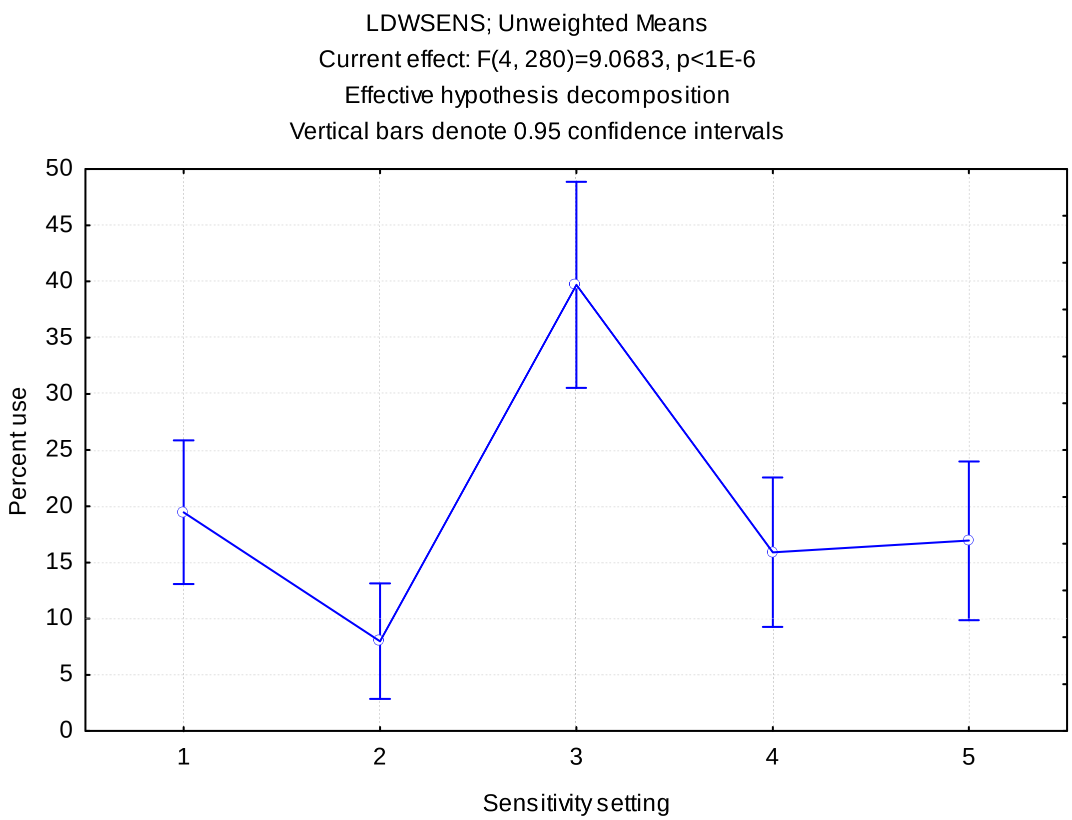


Figure 2-13. Period 4 Percent Use of LDW Sensitivity Settings

As noted, the ANOVA revealed the different age groups preferred different LDW sensitivity settings. Figure 2-14 illustrates this finding. In general, younger participants preferred lower sensitivity settings; middle-aged participants preferred the middle setting, and older participants preferred the middle and highest settings.

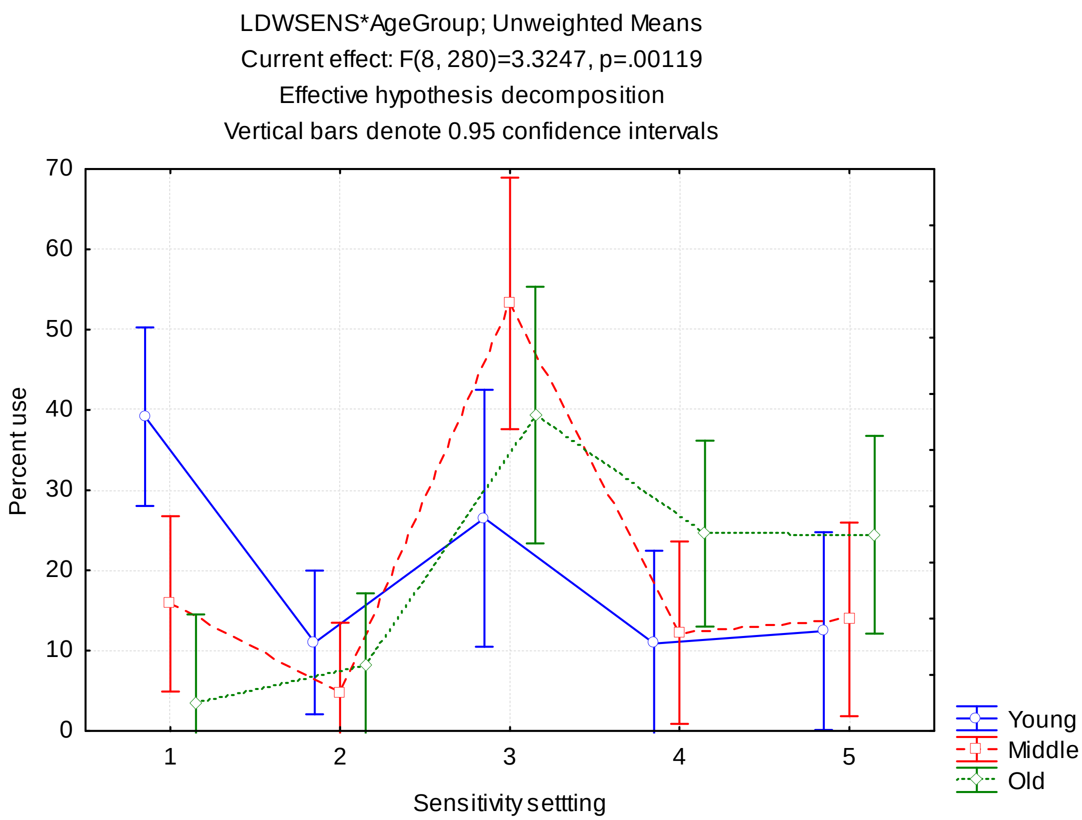


Figure 2-14. Period 4 Percent Use of LDW Sensitivity Settings for Different Age Groups

2.8.4. Curve-Speed Warning Sensitivity Settings in Period 4

The CSW sensitivity settings in Period 4 reflect participants' ultimate preference for CSW sensitivity settings. Table 2-21 presents the ANOVA results for these settings in Period 4. As with the LDW settings, each participant's percent use totals 100 and the mean use over each setting is thus 20. Therefore, neither gender nor age group can be associated with the sensitivity setting. The *F* and p-values for the first five rows in the table are blank. The remaining rows indicate that participants preferred some CSW sensitivity levels over others and that the different age groups differed in these preferences.

Table 2-21. ANOVA Results for Period 4 CSW Sensitivity

	SS	DOF	MS	F	p
Intercept	1.5E+05	1	1.5E+05		
Gender	1.4E-12	1	1.4E-12		
Age Group	-2.5E-12	2	-1.2E-12		
Gender*Age Group	3.2E-12	2	1.6E-12		

	SS	DOF	MS	F	p
Error	-1.4E-11	70	-1.9E-13		
Sensitivity	4.2E+04	4	1.1E+04	9.068	<0.001
Sensitivity*Gender	3.6E+03	4	8.9E+02	0.765	5.5E-01
Sensitivity*Age Group	3.1E+04	8	3.9E+03	3.325	1.2E-03
Sensitivity*Gender*Age Group	7.8E+03	8	9.7E+02	0.830	5.8E-01
Error	3.3E+05	280	1.2E+03		

Figure 2-15 illustrates the first of these findings. Participants preferred the middle CSW sensitivity setting over the others, the same preference shown for LDW sensitivity. Indeed, the similarity between the LDW sensitivity percent use in Figure 2-13 and the CSW equivalent presented below is striking. The post-hoc comparison of the means yielded the same results as the LDW setting: the means for sensitivity settings 1, 2, 4, and 5 are statistically equal, and the percentage use at setting 3 exceeded the use at the other settings.

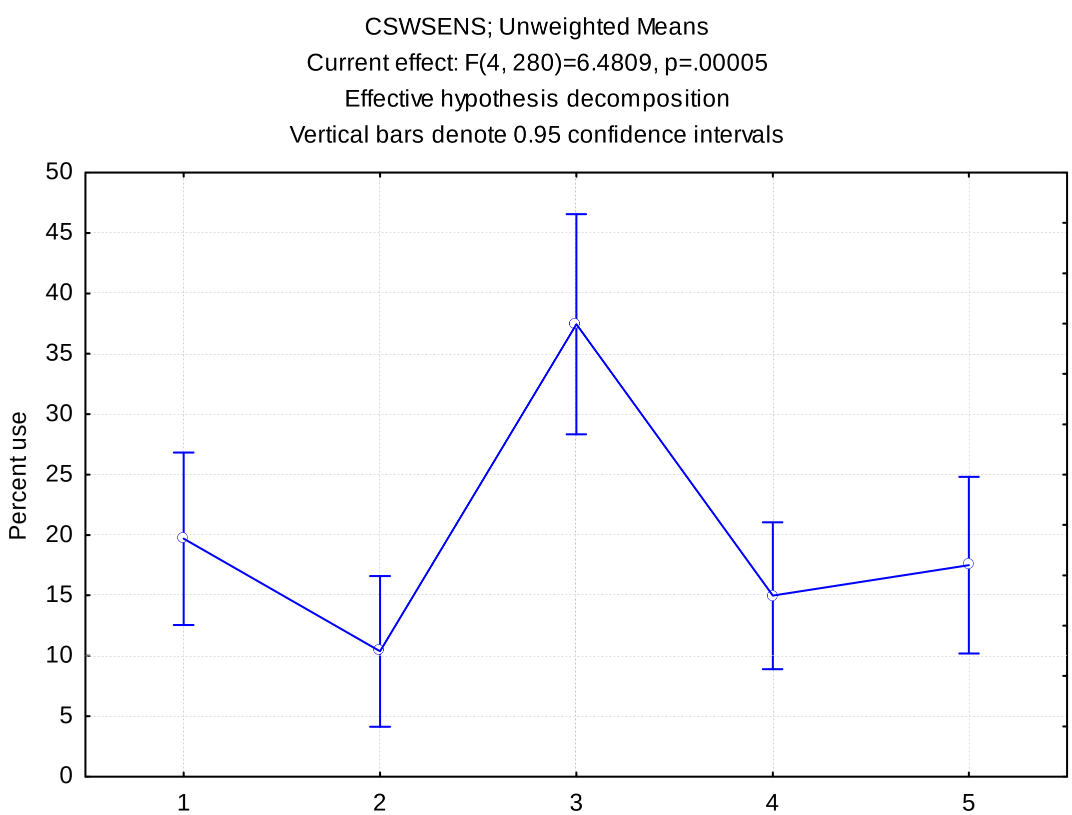


Figure 2-15. Period 4 Percent Use of CSW Sensitivity Settings

The ANOVA also revealed that the different age groups preferred different CSW sensitivity settings. Figure 2-16 illustrates this finding. Parallel to the LDW findings, the data shows that younger participants preferred lower sensitivity settings, middle-aged participants preferred the middle setting, and older participants preferred the middle and highest settings.

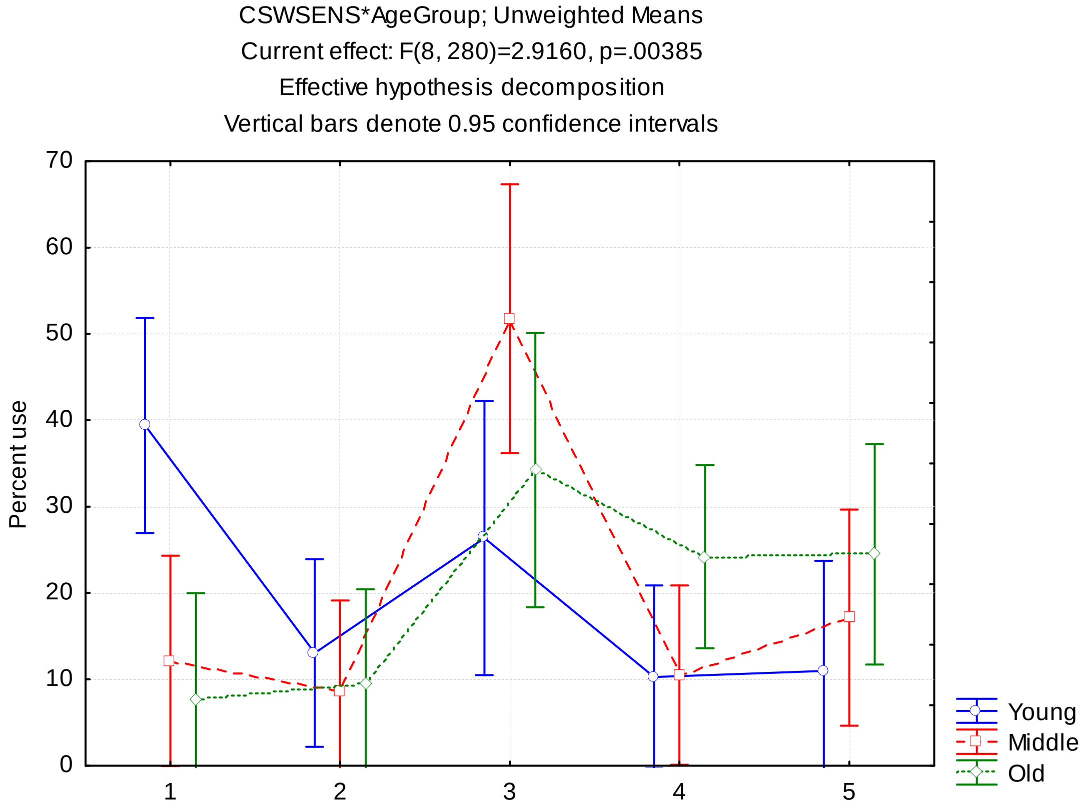


Figure 2-16. Period 4 Percent Use of CSW Sensitivity Settings by Age

3. SYSTEM CAPABILITY

The extent to which the RDCW issues on-time alerts when they are needed and does not issue alerts when they are not needed defines system performance and capability. To warn a driver of impending trouble, the RDCW sensors must provide accurate and robust information, the alert logic must assess and issue an alert in a timely manner, and the system must transmit the alert information clearly to the driver. This chapter evaluates the RDCW performance through the following aspects of the system:

1. *Availability and Accuracy:* Explore system availability frequency and affecting conditions, and document sensor performance with an independent measuring system.
2. *Lateral-Drift-Warning (LDW) Alert Logic:* Assess LDW alert logic response to perceived and actual lateral drift scenarios.
3. *Curve-Speed-Warning (CSW) Alert Logic:* Characterize the CSW alert logic performance in alerting the driver to potential curve speed scenarios, when needed.
4. *Driver-Vehicle Interface (DVI):* Examine the capability of the DVI to properly convey visual, auditory, and haptic information to the driver.

HIGHLIGHTS

- Volpe and NIST engineers collected 1,300 km of characterization test data.
- An Independent Measurement System provided “ground truth” measurements for the characterization testing.
- LDW availability varied with the road type: 76 percent on freeways compared to 36 percent on non-freeways.
- LDW availability varied with lighting and weather: 56 percent during dry days compared to 4 percent during wet nights.
- CSW availability was consistently high: over 95 percent in most conditions.

Three sources provided data to analyze system capability: a system characterization test, FOT objective data, and FOT subjective data. System characterization test data was collected from 1,278 km of driving in the Ann Arbor and Detroit metropolitan area to explore specific LDW and CSW alerting scenarios. Section 3.1.2 and Appendix B provide additional background. FOT objective data consists of FOT availability information and video alert episode analysis. Section 3.3 and Appendix C (Video Logger) provide additional background. FOT subjective data includes subject response to FOT post-drive survey questions. Table 3-1 lists data sources and associated performance-analysis objectives and subobjectives.

Table 3-1. Data Sources and Analyses

Objective	Subobjective	System Characterization Test	FOT Objective Data	FOT Subjective Data
Availability and Accuracy	System Availability	Comparative analysis of system availability for detailed lighting and road conditions	Analysis of lighting and road availability	
	Sensor Performance	Comparison between RDCW and independent measurement system		
LDW Alert Logic	Effectiveness	Response to LDW sensitivity adjustment Imminent alert time to collision analysis for various lateral drift scenarios		Timing of auditory and haptic warnings
	Nuisance	Alert need analysis for different lateral drift conditions	True and false positive rates by vehicle, road, and environmental state	Necessity of warnings False warning occurrence Adverse weather performance
CSW Alert Logic	Effectiveness	Response to CSW sensitivity adjustment Imminent alert time to collision analysis for various curve approach scenarios		Timing of auditory and haptic warnings
	Nuisance	Alert need analysis under different curvature conditions		Necessity of warnings False warning occurrence Adverse weather performance
DVI	Display Readability			Distinguish information in all lighting conditions Recognize warning direction
	Sound Audibility			Hear warnings while driving Recognize warning direction
	Haptic Tactility			Discern seat vibration and direction

Availability and Accuracy. The availability of the LDW and CSW subsystems to issue alerts and the accuracy of these systems in estimating key safety measures were analyzed. To assess system availability, we first reviewed characterization test and FOT data. We then categorized the data according to environmental state, such as lighting and road conditions, to determine the influence of these factors on the RDCW issuing an alert to the driver. We measured sensor performance by comparing system accuracy of critical RDCW measurements to the accompanying values from an independent measurement system equipped to the vehicle during characterization testing. We used these differences in lateral drift and curve speed alert logic sections to hypothesize causes of alert timing or need.

LDW Alert Logic. All three data sources were used to evaluate effectiveness and nuisance topics and conducted targeted test scenarios to evaluate the capability of LDW alert logic in the characterization test, focusing on alert need, issuance, and timing. A breakdown of 3,789 FOT alert episodes by true-positive and false-positive categories from objective data gave us insight into nuisance rates experienced by FOT participants. Finally, FOT survey items provided us with subjective measures of alert timing and false-positive rates.

CSW Alert Logic. Our assessment followed a similar pattern to the LDW alert logic, using system characterization test data and subjective FOT data. CSW characterization tests investigating CSW alert logic over a range of scenarios and conditions provided measurements of both alert effectiveness and nuisance. Subjective responses were similar to LDW questions, allowing us to study CSW alert performance and make comparisons.

DVI. FOT subjective data from survey questions relating to visual, auditory, and haptic elements of the system were used to evaluate the DVI performance. Measures included the ability to convey information to the driver through these three modes and the clarity of the signals.

3.1 SYSTEM AVAILABILITY AND ACCURACY

This section analyzes two aspects of system sensing: when the RDCW system was available to issue an alert and the system accuracy compared to an Independent Measurement System (IMS). Section 3.1.1 describes how often the system was capable of issuing an alert and the conditions influencing availability. Section 3.1.2 outlines how we analyzed data within the IMS. Section 3.1.3 describes the differences between an IMS and the RDCW. In addition to presenting differences between key measures for the LDW and CSW subsystems, we also discuss some of the implications these differences may have on system performance.

3.1.1. System Availability

On-road system characterization tests and FOT driving allow us to evaluate a diverse group of roads and conditions for RDCW alert response and system availability. We defined availability, displayed to the driver using availability icons in the DVI on the dashboard, as a situation when an alert could be issued. Section 3.1.1 will only review availability when the vehicle was operating within the speeds where the system was capable of alerting: above 11.2 m/s for the LDW subsystem and 8.0 m/s for the CSW subsystem. Tables within this section include rows for VDT, the distance driven in kilometers under the given condition rounded to the nearest kilometer for characterization testing and nearest 100 km for the FOT.

VDT data in this subsection is divided into freeways (divided roads with speed limits 55 mph or greater), non-freeways (all other roads that did not meet these criteria but were known), and unknown (GPS information was not available or the GPS location did not match any nearby road). To define road type, we used a post-processing procedure with GPS points and a different map database than the on-board vehicle system. This procedure generates fewer unknown values and identifies some instances where road information disagrees with on-board road information. For all analysis including cases where road information disagrees, we will use the post-processed values.

LDW Road Type Availability

Table 3-2 lists a breakdown of characterization test the LDW subsystem availability by distance traveled for roadside and road type. Overall the LDW was fully (left and right) available 60 percent of distance traveled above the cut-off speed of 11.2 m/s, although non-freeways were 24 percent lower than freeways.

Table 3-2. Characterization Test LDW Availability by Road Type

Road Type		Left only	Right only	Left and Right	None
Unknown	VDT (km)	0	2	7	5
	Row Percent	2%	13%	48%	37%
Freeway	VDT (km)	23	42	539	178
	Row Percent	3%	5%	69%	23%
Non-Freeway	VDT (km)	21	33	195	189
	Row Percent	5%	7%	45%	43%
Average	Row Percent	4%	6%	60%	30%

Table 3-3 presents results for overall LDW FOT availability that are similar to those obtained during the characterization testing. The difference between full availability with FOT data, however, is more pronounced. Whereas the characterization test data yielded 69 percent availability for freeways and 45 percent for non-freeways, the FOT data yielded respective availabilities of 76 and 36 percent. Better-quality lane markings and the simpler road geometry associated with freeways presumably caused this difference.

Table 3-3. FOT LDW Availability by Road Type

Road Type		Left only	Right only	Left and Right	None
Unknown	VDT (km)	100	100	800	800
	Row Percent	5%	3%	47%	45%
Freeway	VDT (km)	1,300	1,500	43,400	10,600
	Row Percent	2%	3%	76%	19%
Non-Freeway	VDT (km)	4,700	3,600	22,900	32,400
	Row Percent	7%	6%	36%	51%
Average	Row Percent	5%	4%	55%	36%

LDW Lighting and Weather Availability

Lighting and weather influence system availability. While it did not rain during on-road system characterization testing, a wide variety of lighting conditions were encountered. Table 3-4 lists characterization test LDW availability by distance traveled for lighting and atmosphere. Performance was consistent in all categories, with “Night” lighting having the highest fully available percentage, 67, and “Other Sun” having the lowest, 55. “Other Sun” denotes any condition when shadows were present, indicating sunlight and the time was within two hours after civil twilight began (in the morning) to two hours before civil twilight ended (in the evening). Times within two hours of the beginning or end of civil twilight with visible shadows were denoted as “Low Angle Sun.”

Table 3-4. Characterization Test LDW Availability by Lighting

Lighting		Left only	Right only	Left and Right	None
Cloudy	VDT (km)	19	24	317	139
	Row Percent	4%	5%	63%	28%
Low-angle sun	VDT (km)	4	6	81	40
	Row Percent	3%	4%	62%	31%
Other sun	VDT (km)	16	44	281	171
	Row Percent	3%	9%	55%	33%
Night	VDT (km)	6	3	62	22
	Row Percent	6%	3%	67%	24%
Average	VDT (km)	4%	6%	60%	30%

Table 3-5 lists similar overall LDW availability results for FOT subject driving. Since there was no detailed FOT data on sunlight conditions, categories were ranked by daylight or night using data from an onboard light sensor. Similarly, atmosphere conditions (wet, dry) were obtained using the windshield wiper setting.

Table 3-5. FOT LDW Availability by Lighting and Atmosphere

Lighting		Left only	Right only	Left and Right	None
Day, dry	VDT (km)	4,300	4,200	50,700	32,100
	Row Percent	5%	5%	56%	35%
Day, wet	VDT (km)	200	300	2,500	2,500
	Row Percent	4%	5%	46%	46%
Dark, dry	VDT (km)	1,400	700	13,800	7,700
	Row Percent	6%	3%	58%	32%
Dark, wet	VDT (km)	0	0	100	1,600
	Row Percent	1%	0%	4%	95%
Average	Row Percent	5%	4%	55%	36%

For LDW FOT availability, day-dry conditions had 10 percent more full LDW availability (56%) than day-wet conditions (46%). Dark-dry conditions had slightly more full availability (58%) than day-dry, similar to the higher availability during night conditions of the characterization test. Dark-wet conditions produced the lowest full availability, 4 percent. Because these conditions represented only 1 percent of total FOT driving, overall availability percentages remained largely unaffected.

CSW Road Type Availability

Table 3-6 and Table 3-7 present CSW availability results derived from characterization-test and FOT data. The results show that the CSW subsystem had a much higher availability percentage than LDW. Overall availability was similar for both tests, 99 percent for characterization testing and 96 percent for the FOT. The availability differed when the road type was unknown. This difference is due to both the small percentage of driving under this condition (1% of the FOT VDT and 2% of the characterization test VDT) and the difference between road processing procedures used by the CSW subsystem and the road type variable. FOT non-freeway availability was 5 percent lower than freeway availability, likely due to complicated road geometry and lower GPS signal accuracy on non-freeways. The overall CSW FOT availability, 96 percent, is high.

Table 3-6. Characterization Test CSW Availability by Road Type

Road Type		Available	Unavailable
Unknown	VDT (km)	0	15
	Row Percent	3%	97%

Road Type		Available	Unavailable
Freeway	VDT (km)	786	0
	Row Percent	100%	0%
Non-Freeway	VDT (km)	454	0
	Row Percent	100%	0%
Average	Row Percent	99%	1%

Table 3-7. FOT CSW Availability by Road Type

Road Type		Available	Unavailable
Unknown	VDT (km)	1,600	400
	Row Percent	79%	21%
Freeway	VDT (km)	56,300	800
	Row Percent	99%	1%
Non-Freeway	VDT (km)	64,400	4,100
	Row Percent	94%	6%
Average	Row Percent	96%	4%

3.1.2. Test Measurement Overview

System characterization test data was collected on public roads to obtain a broad range of conditions and scenarios. Although the RDCW and DAS provided data for assessing system performance, a second, independent system was used to ensure that system performance was characterized with accurate data. The Independent Measurement System (IMS) was developed by the National Institute of Standards and Technology (NIST). The IMS measures accurately and records variables such as vehicle lane position and lateral speed. The IMS also records environmental and road conditions. Appendix B provides more details on the road, lighting, and environmental measures derived from the IMS.

The IMS used four cameras and a differential GPS signal to measure the test vehicles' position. The forward camera allowed a view of the upcoming road and environmental conditions such as sunlight or cloudiness. The left- and right-side cameras recorded the lane position relative to the front wheels and also had a wide enough field of view to find AMR. Another camera facing the instrument cluster and the RDCW DVI logged system information, such as availability, sensitivity, and alert status from the DVI.

Different measures characterized lateral-drift and curve-speed alerts. A multi-step procedure identified vehicle position, drift rate, and available maneuvering information using images captured by the side-facing cameras (Szabo and Norcross, 2006). Key performance measures include:

- *AMR.* AMR is the distance between the inside edge of the lane marker and the end of the paved shoulder, the bottom of an obstacle if one was present, or the middle of the lane marker when there was opposing traffic.
- *TTC*. TTC is a key measure used to analyze LDW performance. For each lateral-drift test, the ultimate gauge of system performance was the time between alert issuance and the impending road-departure. TTC equals the sum of the distance to the lane marker and AMR divided by lateral drift rate. Drift rate equals the ratio of the changes in lane position to the change in time when the lane position was sampled. The departure maneuver was staged so that the drift rate was essentially constant.
- *LDW Alert Timing and Need.* Alerts were denoted as "required" if the vehicle had crossed or was about to cross a lane boundary and a road departure was impending. Even though most alerts fall into this category, some alerts were caused by incorrect system measurements. The latter were denoted as "unneeded." TTC values less than 0 indicate the alert was issued after a road departure occurred, leaving the driver no opportunity to react and prevent the departure. Drifts with TTC values between 0 and 1.5 seconds were considered late because they would not allow most drivers time to respond. The range of 1.5 to 5 seconds was considered a suitable time to warn a driver and ensure enough time to respond appropriately but not so early as to annoy the driver. Alerts issued over 5 seconds before a potential collision were considered early and likely to be considered unnecessary by drivers and potentially a nuisance. These alerts may cause drivers to lose trust in the system and disregard future alerts. These TTC values are somewhat subjective in that an alert that seems early for one driver may seem late for another.
- *Time to CPOI.* The IMS Curvature Point of Interest is the minimum curve radius, calculated by dividing vehicle speed by the absolute value of a 10-sample moving average of yaw rate. Time to CPOI is a measure of the time required to travel between the alert location and CPOI assuming vehicle speed at the time of alert remains constant.
- *Required Deceleration.* The required deceleration is the level required to safely negotiate an upcoming curve. This measure assumes the vehicle needs to reach a given "safe speed" at the IMS CPOI. The assumptions for calculating this measure are that the vehicle will not begin decelerating until 1.5 seconds after the alert and the curve safe speed is that associated with a lateral acceleration of 0.3 g at the CPOI.
- *CSW Alert Timing and Need.* Alerts are categorized based on the required deceleration. A true positive alert has an associated required deceleration greater than 0 and less than 0.11 g. If the alert conditions are such that no deceleration is required because the vehicle is traveling at or below the curve safe speed, the alert is a false positive. These

> alerts maybe useful to some drivers but many will likely consider them a nuisance. Late alerts result when the alert requires a longitudinal deceleration exceeding 0.11 g or the time to CPOI is less than 1.5 seconds. A missed alert results when lateral acceleration in a curve exceeds 0.3 g and no alert is issued.

During characterization lateral-drift-alert tests, we monitored system availability and only attempted a test maneuver when it appeared constant. During some test maneuvers, the LDW subsystem switched from available to unavailable. It was often difficult for the test driver to monitor the road, drive the vehicle, and view the LDW availability status simultaneously. If the test driver noticed during the maneuver that LDW became unavailable, the trial was discarded. If a maneuver was attempted and for a very brief period LDW became unavailable, the alert was flagged as not issued. This approach was adopted because a non-test driver who believed the LDW was available, expected an alert in a certain situation, and didn't receive one due to a very brief period of unavailability would very likely assume the system should have issued an alert. Conversely, if a driver expected an alert but observed that the LDW was unavailable, he or she would not likely have expected the system to issue an alert.

3.1.3. Differences between RDCW and IMS Measurements

Throughout the RDCW on-road system characterization testing, IMS measurements were used as the reference, or "ground truth," source for all analyses. IMS cameras and data post processing provided the TTC, time to CPOI, and all other key system performance measures. The remainder of section discusses differences between IMS and RDCW measurements and describes certain patterns in data discrepancies.

Comparison of LDW and IMS Measurements

The section compares LDW and IMS estimates of the TTC and AMR. The alerts are restricted true-positive lateral-departure alerts. In these cases the mean LDW TTC is 2.9 seconds while mean IMS TTC is 1.6 seconds, indicating the vehicle was, on average, 1.3 seconds closer to departing the road than the LDW estimated. Two reasons account the underestimated TTC: (1) inaccurate LDW estimates of the AMR and (2) many alerts with an AMR less than 1 m.

Figure 3-1 plots the difference between mean IMS and mean LDW TTC as a function of the IMS AMR. The relationship in the figure suggests that the LDW overestimates an AMR less than 1 m, correctly estimates an AMR in a 1 to 2 m range, and underestimates an AMR greater than 2 m. Overestimates of the AMR result in overestimates of the TTC, which explains why the difference between the IMS and LDW TTC is negative for narrow AMRs. Conversely, an underestimate of wide AMRs results in an underestimate of the TTC, which explains why the difference between the IMS and LDW TTC is positive for wide AMRs.

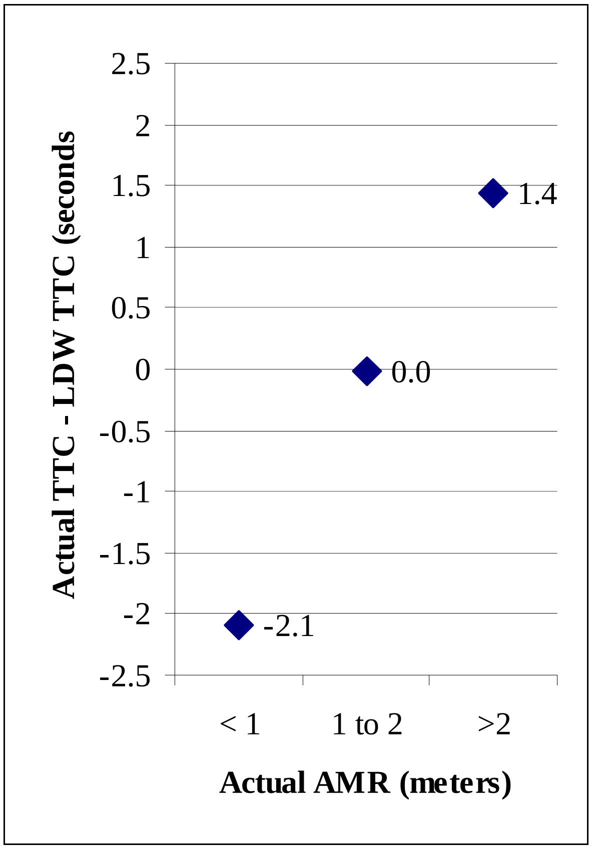


Figure 3-1. TTC Differences for True-Positive Imminent LDW Alerts by IMS AMR

Figure 3-2 supports the explanation given above for discrepancies between IMS and LDW TTCs. The figure plots the difference between mean-IMS and mean-LDW AMR as a function of the actual AMR, where the actual AMR was obtained using a calibrated video tool from NIST. The overestimate of the LDW AMR for small values of the AMR, the accurate estimate for AMRs in the 1 to 2 m range, and the underestimate for AMRs greater than 2 m are all evident in the figure. In general it appeared the LDW selected a moderate or default AMR, which worked well when the AMR was in a 1 to 2 m range, but less well when the AMR was less than 1 m or greater than 2 m. Section 3.2 discusses the implications of this selection on specific lateral-drift scenarios.

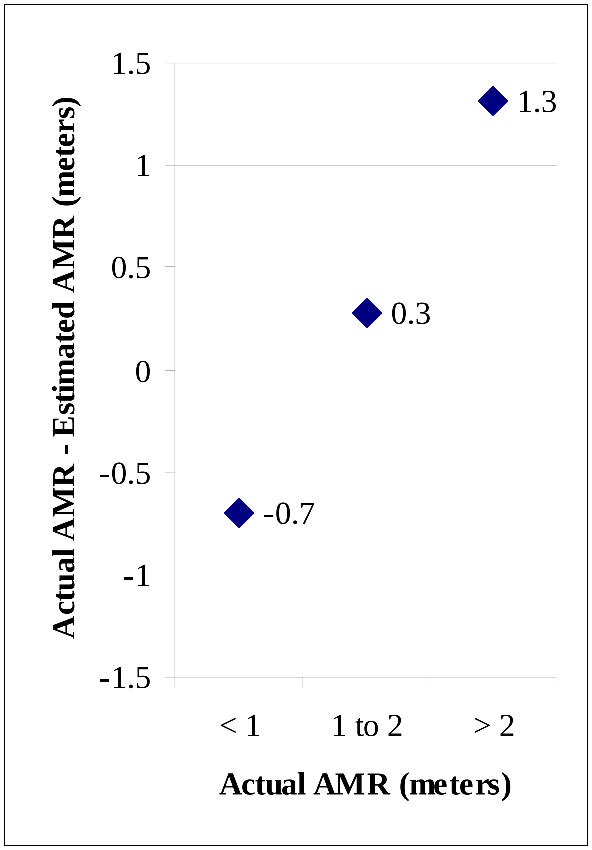


Figure 3-2. AMR Differences for True-Positive Imminent LDW Alerts by Actual AMR

Comparison Between CSW and IMS Measurements

Two measures were used to assess the CSW alert timing: (1) the deceleration required to safely negotiate a curve and (2) the time to reach CPOI. The sample pool included alerts associated with upcoming curves (except Michigan lefts) where a cautionary alert was both needed and issued. Cautionary rather than imminent alerts were analyzed because they were safer to elicit on public roads. Figure 3-3 illustrates the actual and CSW-required deceleration for all true positive CSW alerts.

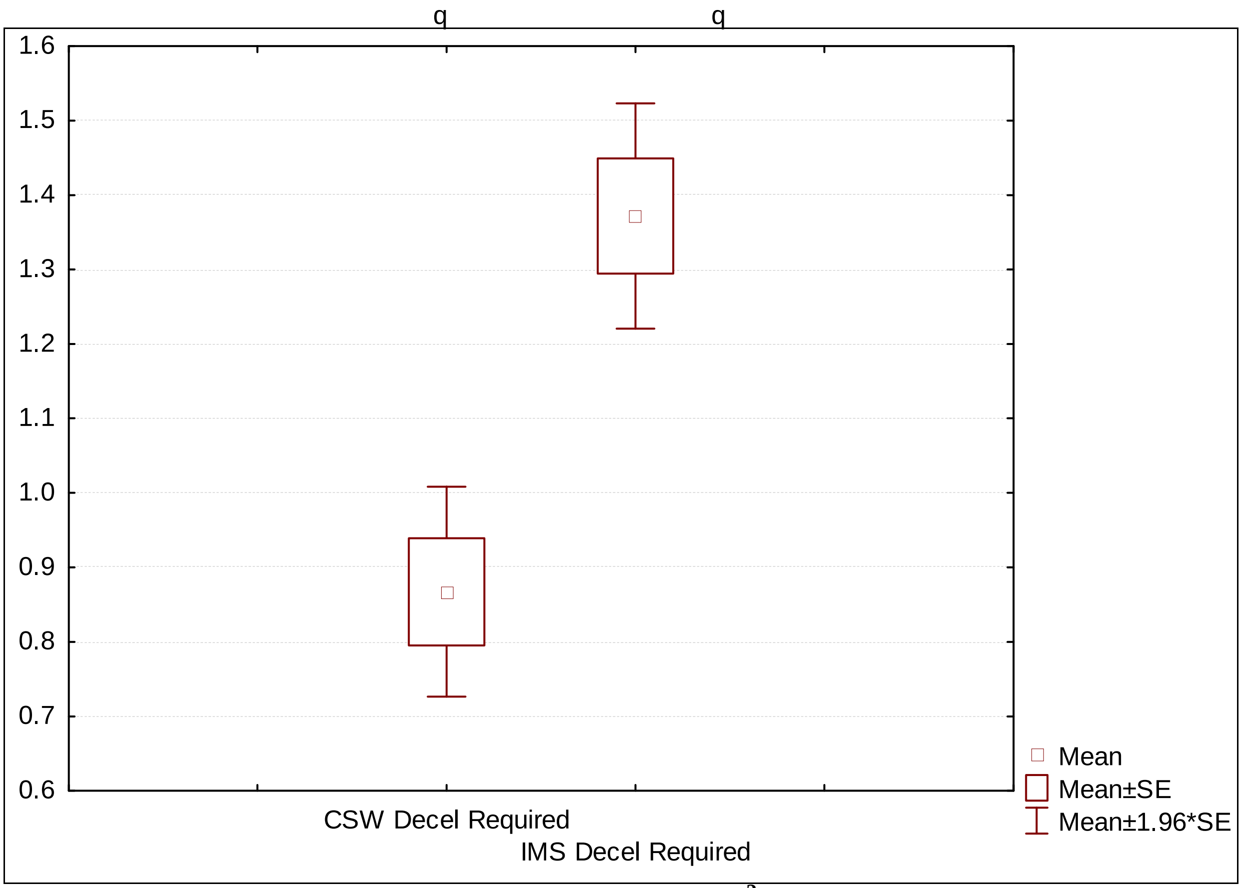


Figure 3-3. CSW and IMS Required Deceleration (m/s^2) for Cautionary CSW Alerts

Figure 3-3 shows the required-deceleration estimate obtained using CSW data is 0.5 m/s^2 less than the value obtained using IMS data. Two discrepancies account for the CSW underestimate: its overestimate of the minimum curvature radius and its overestimate of the distance to the CPOI. The average IMS minimum curvature radius based on yaw rate and speed information from on-board vehicle sensors was 17 percent lower than the radius provided (and used) by CSW.

Figure 3-4 compares the time-to-CPOI when a cautionary alert was issued for CSW and IMS data. This measure was obtained by dividing the distance-to-CPOI by the vehicle speed. The data shows that the actual mean time-to-CPOI, as determined by the IMS, is some 0.9 seconds less than the CSW estimate of this measure. The RDCW tended to underestimate the proximity of the vehicle to the CPOI, i.e., the vehicle was closer than the RDCW estimated. The difference between estimated and actual time-to-CPOI was statistically significant and consistent when broken down by other measures such as curve radius and sensitivity. Section 3.5 provides more details.

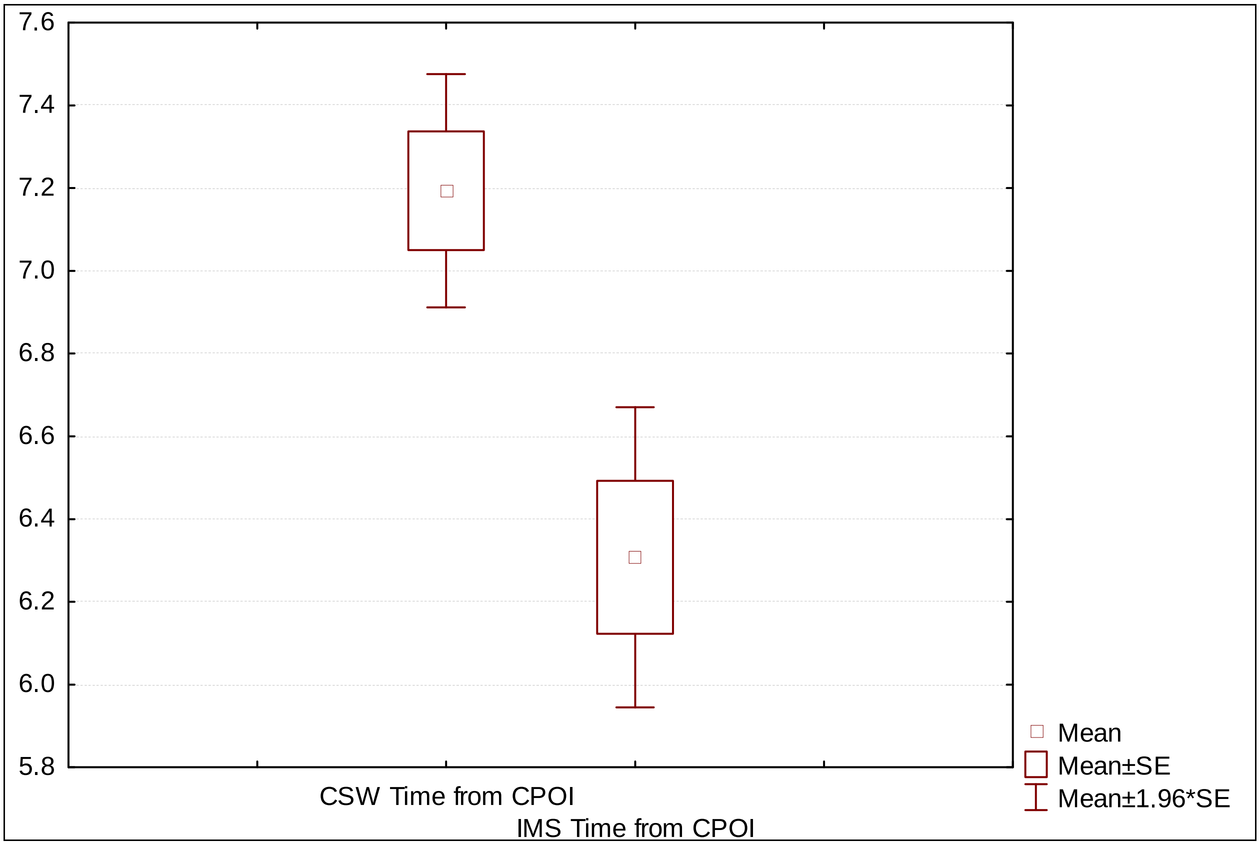


Figure 3-4. CSW and IMS Time to CPOI (seconds) for Cautionary CSW Alerts

3.2 LATERAL DRIFT ALERTS

Several sources provided data to analyze LDW alerts. These included system performance data from targeted on-road lateral drift tests, video analysis of FOT LDW alerts, and participant surveys. We elicited LDW alerts during on-road characterization testing over a wide variety of road and environmental conditions. These alerts fall into the following categories:

- Lateral drift with no obstacle;
- Lateral drift toward vehicle in adjacent lane;
- Lateral drift toward obstacle.

For each of these categories, multiple test runs were conducted on roads with different lane and shoulder widths, lane markings, drift direction, sensitivity settings, adjacent vehicles, and obstacles. Sections 3.2.1 through 3.2.6 describe the results for each of these tests. Section 3.3 presents an analysis of LDW alerts from the FOT. Section 3.4 summarizes FOT subject survey responses.

> - For shoulders less than 1 meter wide, the RDCW overestimated the width by 0.7 meters.
> - For shoulders more than 2 meters wide, the RDCW underestimated the width by 1.3 meters.
> - RDCW shoulder-width estimation errors contributed to:
>
>   1 in 8 false-negative alerts (alert needed but not issued);
>
>   1 in 3 false-positive alerts (alert issued but not needed).
> - The RDCW had the highest percentage of true-positive alerts when the shoulder was 1 to 2 meters wide.

3.2.1. Lateral Drift Sensitivity

Alert sensitivity was set to 3, the middle setting, throughout most of the characterization testing. This ensured consistent system response under all conditions and moderate alert timing, similar to what most FOT participants chose. To understand variations caused by adjusting sensitivity, we conducted a specific test to investigate the effect on alert timing and TTC. The test consisted of repeated drifts of low and high drift rates with system sensitivity set to 1, 3, and 5: the least, moderate, and most sensitive. We conducted the test on a section of road with consistent shoulder and lane width and few roadside objects, none of which affected AMR. However, out of a total 75 alerts, 7 were caused by either objects "seen" by the radar or an object previously marked in the Look Aside Database (LADB). These alerts were excluded from the analysis.

Figure 3-5 illustrates IMS TTC over a range of lateral drift speeds for LDW sensitivity settings of 1, 3, and 5. Although the intention was to conduct lateral drifts at either high or low drift rates, a measurement of lateral drift speed was not available during testing. Consequently, lateral drift rates ranging from 0.11 to 0.62 m/s (according to the IMS) resulted during the testing. A positive outcome of this lateral velocity distribution was the opportunity to observe the relationship between TTC and lateral velocity. For each sensitivity setting, IMS TTC decreased as lateral velocity increased i.e., less severe lateral drifts resulted in earlier warnings than more abrupt lateral drifts. This relationship was true for all sensitivity settings.

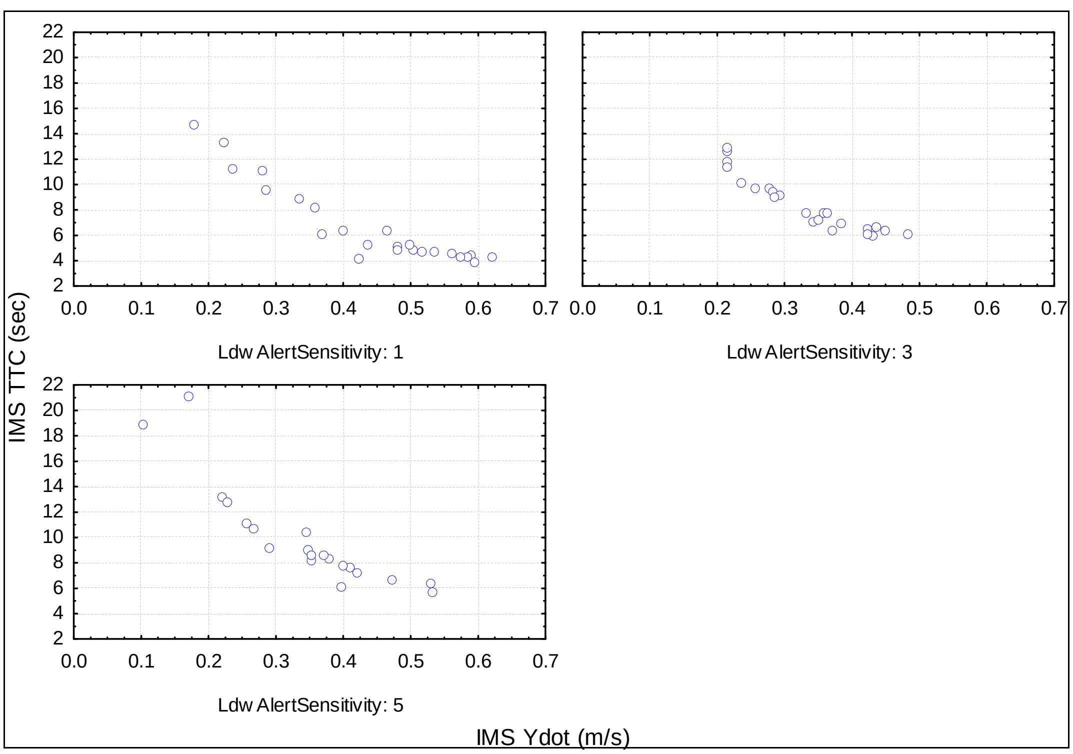


Figure 3-5. TTC by Lateral Drift Speed and Sensitivity Level

An analysis of the data in Figure 3-5 shows higher sensitivity settings result in higher TTC values. Sensitivity settings of 1, 3, 5 had corresponding average TTC values of 6.6, 8.4, and 9.7 seconds. Of the 68 alerts analyzed, only 11 had a TTC in the 1.5 to 5.0 second range. The remaining 57 alerts had TTC values greater than 5 seconds. Underestimation of large AMRs likely caused the RDCW to issue alerts early, resulting in the large TTC values. The shoulder width for all departures conducted during this test was greater than 2 m and the high number of alerts with TTC values greater than 5 seconds is consistent with RDCW and IMS comparison findings in Section 3.1.3.

3.2.2. Drift Toward Solid Lane Boundary

Solid lane boundaries denote a travel lane edge that should not be crossed in most driving situations. In this test we examined the ability of the LDW to recognize solid left and right lane boundaries and issue an alert that accounted for the AMR beyond the lane marker. Figure 3-6 summarizes the results from these alert-needed tests. Thirty-one alerts (13%) were missed when the system was available, a solid lane boundary was crossed, and a road departure occurred or was imminent. Although testing did not measure how many true-negative alert situations we identified correctly, these 31 alerts provide a measure of how many alerts should have been issued but were not. Twenty-five of the 31 missed alerts occurred on roads with narrow shoulders less than 1 m, suggesting the system likely overestimated the AMR.

Other results relating to missed alerts include:

- 42 percent occurred at night (all missed night alerts occurred on one nighttime trip – there was a possible system error for this trip since there were no missed alerts on other night trips);
- 87 percent occurred on non-freeways;
- 65 percent had fair and 35 percent had poor road markers (based on a subjective judgment by the analyst);
- 39 percent of daytime situations had glare due to low sunlight conditions; and
- 55 percent occurred to the right and 45 percent to the left.

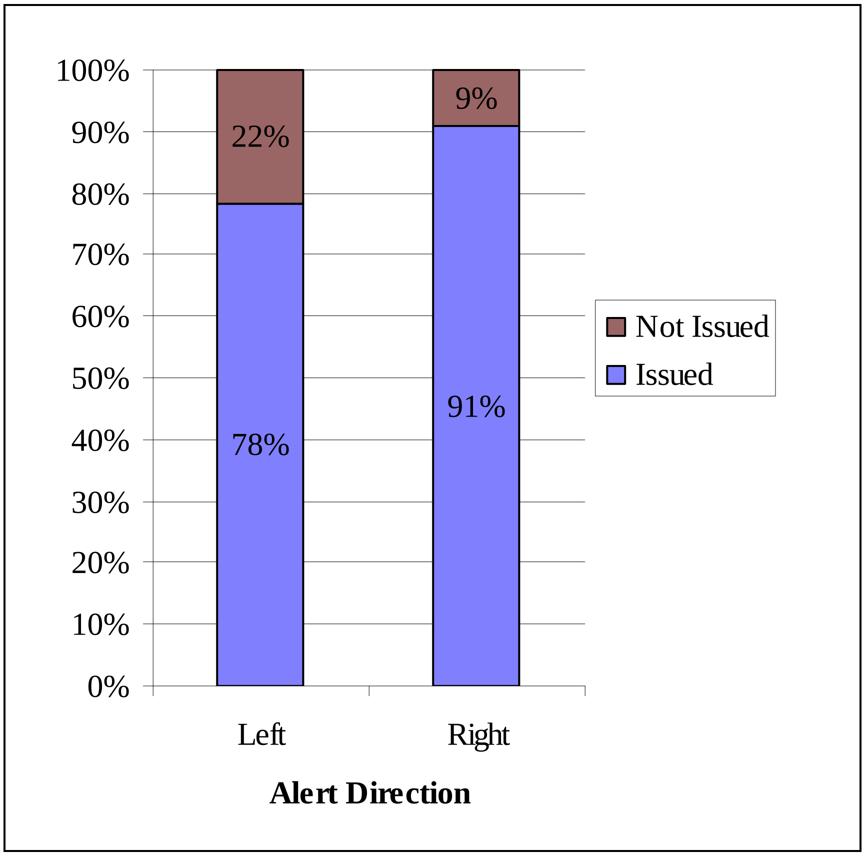


Figure 3-6. Alert Issuance by Direction for Solid Lane Boundary

Figure 3-6 considers situations in which an alert was required and summarizes the data by direction (left, right) and alert status (issued, not issued). Figure 3-7 considers situations in which an alert was issued and summarizes the data by direction and alert validity (true positive, false positive). The vehicle position in the lane, lateral velocity, and available maneuvering room are all factors in determining if an alert was required or not. In these analyses, an alert was needed when the TTC (at the time the alert was issued) was less than 5 seconds. If TTC was greater than 5 seconds, the alert was categorized as a false positive. Although some drivers may find these alerts useful, the assumption was that the majority of drivers would consider a warning with this much advance notice unnecessary. Combined left and right false-positive alerts accounted for 46 percent of all alerts within this analysis. Most false-positive situations occurred when the LDW subsystem underestimated the AMR. The average AMR was 2.9 m for these situations while the average LDW AMR was 1.4 m. Left alerts had a lower false-positive percentage because of the generally lower AMR on the left side than on the right side, 0.9 m and 2.1 m, respectively. Section 3.1.3 discusses inaccuracies in the LDW AMR values.

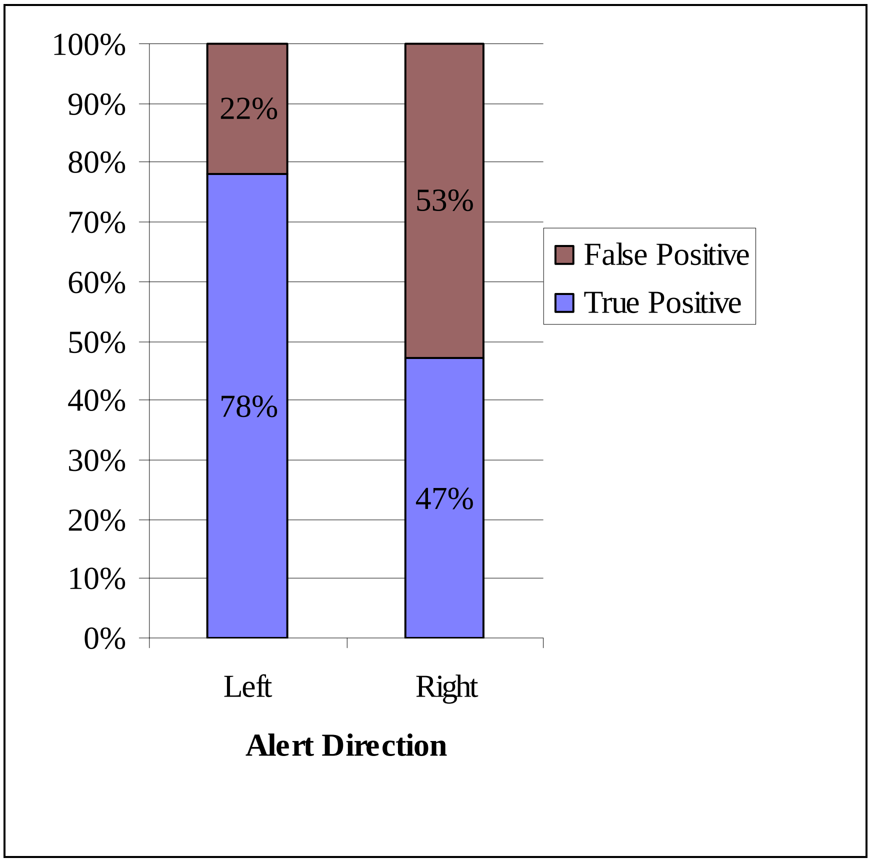


Figure 3-7. Alert Validity by Direction for Solid Lane Boundary

Figure 3-8 illustrates the influence of the AMR on alert timing. On roads with narrow shoulders, 75 percent of the alerts had a TTC less than 1.5 second. In contrast, with wide shoulders 84 percent of the alerts had a TTC greater than 5 seconds. The data suggests that the LDW did not account for the AMR, alerting too late on roads with narrow shoulders and too early on roads with wide shoulders. On roads with medium shoulders, 1 to 2 m, 63 percent of the alerts had a TTC in the range 1.5 to 5 seconds.

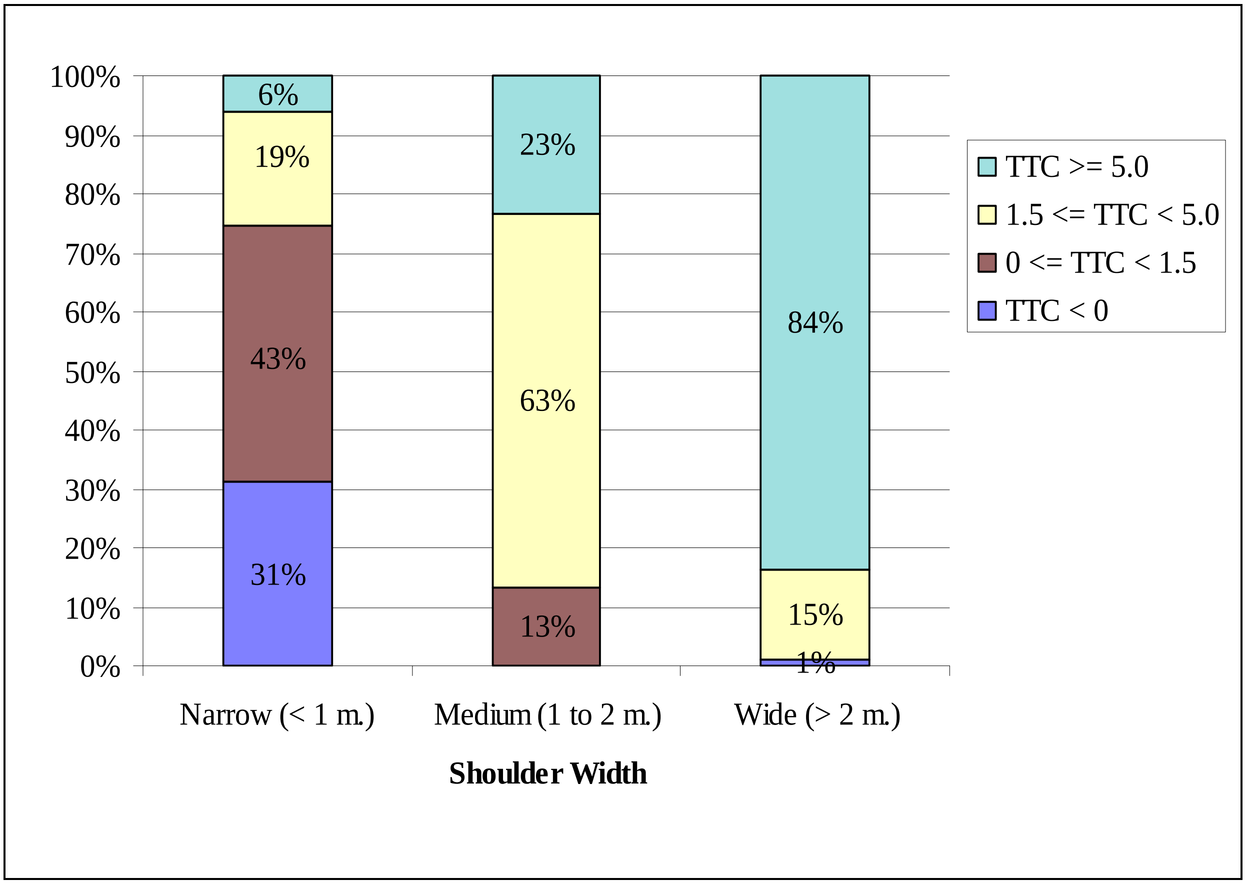


Figure 3-8. TTC by Shoulder Width for Solid Lane Boundary

3.2.3. Drift Toward Dashed Boundary

The majority of LDW characterization tests explored the system's ability to alert the driver in crash-imminent scenarios. The testing did, however, include tests for cautionary alerts. Of the 79 trials involving the test vehicle crossing a dashed boundary without a turn signal, 68 produced alerts and 11 did not. These missed alerts occurred under the following conditions: freeway, either poor or fair lane markings, 9 day and 2 night lighting, and 6 cloudy atmosphere. System difficulty in tracking lane markings or temporary unavailability (Section 3.1.2) accounted for the missed alerts.

Of the same 79 dashed-boundary trials, 17 resulted in imminent alerts. Of these, 6 were caused by radar returns from unknown objects, i.e. no visible object or vehicle was seen in the side or forward cameras in the adjacent lane. Eight resulted from the system mistakenly identifying a dashed lane marker as a solid lane marker.

For all dashed lane markers, we established the TTC using the inside edge of the lane marker plus 1 m of AMR beyond the marker. We selected the AMR based on a reasonable and safe amount of distance allowed beyond a striped boundary when no vehicle was present in the adjacent lane. The AMR value does not reflect the value used by the LDW subsystem nor does it imply that this is the correct value to use in all situations.

Figure 3-9 provides a breakdown of dashed-boundary alerts by both direction and TTC range. Nearly two-thirds of the alerts, 42 of 68, had a TTC less than 1.5 s, one-third had a TTC between 1.5 and 5.0 s and three had TTC greater than 5 seconds. On average, the system issued a cautionary alert with a 2 second TTC, calculated using the datum of the 1 m AMR outside the lane boundary. With the dashed lane boundary itself as the datum, the LDW alerts had an average TTC of -0.4 s, meaning the alert was issued *after* the vehicle crossed the boundary. This is expected and is not a safety concern because this was a lane-departure scenario, not a road-departure scenario.

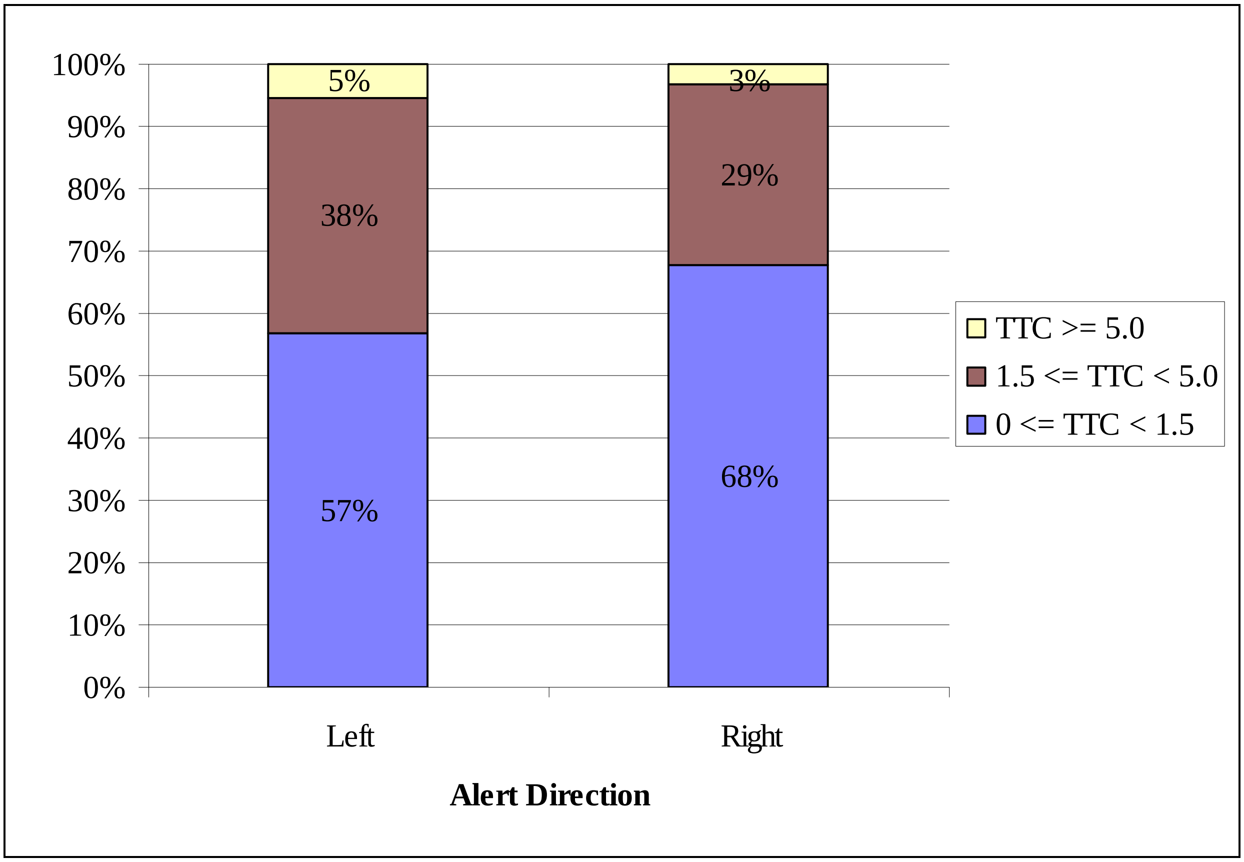


Figure 3-9. TTC Breakdown When Crossing a Dashed Boundary, Based on 1 m Outside Boundary

3.2.4. Drift toward Vehicle Traveling in Adjacent Lane

The LDW was designed to address many types of road drift crash scenarios, including drift toward a vehicle traveling in an adjacent lane. This test was conducted on multilane freeways with the adjacent vehicle traveling at approximately the same speed. The side of the adjacent vehicle determined the AMR limit. This test included 39 samples of an alert being issued (both true positive and false positive) or an alert being required but not issued. Table 3-8 provides a breakdown of these samples.

Table 3-8. Alerting Results for Drift Toward Adjacent Vehicle

Alert Issued	Alert Needed	
	Yes	No
Yes	23	8
No	8	

The 8 false-positive alerts (alert issued but not needed) were evenly split between four on the left side and four on the right side. The false-positives were categorized as such because of TTC values greater than 5 seconds. Indeed, the 8 false-positive alerts had an average TTC of almost 17 seconds. These alerts occurred in similar environmental conditions and were split between good and fair road markings.

Figure 3-10 breaks down the 31 alert needed situations by missed alerts (alert needed but not issued) and true-positive (alert needed and issued) alerts. All 16 right-side situations requiring an alert received one, but only 7 alerts were issued out of 15 trials on the left side. For part of the test period the left-side radar sensor was not working properly, which could explain 7 of 8 missed alerts. The system did not announce this missing capability by making the LDW subsystem left unavailable. If those alerts are removed from the analysis only one alert was not issued when required. For the 23 alerts issued in situations where an alert was needed, all the alerts fell within a 1.5 to 5.0 second TTC range and were true positive. These results, combined with the above failed sensor caveat, show the system provides consistent and timely alerts for vehicles in adjacent lane situations.

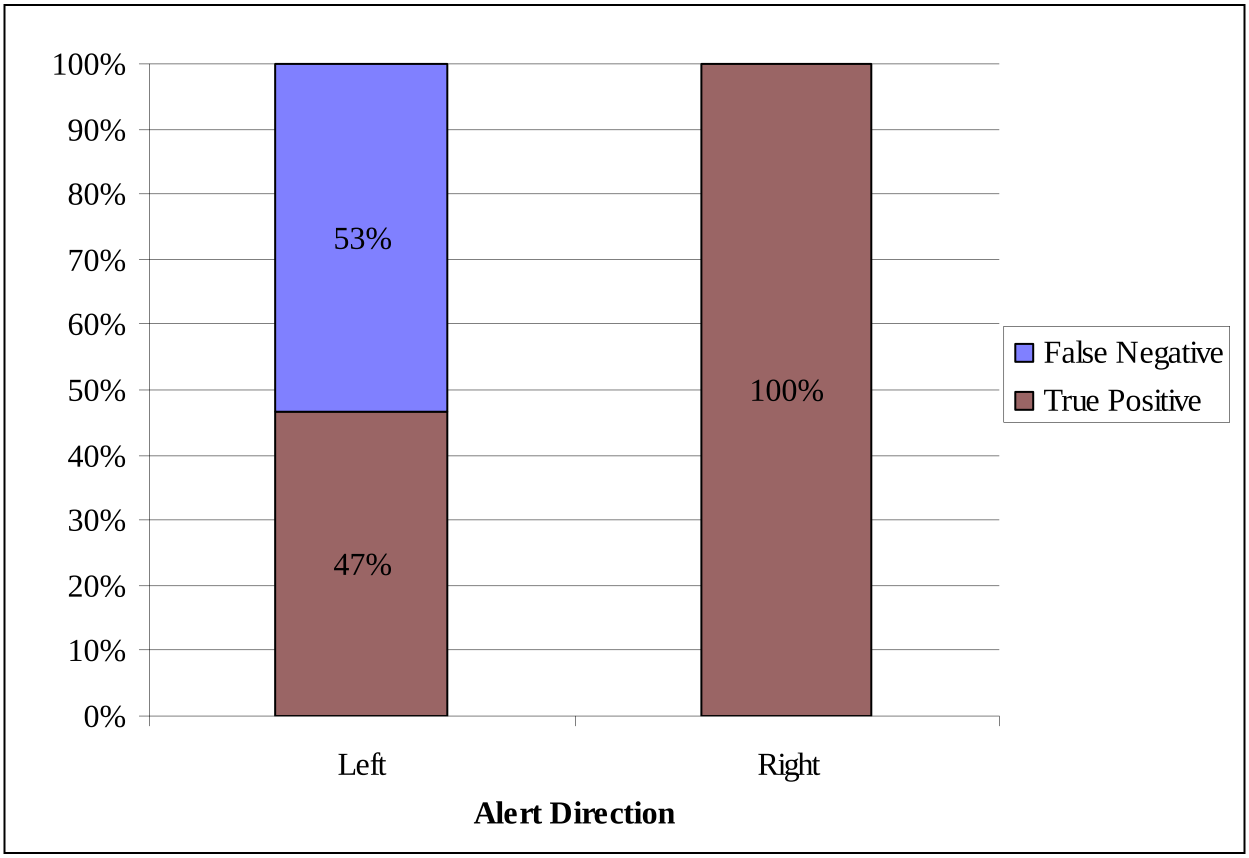


Figure 3-10. Alert Issued by Direction When Drifting Toward Vehicle in Adjacent Lane

3.2.5. Drift toward Parked Vehicle

This test evaluated the ability of the LDW to detect and alert when drifting toward a parked vehicle that the vehicle had not passed previously. This test was conducted on a rural two-lane road with a narrow paved shoulder. A second vehicle was parked with its left side approximately 0.5 m outside the lane marker. For each trial, the second vehicle was moved so that the look aside database would not learn its location. Because the second vehicle was parked without exact measurement of its distance from the lane marker, the system experienced a range of conditions, similar to what it would encounter in actual driving.

Of the 11 trials, 10 produced alerts. The missed alert occurred when the test vehicle was heading toward the parked vehicle but never actually crossed the lane boundary. The missed alert was classified as such because the test vehicle was in very close proximity to the parked vehicle. Six of the 10 alerts had a TTC greater than 1.5 seconds. The mean TTC was 1.8 seconds and the lowest TTC was 1.1 seconds. Although 4 of the alerts were late, with a TTC less than 1.5 seconds, most of the 10 provided sufficient time for a driver to react and avoid a collision. Of note: the system flagged only 3 alerts as being caused by a radar object. The system issued the remaining 7 alerts based on default LDW information and did not alter the alert timing to account for the parked car.

3.2.6. Jersey Barrier and Construction Barrel

Jersey barriers are temporary concrete walls placed along the side of the road in construction areas, as a boundary in place of guardrails. Construction barrels are plastic tubes about the size and shape of a 55-gallon drum and are used to temporarily close lanes. The goal of the test was to see how well the system responded when the vehicle drifted toward these objects. Some objects were approached only once during testing while others were approached multiple times, allowing the system to potentially use information from previous tests to adjust the alert. The test included 31 approaches, 21 toward Jersey barriers and 10 toward construction barrels.

Table 3-9 illustrates alert need and issuance by direction. Three approaches produced false-positive alerts because the LDW interpreted the object as being closer to the vehicle than it actually was. The table also shows 7 missed alerts. The missed alerts occurred during the day under dry and clear conditions on freeways with a 1.0 m AMR.

Table 3-9. Alerting Results for Jersey Barriers and Traffic Barrels

Alert Issued		Alert Needed				Total
		Yes		No		
		Left	Right	Left	Right	
Yes	Count	19	2	0	3	24
	Row Percent	61%	6%	0%	10%	77%
No	Count	5	2	0	0	7
	Row Percent	16%	6%	0%	0%	23%

Figure 3-11 provides a breakdown of Jersey barrier and traffic-barrel alerts by both direction and TTC range. The system responded later to obstacles on the left, with 37 percent of the left-side alerts having a TTC less than 1.5 seconds and 60 percent of the right-side alerts having a TTC greater than 5 seconds. Incorrect radar readings of the lateral distance appeared to account for the system’s occasional failure to issue alerts on time (both early and late). Over the 31 trials, 24 on the left, the respective left and right AMR averaged 0.9 m and 1.5 m. This difference contributed to the association between the left side and a higher percentage of late alerts.

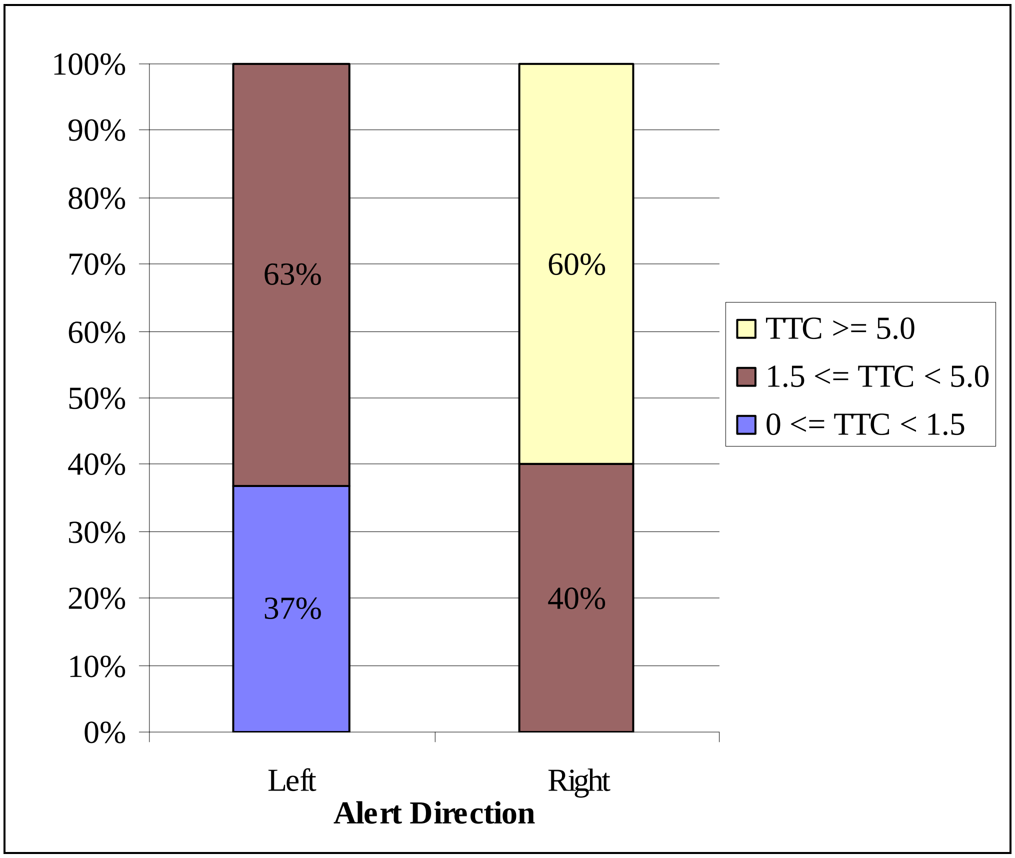


Figure 3-11. TTC When Drifting Toward Jersey Barrier or Traffic Barrel

3.3 FOT LATERAL-DRIFT-WARNING VIDEO ANALYSIS

RDCW FOT alerts were analyzed using a video logger tool. Following the instruction set shown in Appendix C (logger manual), video analysts loaded video and data files into the logger, played the video, and described the circumstances surrounding LDW and CSW imminent alerts. This manual analysis supplements the DAS information and provides a comprehensive understanding of the RDCW alert scenarios.

- The Volpe Center analyzed 3,800 alerts using video and numerical data.
- Of the 3,800 alerts, 62 percent were true positive.
- In dry weather 70 percent of the alerts were true positive; decreasing to 39 percent in rainy weather.
- On wet surfaces 44 percent of the alerts were true positive.
- On a scale of 1 to 7, participants rated the LDW alert timing favorably- above 5.

A gender-and-age-balanced mix of 66 of the 78 FOT participants was analyzed. The information recorded relates to driver safety and device performance. The GES coding manual provided numerous descriptive elements. Other elements relate to driver attention and distraction. Still others objectively describe the need for an alert. The goal was to obtain data to distinguish between true- and false-positive alerts.

The first step involved assigning 1 of 7 vehicle-maneuvers and an alert need rating to each LDW FOT alert. Alert need was rated on a 1 to 5 scale, based on the necessity of an alert given the situation at the time of alert. Appendix C (logger manual) provides more details. Alert-need ratings of 4 (probably not needed) or 5 (definitely not needed) were later grouped into a false-positive rating, and ratings of 1 (definitely needed) or 2 (probably needed) were grouped into a true-positive rating.

Table 3-10 shows that of the 3,789 LDW imminent alerts analyzed, 2,363 (62%) were true positive. The highest percentage of true-positive alerts, 75 percent, occurred on a curve, while 59 percent of the "going-straight" alerts were true positive. Conversely, 1,426 (38%) of the imminent alerts were false positives. The highest percentage, 65 percent, occurred during lane changes, and the second highest, 61 percent, occurred while entering a ramp.

Table 3-10. LDW Alert Classification by Vehicle Maneuver

	Maneuver	False Pos	True Pos	Row Totals
Count	**Lane Change**	264	141	**405**
Row Percent		65.19%	34.81%	
Total Percent		6.97%	3.72%	**10.69%**
Count	**Going Straight**	699	999	**1698**
Row Percent		41.17%	58.83%	
Total Percent		18.45%	26.37%	**44.81%**
Count	**On Curve**	376	1154	**1530**
Row Percent		24.58%	75.42%	
Total Percent		9.92%	30.46%	**40.38%**
Count	**Passing**	42	34	**76**
Row Percent		55.26%	44.74%	
Total Percent		1.11%	0.90%	**2.01%**
Count	**Merging**	22	21	**43**
Row Percent		51.16%	48.84%	
Total Percent		0.58%	0.55%	**1.13%**
Count	**Entering Ramp**	22	14	**36**
Row Percent		61.11%	38.89%	
Total Percent		0.58%	0.37%	**0.95%**
Count	**Turning**	1	0	**1**
Row Percent		100.00%	0.00%	
Total Percent		0.03%	0.00%	**0.03%**
Count	**All Groups**	1426	2363	**3789**

	Maneuver	False Pos	True Pos	Row Totals
Total Percent		**37.64%**	**62.36%**	

As noted, a high percentage of false positives were associated with lane changes. The video analyst examined lane markings to determine the need for an LDW imminent alert, but did not examine RDCW radar data to determine if there was an adjacent vehicle present during the lane change. The video view displayed only the forward scene with a moderate field of view to the analyst. There was no side view to determine the presence of adjacent vehicles. During most unsignaled lane changes, the lane marker in the direction of the lane change was striped, and the analyst coded an imminent alert as *not required*, i.e., a false positive. Many of these imminent alerts were likely due to the presence of an unobserved adjacent vehicle, so the 65 percent false-positive rate in Table 3-10 does not reflect the true false-positive rate of alerts issued during this maneuver. For this reason, the 405 lane-change alerts were excluded from subsequent video-data-based analyses.

Table 3-11 also tabulates the LDW alerts by vehicle maneuver, but does not include lane changes. Excluding these 405 alerts leaves 3,384 alerts for subsequent analysis and increases the true-positive percentage from 62 to 66 percent.

Table 3-11. LDW Alert Classification by Vehicle Maneuver Without Lane Changes

	Maneuver	False Pos	True Pos	Row Totals
Count	**Going Straight**	699	999	**1,698**
Row Percent		41.17%	58.83%	
Total Percent		20.66%	29.52%	**50.18%**
Count	**On Curve**	376	1154	**1,530**
Row Percent		24.58%	75.42%	
Total Percent		11.11%	34.10%	**45.21%**
Count	**Passing**	42	34	**76**
Row Percent		55.26%	44.74%	
Total Percent		1.24%	1.00%	**2.25%**
Count	**Merging**	22	21	**43**
Row Percent		51.16%	48.84%	
Total Percent		0.65%	0.62%	**1.27%**
Count	**Entering Ramp**	22	14	**36**
Row Percent		61.11%	38.89%	
Total Percent		0.65%	0.41%	**1.06%**
Count	**Turning**	1	0	**1**
Row Percent		100.00%	0.00%	

	Maneuver	False Pos	True Pos	Row Totals
Total Percent		0.03%	0.00%	**0.03%**
Count	**All Groups**	1,162	2,222	**3,384**
Total Percent		**34.34%**	**65.66%**	

3.3.1. Light Level

The effect of light level on LDW performance was analyzed by calculating the odds ratio of the association between light level and true- and false-positive alerts. Table 3-12 shows although only 36 percent (1,221 of 3,384) of the alerts occurred during the “Other” light category (dawn, dusk, or night), 45 percent of the false-positive alerts occurred under these conditions. Based on the alert counts and categories in the table, the odds of receiving a false-positive alert in light other than daylight are 1.8 times the odds during daylight. Equivalently, the odds of a true positive during daylight are 1.8 times the odds in light other than daylight. However, both system characterization and FOT data indicated that the LDW was available less during daylight than during dark or other light conditions. This suggests that although the LDW subsystem may indicate availability at night, it appears not to calculate vehicle position as accurately, resulting in a higher incidence of false positives at night.

Table 3-12. LDW Alert Classification by Light Level

Light Level	False Pos	True Pos	Row Totals
Other	523	698	1,221
Column %	45.01%	31.41%	
Row %	42.83%	57.17%	
Day	639	1524	2,163
Column %	54.99%	68.59%	
Row %	29.54%	70.46%	
Totals	1162	2222	3,384
Total %	34.34%	65.66%	100.00%

3.3.2. Precipitation

The next analysis examines the effect of atmospheric precipitation on LDW subsystem performance, categorizing weather as Dry or Rain. Excluded from this analysis are 40 alerts with either snow or fog conditions. The data in Table 3-13 show that 61 percent of the alerts in the rain were false positives. The data also indicate that while only 13 percent (421 of 3344) of the alerts in this sample occurred in rainy weather, 22 percent of all false-positive alerts occurred in rainy weather. The odds of a false positive while driving in rain are 3.6 times the odds of those driving in dry weather. In addition, LDW rain availability during the FOT was 20 percent lower than dry conditions. In rain the system had difficulties in identifying and tracking lane markings and in issuing valid alerts.

Table 3-13. LDW Alert Classification by Atmosphere

Atmosphere	False Pos	True Pos	Row Totals
Rain	256	165	421
Column %	22.40%	7.50%	
Row %	60.81%	39.19%	
Dry	887	2036	2,923
Column %	77.60%	92.50%	
Row %	30.35%	69.65%	
Totals	1143	2201	3,344
Total %	34.18%	65.82%	100.00%

3.3.3. Road Surface Moisture

The effect of road surface moisture on LDW subsystem performance was also analyzed, with road surface categorized as Dry or Other. Although this measure often matches the atmosphere variable, there are some cases where it differs. The Other category consists of samples from wet roads and a few samples from snowy roads. Table 3-14 shows that while 19 percent (639 of 3,384) of LDW alerts occurred on Other roads, 31 percent of the false positives occurred on these roads. An analysis of the count data reveals that the odds of a wet-surface alert being a false positive are 3 times the odds of a dry-surface alert being a false positive. Overall, 56 percent of the wet-surface alerts were false positives; 5 percent lower than rain atmosphere false positive percentage in Table 3-13, while the false-positive odds ratio was 0.5 lower, indicating that rain produced slightly higher false-positive rates than Other surface conditions.

Table 3-14. LDW Alert Classification by Surface Moisture

Surface Moisture	False Pos	True Pos	Row Totals
Other	356	283	639
Column %	30.64%	12.74%	
Row %	55.71%	44.29%	
Dry	806	1939	2,745
Column %	69.36%	87.26%	
Row %	29.36%	70.64%	
Totals	1,162	2,222	3,384

Surface Moisture	False Pos	True Pos	Row Totals
Total %	34.34%	65.66%	100.00%

3.3.4. Construction Zone

Construction zones usually include a combination of temporary lane markers, construction barrels, Jersey barriers, and pavement irregularities. Any one of these items can cause spurious readings by LDW sensors and consequently cause the system to issue false-positive alerts. Table 3-15 classifies LDW alerts by the presence or absence of a construction zone. The data show that 6 percent of the false positives occurred in a construction zone, but only 5 percent (165 of 3,384) of all alerts occurred in these zones. The odds ratio is 1.6, indicating the odds of a construction-zone alert being a false positive are 1.6 times the odds of an alert outside of a construction zone being a false positive. The odds ratio is close to the odds ratio associated with light level in Table 3-12. Thus the increased odds of the system issuing a false positive in a construction zone are close to the increased odds at night. The construction zone FOT false-positive rate, 45 percent, is nearly double that of the characterization test rate, 23 percent, discussed in Section 3.2.6. Since the FOT data provides a much larger alert sample pool, the 45 percent false-positive rate observed in FOT data is more likely to be the rate observed in practice.

Table 3-15. LDW Alert Classification by Construction Zone

Construction Zone	False Pos	True Pos	Row Totals
Yes	74	91	165
Column %	6.37%	4.10%	
Row %	44.85%	55.15%	
No	1088	2131	3,219
Column %	93.63%	95.90%	
Row %	33.80%	66.20%	
Totals	1,162	2,222	3,384
Total %	34.34%	65.66%	100.00%

3.3.5. Pavement Marking

Convergent or divergent pavement markings occur where two lanes merge or a single lane divides. Like temporary lane markings or construction hardware, these markings may cause spurious LDW readings and alerts.

Table 3-16 classifies LDW alerts by pavement markings: Atypical (convergent or divergent) and Typical. While only 7 percent (246 of 3,384) of the LDW alerts occurred around atypical markings, 15 percent of the false positives occurred around these markings. The odds of a false positive occurring around atypical pavement markings were 5.3 times the odds around typical pavement markings.

Table 3-16. LDW Alert Classification by Pavement Marking

Pavement Marking	False Pos	True Pos	Row Totals
Atypical	174	72	246
Column %	14.97%	3.24%	
Row %	70.73%	29.27%	
Typical	988	2,150	3,138
Column %	85.03%	96.76%	
Row %	31.49%	68.51%	
Totals	1,162	2,222	3,384
Total %	34.34%	65.66%	100.00%

3.4 SUBJECTIVE RESPONSE TO LATERAL DRIFT SURVEY

FOT participants rated LDW subsystem performance by responding to several survey questions related to warning timing, need, and necessity. The questions were scaled from 1 (strongly disagree) to 7 (strongly agree). The analyses to these survey questions include mean values and standard deviations. Participant responses were also grouped into *agreement* (scales 5-7), *neutral* (scale 4), and *disagreement* (scales 1-3). Figure 3-12 illustrates mean and standard deviation values for the following two questions relating to alert timing:

1. Overall, I thought the LDW auditory warnings were provided at the right time (i.e., they were not presented too early or too late).
2. Overall, I thought the LDW seat vibration warnings were provided at the right time (i.e., they were not presented too early or too late).

Based on the three groups described above, 78 percent of the participants agreed with the timing of LDW seat vibration warnings, while 71 percent agreed with the timing of LDW auditory warnings. Although analysis in previous sections showed mixed results for LDW alert timing, roughly three-fourths of the participants believed the alerts were appropriately timed.

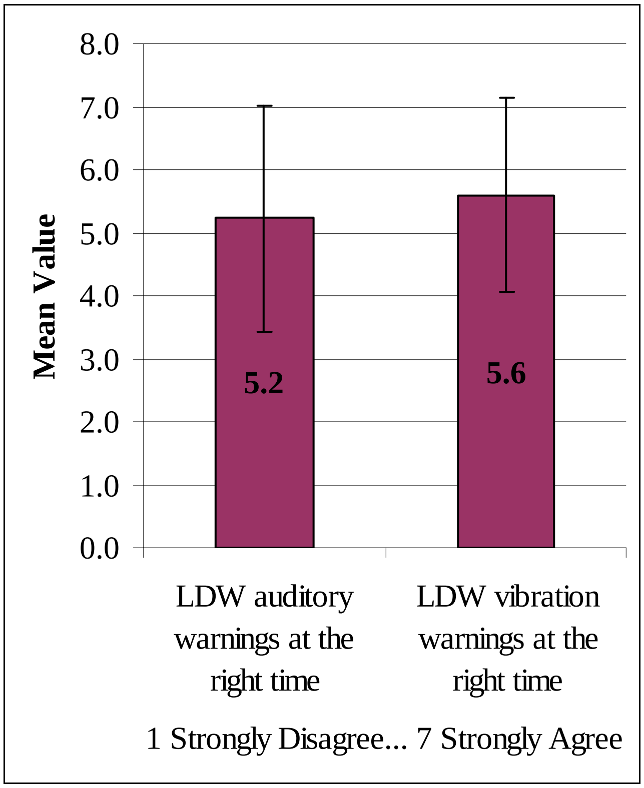


Figure 3-12. Subjective Responses to LDW Alert Timing

Figure 3-13 illustrates survey responses to three questions relating to LDW alert need and false alerts:

1. The LDW always provided a warning when I thought it should.
2. I did not receive any unnecessary LDW warnings.
3. I did not receive any false LDW warnings.

The first question, with a follow up question asking participants to describe situations where the LDW did not issue a warning when expected, generated a 48 percent agreement, 35 percent disagreement and 17 percent neutral subjective response. The second question relating to unnecessary warnings generated a 42 percent agreement, while the third questions relating to unnecessary and false alerts generated a 52 percent agreement. Forty-four percent of participants disagreed with the question “I did not receive any unnecessary LDW warning.” This result is supported by the findings in the LDW FOT alert analysis of false-positive rates in Section 3.3.

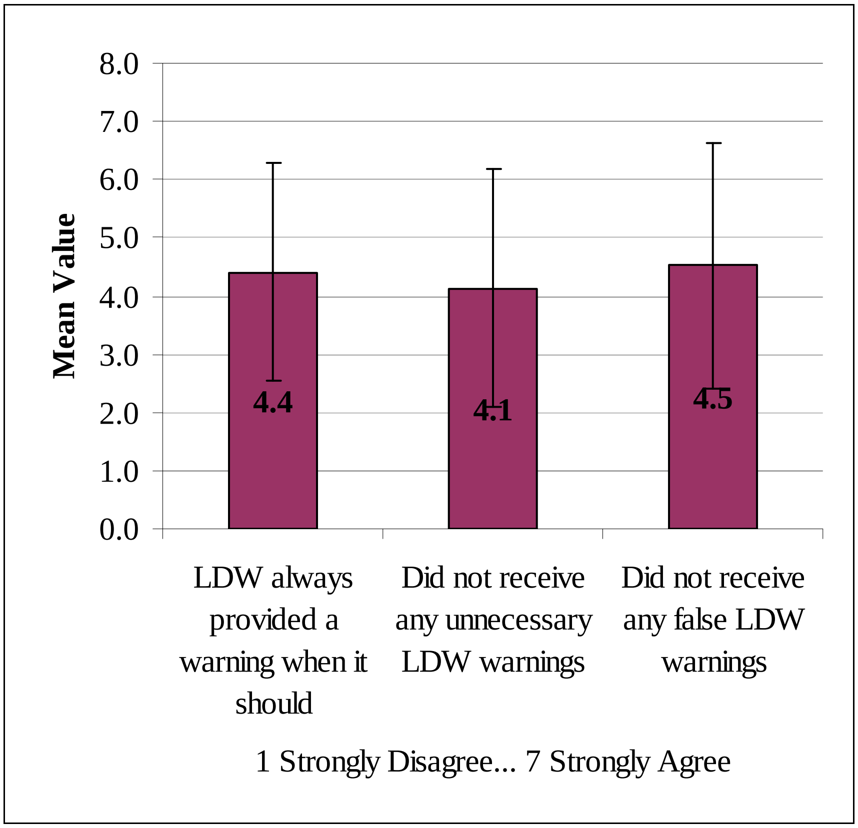


Figure 3-13. Subjective Responses to LDW Alert Need and False Alerts

Finally, participants had a mean response of 3.9 to the question "I found the LDW useful in adverse weather conditions." Thirty-three percent agreed, 41 percent disagreed, and 25 percent answered neutrally. This agrees with the previous assessments that showed much higher false-positive odds ratios and lower availability in adverse weather, particularly at night.

3.5 CURVE-SPEED ALERTS

This section analyzes CSW alert performance. The data sources include on-road characterization test data for particular curve scenarios and FOT subject response to survey questions. Although the FOT provided many CSW alert episodes, the data could not be analyzed in the same way the LDW data was analyzed. The FOT LDW alerts analyzed in Section 3.2 were categorized as a true-positive or a false-positive (based on lane markings, vehicle position, and lateral speed gleaned from video analysis) with little or no ambiguity. CSW alerts, however, did not lend themselves to an unambiguous true- or false-positive video-based categorization. Use of the CSW data to categorize alerts would not have helped matters, because the CSW data would naturally indicate an alert was needed when one was issued and not needed when one was not issued. CSW FOT data are thus not used for analyses in this section. The two remaining data sources, characterization test data and survey responses, provide an accurate and comprehensive measure of CSW alert logic performance.

On-road characterization testing generated alerts over a wide variety of road conditions in the following categories:

1. Approach curves of different radii;
2. Pass or take exit ramps or U-turns.

For each of these categories we analyzed multiple outcomes, including alert need and alert timing (quantified using time to CPOI and required deceleration) based on derived safety measures. In addition to analyzing issued alerts, we also analyzed situations where safety criteria indicated an alert was needed, but an alert was not issued.

- When an alert was required on a curve with a radius less than 100 meters, the RDCW missed 1 out of 5 times.
- When an alert was required on a curve with a radius greater than 100 meters, the RDCW missed 2 out of 5 times.
- Of the alerts issued on curves whose radius was less than 100 meters, 94 percent were on time, neither too early nor too late.
- On a scale of 1 to 7, participants rated the CSW alert timing favorably; at 5.

3.5.1. By Sensitivity

During most of the on-road characterization test, the CSW sensitivity was generally set to a middle level of 3. The intent was to have consistent system response under all conditions. For curve speed sensitivity tests, however, the CSW response over a two by three matrix of approach speeds and sensitivity settings was analyzed. The test was conducted on a freeway cloverleaf interchange, which allowed repeated runs on nearly identical curves. Two approach speeds, 40 mph (64 kph) and 50 mph (80 kph), were used, which accommodated the needs to maintain safety on public roads and to illicit alerts at all sensitivity settings. To minimize variability and lower alert thresholds within the CSW alert decision logic, all tests were conducted using active turn signals and activated wipers. Sensitivity testing took place over a narrow temperature range, 0 to -2 degrees Celsius, which eliminated the possibility of temperature effects confounding the alert timing.

Of the 147 alerts issued during sensitivity testing, 38 were imminent and 109 were cautionary. Since cautionary alerts were easier to obtain and a greater number were available for analysis, this analysis focused on cautionary alerts. Of the 109 cautionary alerts, 25 were issued after a previous cautionary alert while approaching the same curve or near the end of the curve as the vehicle accelerated for the next exit ramp. These alerts were removed from the analysis because the system had either already issued an alert or the situation did not relate to an upcoming curve. We also removed one alert from the analysis because it was issued too close to the CPOI to calculate the required deceleration. Required deceleration, one of the derived performance measures, is the deceleration required to negotiate a curve at a safe speed once it reaches the CPOI. The required deceleration calculation assumes a 1.5 second reaction time (after the alert) to brake the vehicle. Section 3.1.2 provides more details on this calculation. Of the 109 original cautionary alerts, 83 remained for analysis.

Table 3-17 summarizes the 83 cautionary alerts based on approach speed and CSW sensitivity setting. The alerts are approximately balanced across sensitivity settings and speed.

Table 3-17. Breakdown of Cautionary Alerts Used in Sensitivity Test Analysis

CSW Sensitivity	Approach Speed	
	40 mph	50 mph
1	11	18
3	15	16
5	11	12

Separate ANOVA studies with three outcome measures were performed using the 83 cautionary alerts in Table 3-17:

1. The required deceleration, determined using IMS measures;
2. The actual time to the CPOI, determined using IMS measures; and
3. The estimated time to the CPOI, determined using CSW measures.

For the first of these, speed was the only statistically significant predictor of the required deceleration; the sensitivity setting had no statistically significant effect on this measure. Figure 3-14 plots the required deceleration by approach speed. The required deceleration increases as approach speed increases, with means of 0.95 and 1.37 m/s^2 for approach speeds of 40 and 50 mph. From a human factors perspective, the difference in required deceleration is not particularly pronounced. Although one could argue that the required deceleration should be consistent regardless of approach speed, one could also argue that drivers traveling at higher speeds will likely expect to apply higher decelerations. More pronounced is the lack of a statistically significant association between the sensitivity setting and the required deceleration. In this case we expect that higher sensitivity settings will result in earlier warnings and, hence, lower required decelerations. The data does show this trend, but, again, the association is not statistically significant.

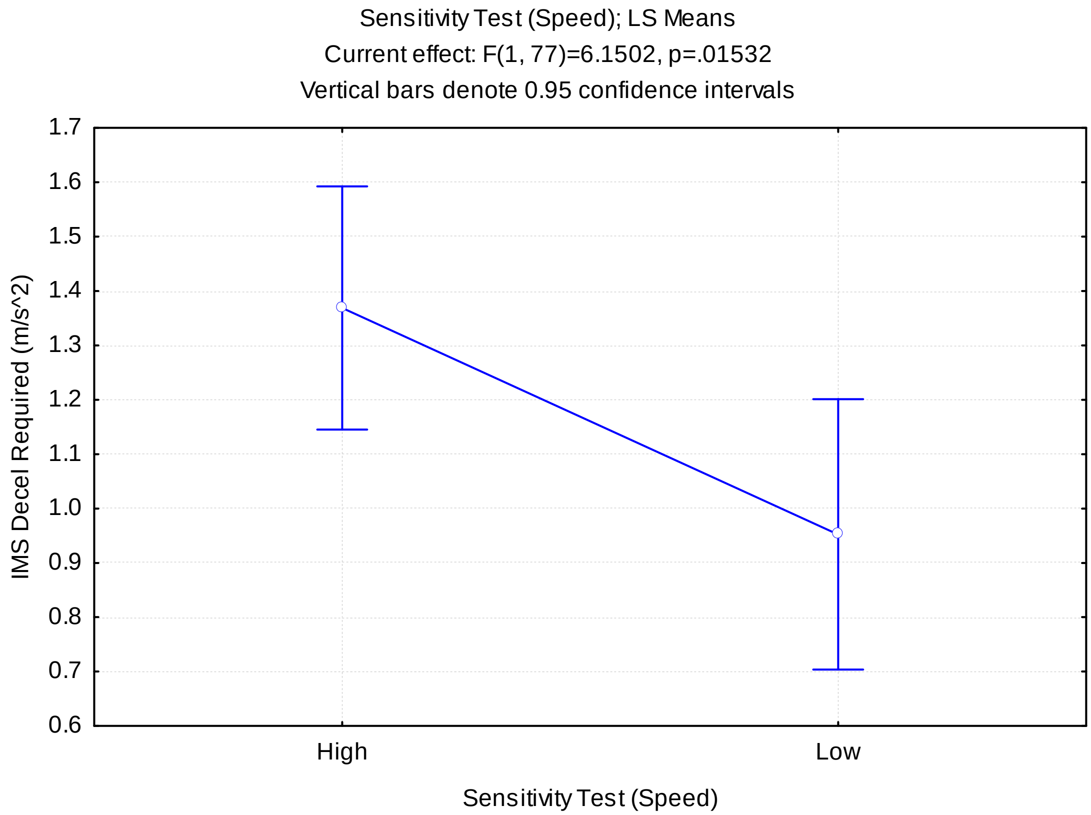


Figure 3-14. Required Deceleration by Approach Speed

Speed was also the sole statistically significant predictor of the actual time to CPOI; again, the CSW sensitivity setting had no statistically significant effect on this measure. Figure 3-15 plots the time to CPOI by approach speed. The time to CPOI increases as approach speed increases, with means of 6.42 and 7.46 seconds for approach speeds of 40 and 50 mph. The difference in alert timing is expected, since higher speed travel is associated with higher decelerations and larger distances covered during the reaction time. The earlier alert provides drivers with a larger margin for decelerating before entering the curve. As discussed with the required deceleration as the outcome measure, it is surprising that the sensitivity setting has no effect on the timing of the alert. We expect that higher sensitivity settings would result in earlier alerts, but the data do not show this.

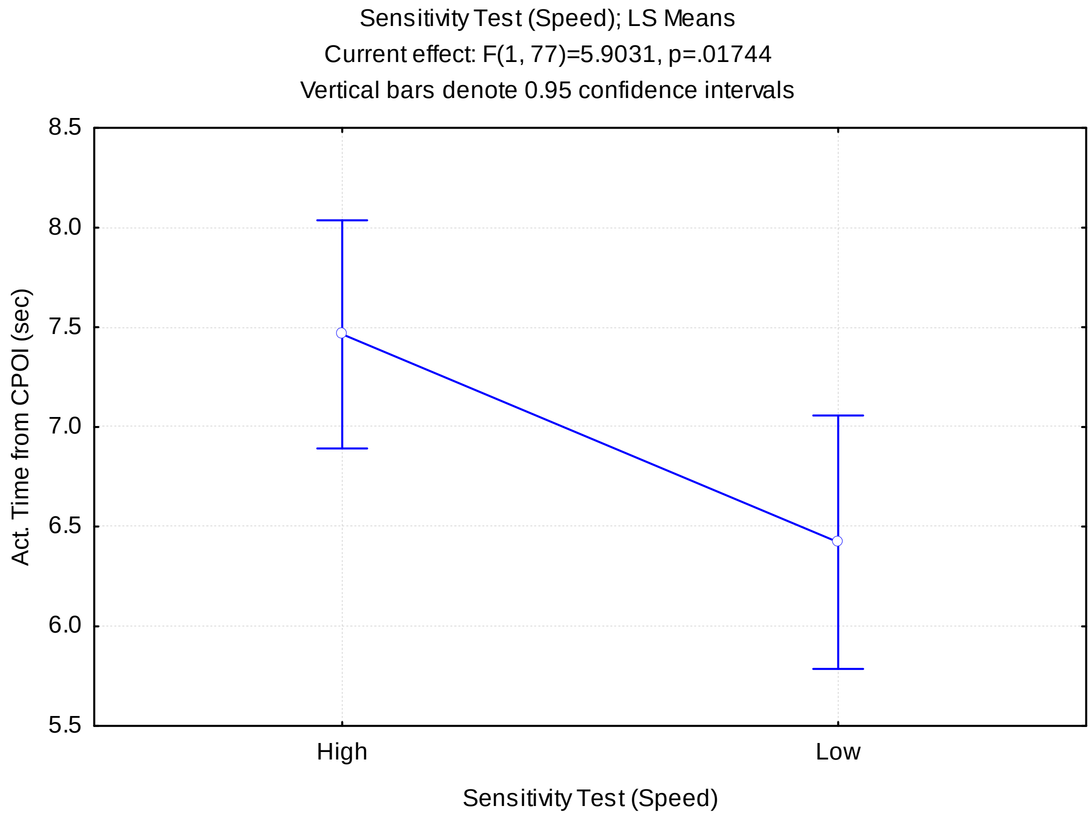


Figure 3-15. Actual Time to CPOI by Approach Speed

The final ANOVA study in this section uses the estimated time to the CPOI, determined using CSW measures, as the outcome measure. In this case, both the CSW sensitivity and the approach speed have statistically significant associations with the outcome measure. The results, shown in Figure 3-16, show an increase with the time to CPOI as the approach speed increases and a decrease in the time to CPOI for the lowest sensitivity setting. The first of these results is expected, but the second is not. We expect that the estimated time to CPOI would increase as the sensitivity increases, but the data shows the opposite. A separate contrast analysis revealed that the mean for the lowest setting and those from the two other settings differed, but the means for settings 3 and 5 were identical. The differences in the means, however, are minor, 7.73 and 8.23 seconds for setting 1 and the combined settings 3 and 5.

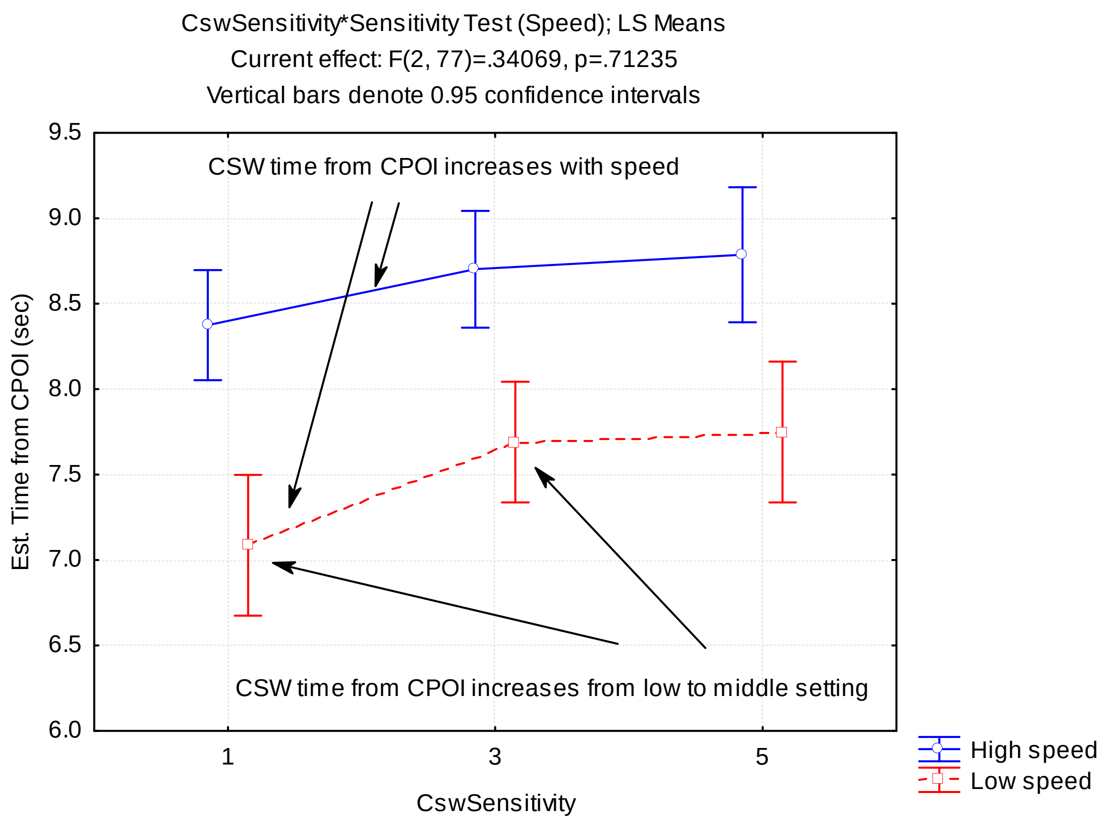


Figure 3-16. Estimated Time to CPOI by Approach Speed and Sensitivity Setting

3.5.2. By Radius

During system characterization testing curves with varying radii were traversed. Two categories of minimum curve radius, below and above 100 m, were used to evaluate how curve radius influences system performance. (Section 3.1.2 discusses estimation of the curve radius.) The alerted-curve sample pool for this section includes 142 curves. This sample excludes specific test scenarios identified in other sections of curve speed alert analysis, i.e., sensitivity tests, exit ramp, and Michigan lefts.

Similar to the LDW subsystem analysis, the CSW analysis focuses on true-positive, false-positive, and missed alerts. True-negative CSW situations were not analyzed because preliminary calculations located more than 1,000 curves during characterization testing. The assignment of an alert as a true positive or a false positive depended on if an alert was required, which in turn depended on the speed of the vehicle and the lateral acceleration. An alert was required when the vehicle speed exceeded 8 m/s (the CSW threshold for operation) and the lateral acceleration on a curve exceeded 0.3 g. Of the 127 curve situations that required an alert, 94 (74%) resulted in an alert and 33 did not. Figure 3-17 illustrates the breakdown of these alerts and missed alerts by curve radius.

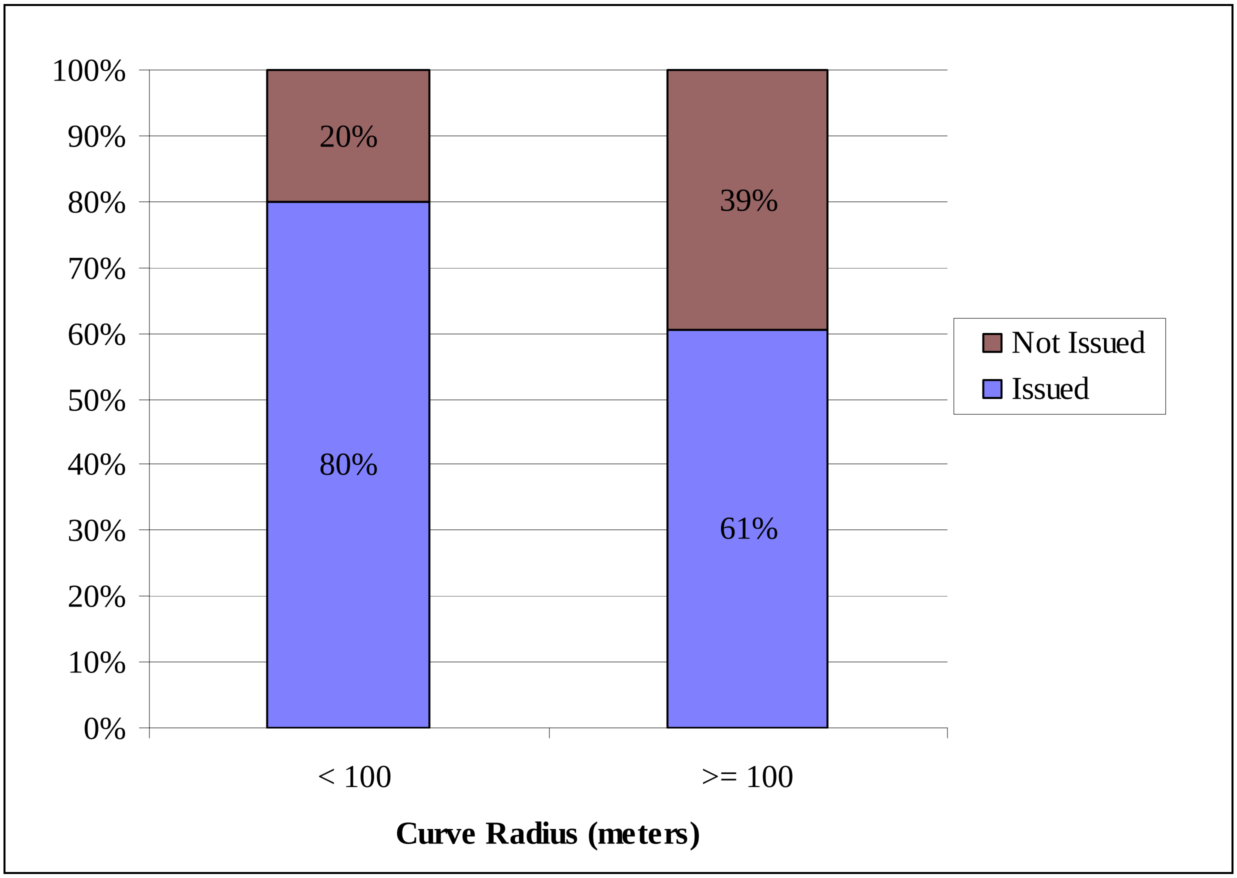


Figure 3-17. CSW Alert Issued by Minimum Curve Radius

The 33 missed alerts had the following characteristics:

- 18 with curve radius less than 100 m, 15 with curve radius greater than 100 m;
- 12 left curves, 21 right curves; and
- Maximum lateral acceleration between 3.0 m/s2 and 5.4 m/s2.

Twenty-seven misses occurred around ramps, with no alert issued while approaching or on the ramp. These are missed alerts because the lateral acceleration exceeded a safety threshold, although some drivers might find an alert in this situation unnecessary. No consistent condition or set of conditions associated with missed CSW alerts was identified.

CSW false-positive alerts are typically caused by one or more errors in path prediction, curvature estimation, or distance to curve estimation. We identified 14 alerts, 10 percent of alerts in this analysis, as false-positive because there was no upcoming curve. Five of the 14 alerts occurred at the same location during testing, where an error in the map data caused the system to incorrectly estimate a curve ahead when none existed.

Figure 3-18 illustrates cautionary alerts for an upcoming curve, categorized by alert timing and curve radius. False-positive alerts occur where vehicle speed at the time of the alert was less than or equal to the calculated curve safe speed, so the alert was not necessary. True-positive alerts occur when vehicle speed at the alert time was greater than curve safe speed so the vehicle required deceleration. Finally, late alerts are those when the vehicle speed exceeded the safe speed, but (assuming a 1.5-second reaction time) the vehicle would have reached the CPOI before deceleration could begin.

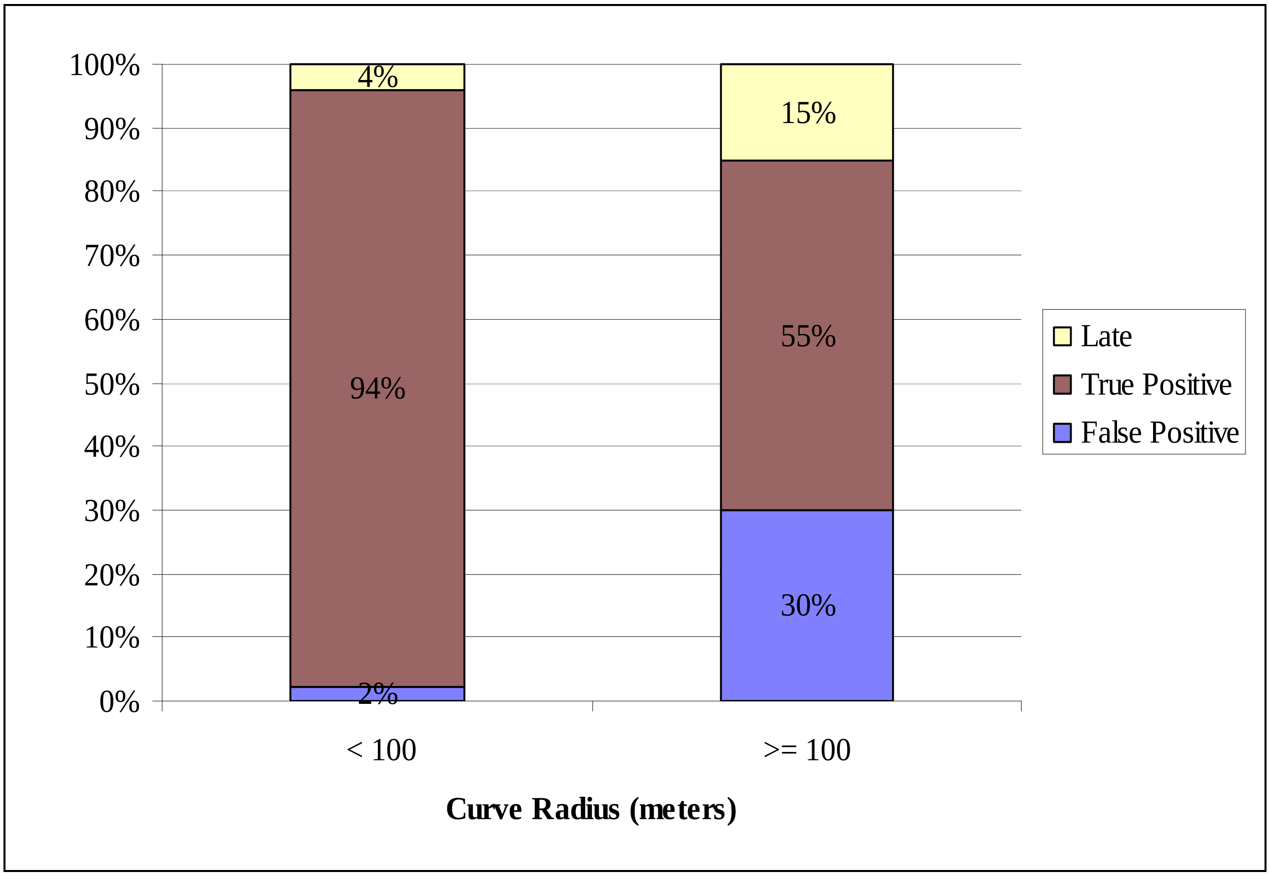


Figure 3-18. Distribution of Cautionary Alert Need When Approaching a Curve-by-Curve Radius

For curves with radii less than 100 m, 94 percent of issued and needed alerts were true positive; however, curves with radii greater than or equal to 100 m captured only 55 percent of these situations. For curves with radii more than 100 m, 6 out of 20 scenarios resulted in false-positive alerts. An underestimate of the upcoming curve radii caused two of these alerts, while the remaining 4 alerts may have been triggered by other incorrect curve information. An overestimate of the distance to CPOI or curve radius was the likely cause of late alerts.

Overall, 82 percent of the alerts in this section were true positive with sufficient time for a driver to brake to a safe speed. The average required deceleration and time to CPOI for true-positive alerts was 1.3 m/s^2 and 5.7 s, respectively. These values are reasonable, allowing comfortable braking levels and with an average driver reaction time.

3.5.3. Exit Ramps

This series of tests provided data to evaluate system performance in exit ramp areas and to analyze the effect of the turn signal on path prediction and issuing alerts. In the current context, an *exit ramp* is an exit from a limited access freeway. Tests are grouped into four categories, turn-signal status (on, off) crossed with pass or turn onto ramp. The assumption of whether the CSW subsystem should or should not issue an alert originates only from safety concerns, not driver intent. Some tests may be construed as an attempt to trick the system with false turn-signal use; however, their purpose was to see how the system performed under a variety of real-world situations.

The first two test categories involved a turn onto an exit ramp with the turn signal either on or off. Both scenarios produced equal results, a 90-percent alert-issued rate. Although the CSW subsystem uses the turn-signal status as one of the cues to estimate the upcoming path, an inactive turn signal did not cause a higher miss rate during this test. Two missed alerts when taking a ramp with an active turn signal had maximum lateral accelerations of 4.8 and 3.4 m/s^2. The CSW sensed the upcoming ramp and rightly selected the ramp as the likely path, but overestimated curve radius and distance to CPOI. Taking a ramp with an inactive turn signal produced only one missed alert. As with the previous situations when no alert was issued, the CSW identified and choose the ramp as the upcoming path, but assumed a larger curve radius of 227 m, rather than the actual curve radius of 159 m. The peak lateral acceleration on this curve was 3.6 m/s^2.

Independently of the turn-signal status, a turn onto a tight exit ramp at a high speed assesses the ability of the CSW subsystem to predict vehicle path, estimate curvature, and issue an alert to avoid a potentially dangerous situation. Conversely, passing a ramp with or without a turn signal active is not a safety issue. Instead, this scenario tests how well the CSW can predict vehicle path with true- and false-turn-signal input. Figure 3-19 shows results from two passing exit ramp test categories broken down by turn-signal status and alert response. Only exit ramps passed while the vehicle was in the travel lane closest to the exit are included in this analysis.

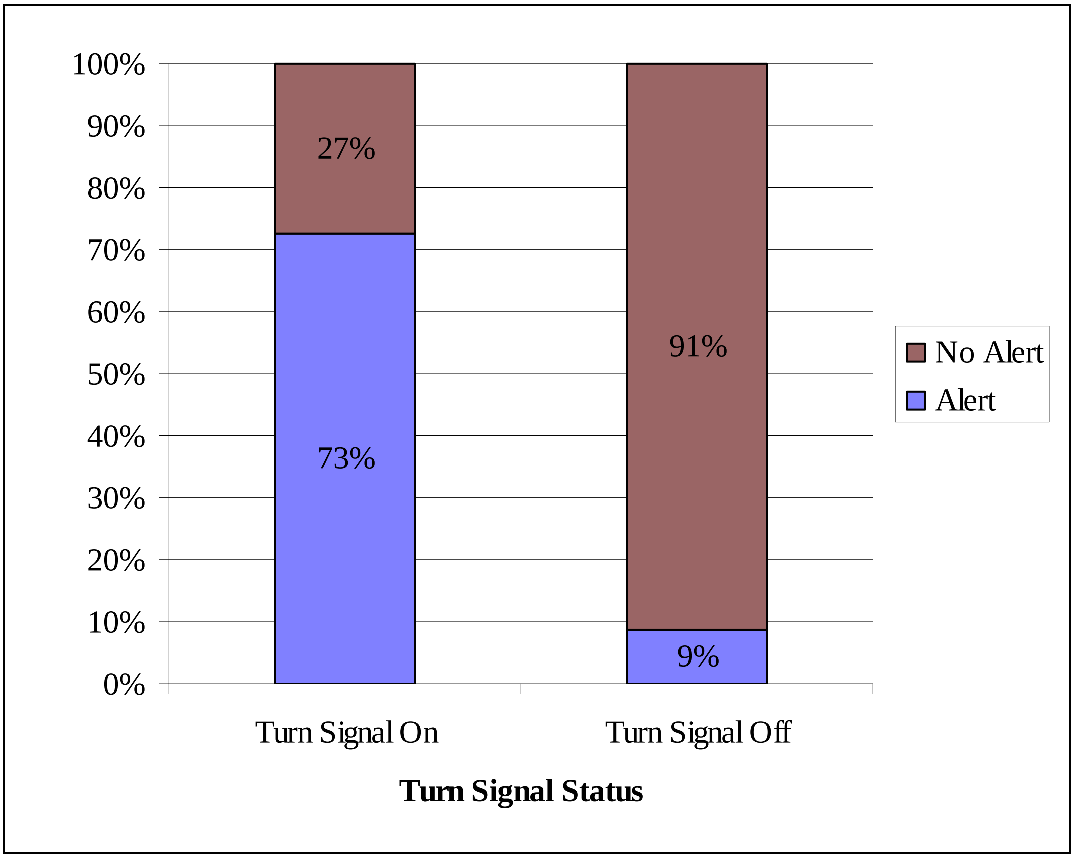


Figure 3-19. Alert Issued By Turn-Signal Use When Passing Exit Ramp

Twenty-seven percent (3 of 11) of the scenarios involving passing an exit ramp with an active turn signal resulted in no alert issued. These scenarios did not share a common characteristic such as road type, speed, or ramp. The 8 alerts occurred over a wide variety of road conditions and geometries. These results do not imply the system either should or should not issue an alert when passing a ramp with the turn signal on.

Figure 3-19 also presents CSW alert response when passing a ramp with the turn signal off. Unlike the scenario of passing a ramp with an active turn signal (intended to introduce ambiguity into the path selection), this test examines how well the CSW selects the correct and intended upcoming path with no false turn-signal inputs. Overall, the subsystem correctly rejected 91 percent of passing ramp situations. There were 6 false-positive alerts with no identifying characteristics, although 2 alerts may have been caused by recent turn-signal use prior to passing the ramp. The data show a large difference in device performance with and without an active turn signal, 27 percent versus 91 percent resulting in no alert. The data shows that although the CSW can operate without turn signal input, such input improves performance.

Ramp geometry can play a significant role in path prediction and CSW alerts. During on-road characterization testing, most ramps had a large radius curve for several hundred meters before progressing to a lower radius, tighter curve. This type of exit ramp allowed the CSW subsystem more time and separation from the main freeway lanes to determine it was on a ramp. In contrast, some ramps encountered little or no separation from the main freeway lanes before the lower radius curve of the ramp began. This presented a much more challenging situation for the CSW, because it did not have time and distance separation to discern the correct upcoming path. Since there was such a wide variety of road geometry, we did not distinguish between these two general types of exit ramps, however this difference may explain some of the performance results, particularly when passing an exit ramp.

3.5.4. Michigan Lefts

System performance while turning onto or passing Michigan left turns was also evaluated. Figure 3-20 illustrates a Michigan left movement where a vehicle turns right from the N-S road, then completes a U-turn on the E-W road to accomplish the equivalent of a left turn from the N-S road to the E-W road. This maneuver was the only (legal) way to make a left turn in many parts of metropolitan Detroit where RDCW testing was conducted. Michigan lefts are similar to the most difficult exit ramp scenarios because there is very little information available for the CSW subsystem to determine the correct path.

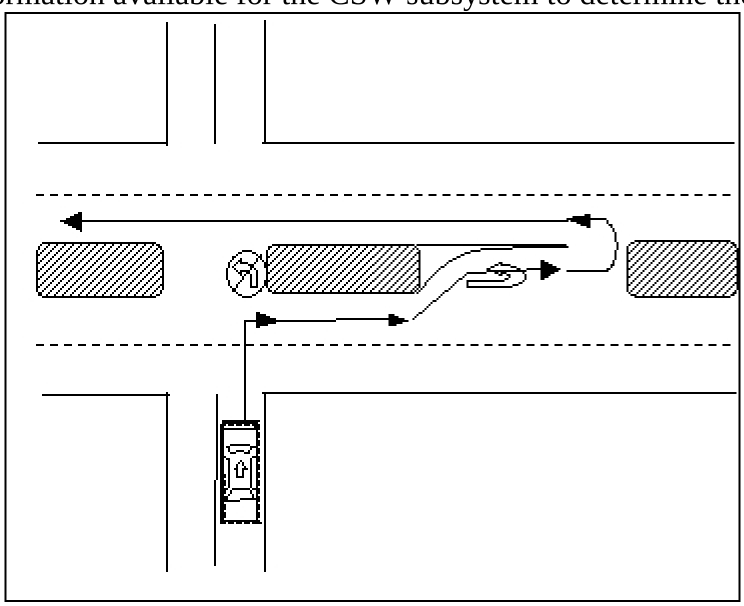


Figure 3-20. Michigan Left Example Diagram

Despite the challenges caused by the Michigan left geometry, CSW performance was very consistent when passing and taking the U-turn part of Michigan lefts. Every U-turn taken with a turn signal resulted in a true-positive alert, while no turn signal results in no alert. Likewise, when passing a Michigan left U-turn in the leftmost travel lane, alerts were only issued when the turn signal was active. These results demonstrate how the CSW used turn-signal status during Michigan left U-turn maneuvers to enhance path prediction.

3.5.5. Subjective Response to Curve-Speed Warning Survey

The FOT subjective response to questions of CSW alert timing, need, and necessity were evaluated. Scaling ranged from 1 (strongly disagree) to 7 (strongly agree). Figure 3-21 presents mean and standard deviation values for the following two questions relating to auditory and vibration warnings.

1. Overall, I thought the CSW auditory warnings were provided at the right time (i.e., they were not presented too early or too late).
2. Overall, I thought the CSW seat vibration warnings were provided at the right time (i.e., they were not presented too early or too late).

Participants rated auditory warning timing as 63 percent agreeable (scale 5-7) and haptic seat vibration as 68 percent agreeable. These values are 8 percent and 10 percent lower than the companion LDW questions in Section 3.4, indicating participants preferred LDW alert timing. This finding is supported by characterization test data in Section 3.1.3 showing CSW alert timing varied from actual measurements.

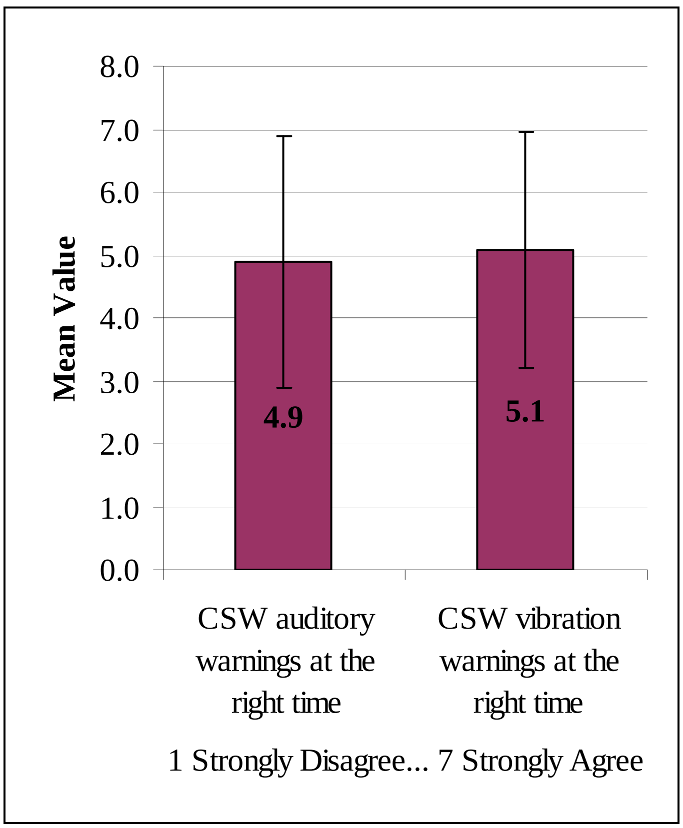


Figure 3-21. Subjective Responses to CSW Alert Timing

Figure 3-22 summarizes subjective responses to CSW alert need and false alerts based on the following questions:

1. The CSW always provided a warning when I thought it should.

2. I did not receive any unnecessary CSW warnings.
3. I did not receive any false CSW warnings.

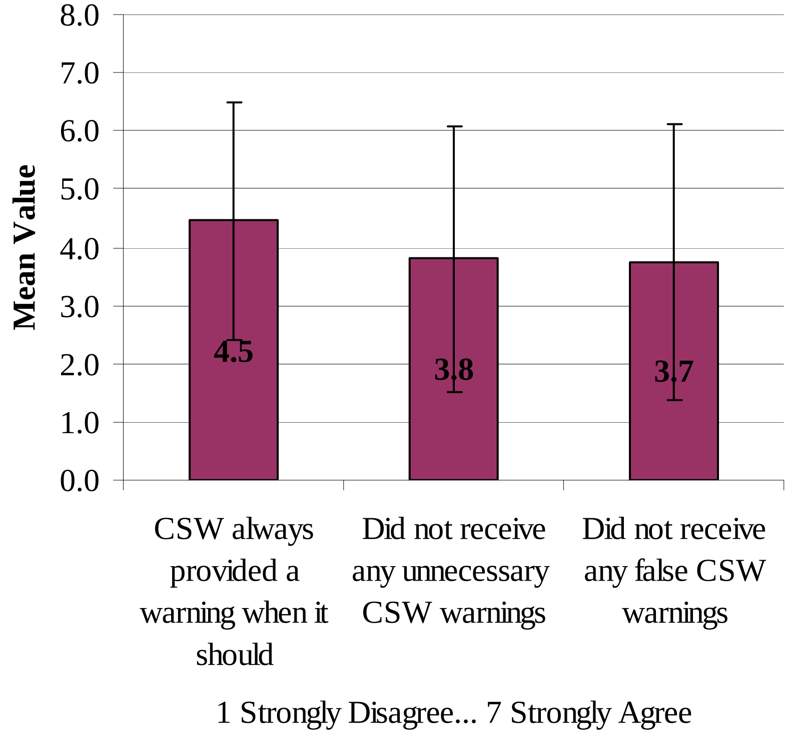


Figure 3-22. Subjective Responses to CSW Alert Need and False Alerts

Fifty-five percent of the participants agreed with the first question, 7 percent more than agreed with the similar LDW question in Figure 3-13. Fifty-one percent disagreed with the second question, stating the CSW did not always provide warnings in situations where they thought it should. This concurs with Section 3.5.2 where no alert was issued for 23 percent of curves approached where an alert was needed. Participants recognized false and unnecessary alerts as very similar and rated the second and third questions identically with means below 4, 51 percent disagreed, and 42 percent agreed. In comparison to similar LDW questions in Section 3.5.2, an increased percentage of participants, 7 and 15 percent respectively, disagreed. This indicates that participants felt they received more unnecessary and false CSW alerts than LDW alerts.

Last, participants responded to the question “I found the CSW system useful in adverse weather conditions” with an average value of 4.4, 0.5 higher than the similar LDW question. Subjective response is consistent with both availability and FOT alert analysis, showing that adverse weather had no affect on the CSW, in contrast to LDW performance.

3.6 DRIVER-VEHICLE INTERFACE

This section evaluates the DVI ability to accurately and clearly transmit information to the driver through visual display, warning tones, and seat vibration. The post-drive survey included the following items relating to visual display readability and clarity:

1. The graphics presented on the RDCW display were about the right size.
2. The graphics presented on the LDW display were about the right size.
3. The graphics presented on the CSW display were about the right size.
4. It was easy to see the graphics in the LDW display (i.e., there was no glare, and the graphics were neither too light nor too dark).
5. It was easy to see the graphics in the CSW display (i.e., there was no glare, and the graphics were neither too light nor too dark).
6. It was easy to distinguish between the different LDW visual warnings toward the left and toward the right (cautionary and imminent alerts).
7. It was easy to distinguish between the different CSW visual warnings (cautionary and imminent alerts).

Figure 3-23 shows the mean and standard deviation of the participants' survey responses to these questions.

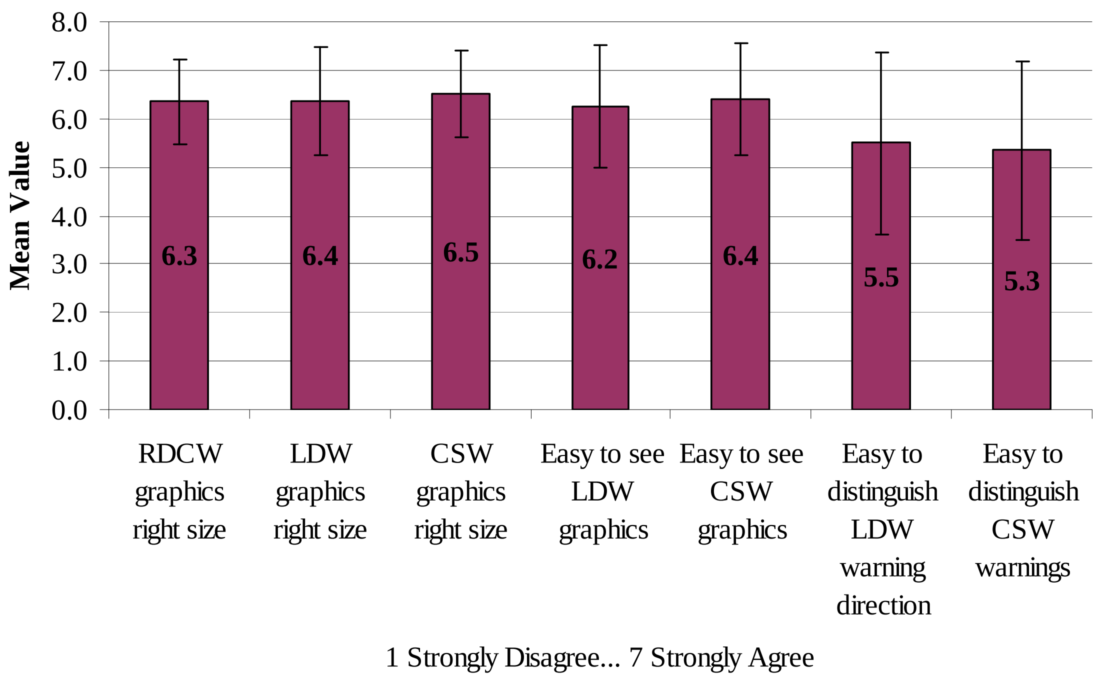


Figure 3-23. Subjective Evaluation of DVI Readability

Greater than 90 percent of all participants responded with some level of agreement (scales 5-7) for all questions, with the exception of questions 6 and 7. Seventy-eight per-

cent and 70 percent of all participants agreed they could distinguish between left and right visual warnings, while 14 percent and 16 percent disagreed (scales 1-3) for the LDW and CSW subsystems, respectively. The survey responses indicate that the participants strongly approved of the DVI visual element size, graphics and performance.
The post-drive survey included the following items relating to warning audibility:

1. I could easily hear the LDW auditory warnings while I was driving.
2. I could easily hear the CSW auditory warnings while I was driving.
3. I could easily recognize which direction the LDW auditory warning was coming from (the left or the right speakers).
4. I could easily recognize that the CSW auditory warning was coming from the front speakers.

Figure 3-24 shows the mean and standard deviation of the participants' survey responses to these questions.

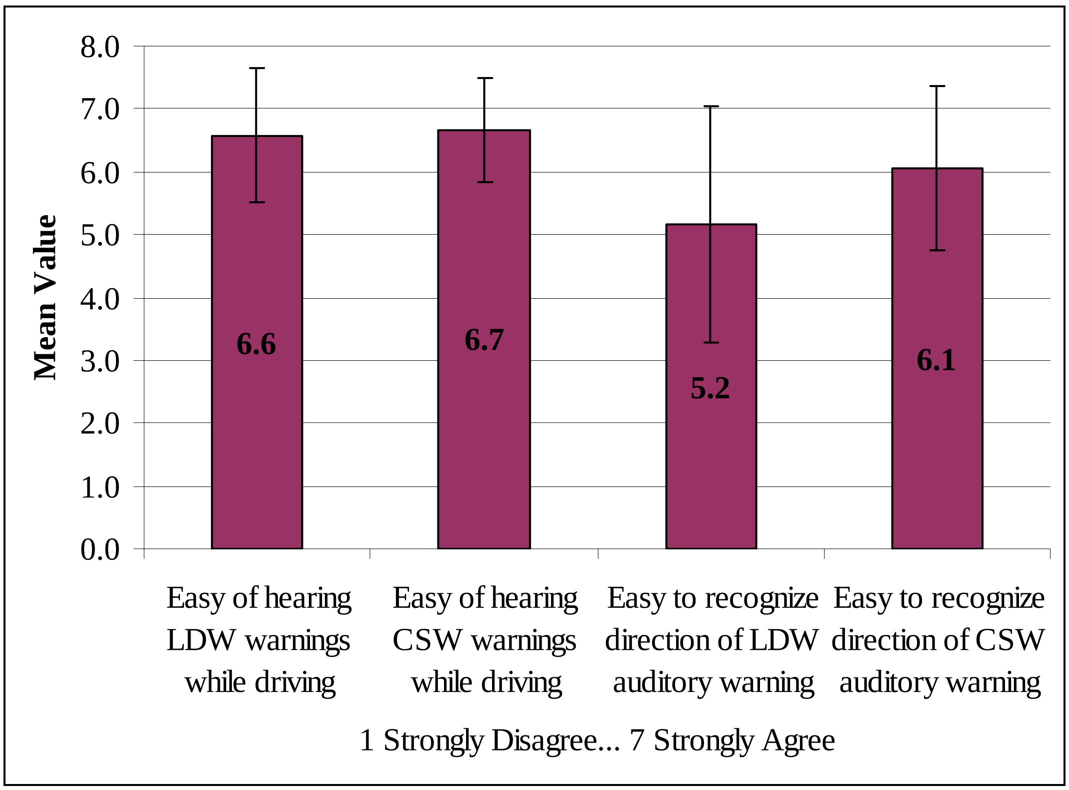


Figure 3-24. Subjective Evaluation of Warning Audibility

Participants had the lowest overall audibility response to the third item. Sixty-eight percent agreed they could easily recognize the direction of the LDW auditory warning, 21 percent disagreed, and 11 percent were unsure. For the CSW counterpart, the fourth item, 84 percent agreed they could easily recognize the warning direction, 7 percent disagreed, and 9 percent were unsure. Overall subject responses reveal auditory alert loudness and location accurately convey warning information to the driver.

The post-drive survey included the following items relating to seat vibration:

1. I could easily recognize under which leg the LDW seat vibration warnings were being presented (under my left leg or my right leg).
2. I could easily recognize that the CSW seat vibration warnings were being presented under my legs on the front portion of the seat.

Figure 3-25 shows the mean and standard deviation of the participants' survey responses to these questions. Subject responses to both questions were nearly identical: 87 percent agreed that seat vibration signals provided useful and discernable warning to test participants.

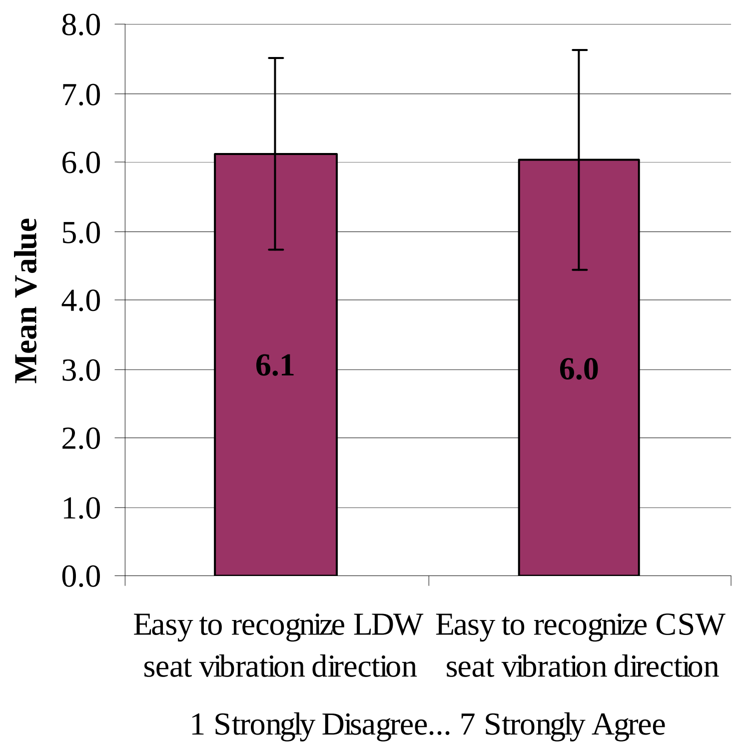


Figure 3-25. Subjective Evaluation of Warning Tactility

3.7 CONCLUSIONS

3.7.1. LDW Characterization Test Alerts

Conclusions based on an analysis of LDW characterization test data include:

1. Changes in the sensitivity level affect LDW alert timing. Under similar conditions, a decrease in the sensitivity setting from 3 to 1 decreased the TTC by 1.8 seconds, and a sensitivity increase from 3 to 5 increased the TTC by 1.5 seconds.
2. Inaccurate AMR estimates led to numerous missed and false-positive alerts. With solid markers and the situation requiring an alert, the LDW failed to issue an alert in approximately of 1 out of every 8 cases. An overestimate of the AMR caused the LDW to not issue an alert. With solid markers and an alert issued, approximately half of these alerts were false positive, with corresponding TTCs

greater than 5 seconds; approximately one-third had TTCs less than 1.5 seconds. The large TTCs resulted because the LDW underestimated the AMR, and the small TTCs resulted because the LDW overestimated the AMR.

3. Although not its primary purpose, the LDW appears robust in detecting unsignaled dashed boundary crossings. In 6 out of every 7 cases with these conditions, the LDW issued an alert. Of the alerts issued, two-thirds had TTCs (based on an AMR 1 m beyond the boundary) less than 1.5 second.
4. The LDW detects objects in the adjacent lane reasonably well. When the test vehicle drifted toward an adjacent vehicle, the LDW issued an alert in 4 out of every 5 cases. Malfunctioning radar during one test run was responsible for most of the missed alerts. Of the alerts issued in this scenario, however, almost one-fourth were false positive.
5. The LDW detects stationary roadside objects, particularly parked vehicles, reasonably well. In 9 out of every 10 cases, the LDW alerted when drifting toward a parked vehicle. With Jersey barriers and construction barrels and a drift, the LDW correctly alerted in 3 out of every 4 cases. Of the alerts issued, 7 out of every 8 were required.

3.7.2. LDW FOT Alerts

Conclusions based on an analysis of a sizable quantity of LDW FOT alerts include:

1. Inaccuracies in AMR estimation appear to limit LDW alert performance. Of the LDW alerts issued, 1 out of every 3 was a false-positive, a fraction identical to that observed in characterization testing. An underestimation of the AMR seems responsible for most of the false-positive alerts.
2. Although the LDW is available more consistently at night, performance appears compromised. The odds of an alert being a false positive for nighttime driving were 1.8 times the odds for daytime driving.
3. Degraded visual and surface conditions significantly compromised LDW performance. The odds of an alert being false positive for driving in the rain were 3.6 the odds for driving under dry conditions. The odds of an alert being a false-positive alert for wet surfaces were 3.0 the odds for dry surfaces. Wiper use decreased LDW daytime availability from 56 percent to 46 percent and nighttime availability from 58 percent to only 4 percent. Since an image-based lane tracking system relies on clear visual information, degraded visual or surface conditions understandably decrease performance.
4. Constructions zones, with barrels, barriers, and poor or no lane markings, are also a form of degraded visual conditions. Of the alerts issued in construction zones, almost half were false positive.

3.7.3. Curve-Speed Warnings

Conclusions based on an analysis of CSW characterization test data include:

1. Changes in the sensitivity settings did not affect the CSW alert timing. When we approached curves at excessive speeds, the actual timing of the alert before the curve changed with the approach speed, but not with the sensitivity setting.
2. CSW alert timing is sensitive to approach speed and sensitivity setting. An increase in approach speed resulted in earlier alerts and, unexpectedly, lower sensitivity settings resulted in earlier alerts.
3. Inaccurate estimates of the distance to the curve, the curve radius, or both compromised CSW subsystem performance. When approaching typical curves at excessive speeds (not ramps nor Michigan lefts), the system failed to alert in 1 out of every 4 cases. Of the alerts issued, 1 out of every 14 were too late for drivers to brake and negotiate the curve safely. In a few instances a CSW map error indicated a sharp curve when none was present; this generated a large fraction of the false-positive alerts. In general, an underestimate of the distance to the curve or the curve radius resulted in a false positive, and an overestimate of these measures resulted in a missed alert
4. The CSW performs well near ramps. In 9 out of every 10 10 cases, the CSW correctly issued an alert when taking an exit ramp, regardless of turn-signal status. One out of every 10 10 ramp passes without a turn signal resulted in a false-positive alert.
5. The CSW performed well in Michigan left U-turn scenarios. An activated turn signal near a U-turn produced an alert, and an inactivated turn signal did not.

3.7.4. FOT Surveys

Conclusions based on an analysis of FOT participant surveys include:

1. Participants rated LDW and CSW alert-timing, false-positive, and missed-alert performance favorably, except for CSW false positives, which they rated unfavorably.
2. Participants recognize the limitations of the LDW subsystem for poor lighting and road surface conditions, providing a neutral rating of system usefulness in adverse conditions.
3. Of the various alert modes, 7 out of every 8 participants found it easy to interpret the seat vibration alerts, 4 in 5 found the LDW audible alerts easy to interpret, and 6 out of every 7 found the visual alerts easy to interpret.

3.7.5. Other Observations

Although the LDW and CSW subsystems performed reasonably well in most scenarios, as indicated in the earlier comments in this section, the characterization-test and FOT data revealed several idiosyncrasies in system performance:

1. The LDW can appear available to the driver but disappear during a lateral drift maneuver, confusing the driver as to when the system is available to provide alerts and when it is not.

2. When available at night on wet roads, the LDW issues many false positives, particularly in the presence of overhead lighting or oncoming traffic.
3. Poor lane markings, daytime shadows, and tar strips all degrade LDW performance
4. Inaccurate or spurious radar readings resulted in false-positive LDW alerts during dashed-boundary lane changes and minor lateral drifts.
5. Mapping errors near overpasses created a false curvature in the road and produced false-positive CSW alerts.
6. The second half of S-curve geometry appears to cause problems with the CSW alert logic, resulting in false-positive alerts during the transition from the first part of the S-curve to the second.

4. SAFETY BENEFITS

RESEARCH HIGHLIGHTS

- The FOT data shows no significant unintended consequences.
- The FOT data shows a decrease in conflict exposure.
- The data shows no safety benefit in the negotiating-a-curve-and-lost-control pre-crash scenario.
- With full RDCW deployment and full availability, an annual reduction of 9,400 to 74,800 road-departure crashes is predicted.

This chapter analyzes the safety benefits associated with the RDCW. Retrospective driver (participant) performance is analyzed using measures obtained during the FOT. These measures are then used to predict changes in road-departure crash statistics that could occur with widespread RDCW deployment. Since drivers may actually become less vigilant or more aggressive in their driving by using new technology such as the RDCW, unintended consequences associated with RDCW use are also examined.

Figure 4-1 illustrates the principal uses of FOT driving data and summarizes the safety benefits approach. We identified and analyzed both *conflicts* and *events* in the FOT driving data, focusing on types the RDCW is expected to influence. Conflict categories, taken from the major road-departure pre-crash scenarios, include:

1. Going straight and departed road;
2. Negotiating a curve and lost control; and
3. Negotiating a curve and departed road.

The frequency and severity of these conflicts are not only useful independent safety measures but are also key parameters in estimating the prospective crash changes associated with RDCW deployment.

Event categories, the driving situations the RDCW is likely to influence, include:

1. Curves;
2. In-lane driving;
3. Lane changes; and
4. Turns.

In analyzing event-related behavior, we focus on event-specific performance measures to determine if driving improved or degraded with RDCW use. These measures include lateral accelerations, turn-signal use, and lane position.

- The safety benefits analysis focused on three pre-crash scenarios:
  a. Going straight and departed road;
  b. Negotiating a curve and departed road; and
  c. Negotiating a curve and lost control.
- The analysis focused on four event categories: curves, in-lane driving, lane changes, and turns.

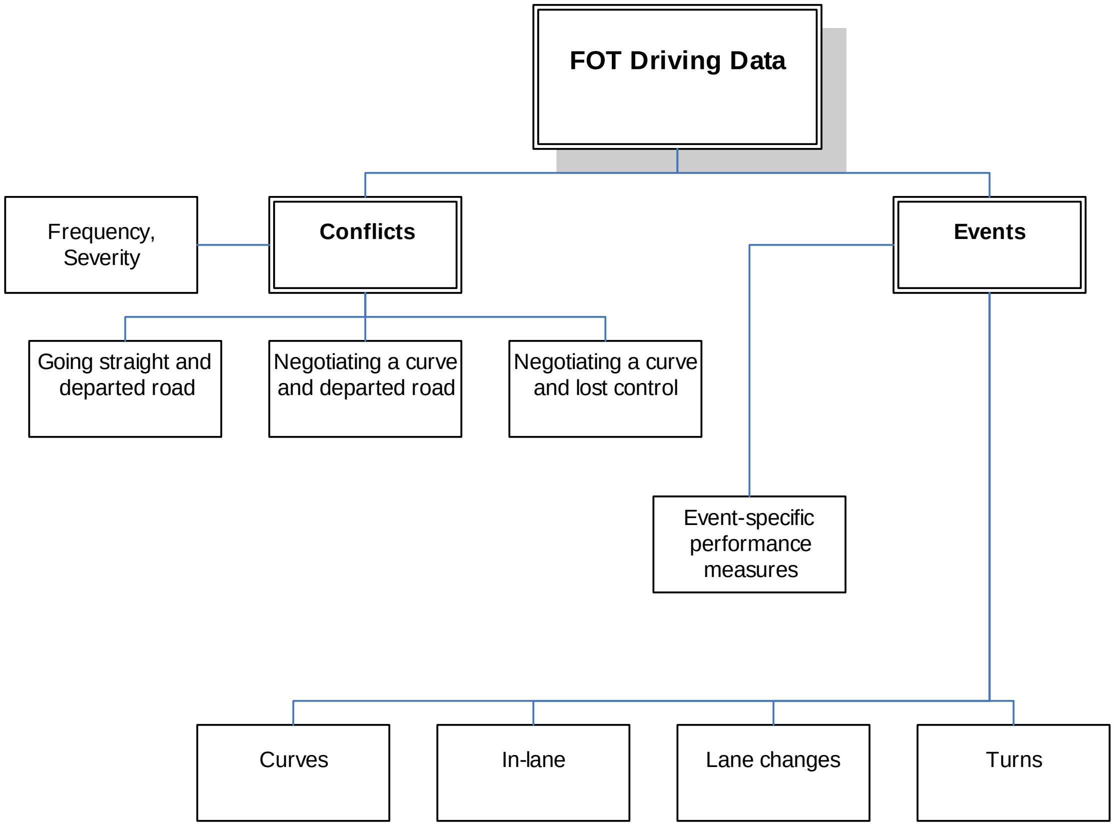


Figure 4-1. Uses of FOT Data

Section 4.1 presents an overview of road-departure crash statistics and the pre-crash scenarios analyzed in this report. Section 4.2 analyzes road-departure conflicts. Section 4.3 analyzes control-loss conflicts in various contexts. Both Section 4.2 and Section 4.3 analyze the FOT data at a high level, with gender and age as between-subjects variables and period (baseline versus treatment) as a within-subjects variable. These sections also include additional analyses, in which the road type (freeway, nonfreeway), light level (day, night), and speed bin (four bins) are included as within-subjects variables. The FOT data was insufficient to support crossing of these second-level variables, e.g., road type by light level. Furthermore, as indicated in Section 2, Exposure, the FOT participants did not experience sufficient wet-weather driving to support an analysis of wet versus dry weather.

Section 4.4 estimates the effect of RDCW deployment on future crash statistics. Section 4.5 evaluates unintended consequences associated with RDCW use. Section 4.6 summarizes the RDCW safety benefits. In addition, Appendix I discusses a non-FOT experiment using a simulator with an RDCW to determine participants' responses to near- or actual departure conflicts, with and without an RDCW.

4.1 CRASH STATISTICS AND PRECRASH SCENARIOS

Table 4-1 lists road-departure crash statistics for the United States in 2003, broken down by pre-crash scenarios, i.e., *critical events* and *vehicle movements*. Road departure was the critical event just prior to the collision for 43 percent of the over 1.2 million crashes, while lost control was the critical event for 42 percent of the crashes. For vehicle movements prior to the crash, the vehicle was going straight in almost 46 percent of the crashes, and negotiating a curve in 28 percent of the crashes. The remaining movement categories, Initiating a Maneuver and Other, accounted for 26.3 percent of the crashes. The Other scenario refers to single-vehicle crashes caused by vehicle failure, such as a blown tire or an evasive maneuver.

Table 4-1. Road-Departure Precrash Scenarios (Thousands) GES 2003

		Critical Event			
	Vehicle Movement	**Departed Road Edge**	**Lost Control**	**Other**	**Row Totals**
Count		**261**	208		**469**
Row Percent	**Going Straight**	55.7%	44.3%		
Percent		25.4%	20.3%		**45.7%**
Count		**116**	**172**		**288**
Row Percent	**Negotiating a Curve**	40.3%	59.7%		
Percent		11.3%	16.7%		**28.0%**
Count		65	55		**120**
Row Percent	**Initiating a Maneuver**	54.2%	45.8%		
Percent		6.3%	5.4%		**11.7%**
Count	**Other**			150	**150**
Percent					**14.6%**
Count	**All Groups**	**442**	**435**	**150**	**1,027**
Percent		**43.0%**	**42.4%**	**14.6%**	

Note: highlighted cells *are pre-crash scenarios the RDCW is likely to benefit*

The RDCW FOT provided data to determine if the warning system can be expected to reduce road-departure crashes. As a first step, the pre-crash scenarios in Table 4-1 the RDCW may influence are identified. As discussed in Section 1, the RDCW consists of two warning subsystems: one for lateral drift and the other for excessive curve speed. The LDW subsystem relies primarily on a forward camera tracking a vehicle's lane position and lateral speed. When the combination of lane position and lateral speed is such that a vehicle appears likely to depart the road or to crash into an adjacent vehicle, the RDCW issues an LDW imminent alert.

The highlighted cells in the Departed-Road-Edge column of Table 4-1, corresponding to vehicle movements of *going straight* and *negotiating a curve*, are the pre-crash scenarios the LDW is most likely to benefit. The LDW does not warn participants when they are taking a turn too quickly (i.e., initiating a maneuver) and approaching the road edge, because the subsystem is not capable, nor was it designed to be, of sensing imminent road departure in such a scenario. Similarly, the LDW is not expected to provide useful warnings during the Other scenarios, because the driver is either coping with a blown tire or the like or avoiding an object in the road. *Based on this information, two pre-crash scenarios were selected to evaluate the LDW: going straight and departed road edge, and negotiating a curve and departed road edge.*

The CSW subsystem relies on a GPS receiver, digital map, and vehicle sensors to determine if a vehicle is in danger of losing control because of negotiating a specific curve at an excessive speed. The CSW provides no warnings for excessive speed on straight sections, nor does it warn of impending control loss during high-speed turns, evasive maneuvers, or vehicle failure. The only pre-crash scenario the CSW can be expected to issue warnings for is *negotiating a curve and lost control.*

4.2 ROAD-DEPARTURE CONFLICTS

As a major part of the safety-benefits analysis, the independent evaluation identified and analyzed going-straight-and-departed-road and negotiating-a-curve-and-departed-road conflicts. These conflicts were identified using a combination of DAS data and video analysis. Figure 4-2 illustrates the criteria and the conflict identification approach. A combination of lateral speed, solid boundary proximity (or crossing), and a lack of a turn signal are required to generate an imminent LDW alert. As shown in the figure, FOT data is initially limited to instances in which an LDW imminent alert is issued. Within these, we required video logger data. Video analysts reviewed these alerts and identified the boundary (e.g., single solid line) associated with an alert and the validity (e.g., definitely needed) of an alert. For an alert to be considered a conflict, the vehicle needed to approach or cross a single solid boundary, indicating potential road departure. In addition, the alert needed be a true positive, determined objectively by vehicle conditions (lateral speed and position) and lane markings.

- Analyses of road-departure-conflict exposure and severity were based on 900 FOT conflicts.
- The baseline road-departure conflict rate of 1.76 per 100 km decreased by 31 percent during the treatment period.
- For departure conflicts during the baseline period, participants violated the lane boundary by an average of 0.04 m.
- For departure conflicts during the treatment period, participants remained inside the lane boundary by an average of 0.07 m.
- The baseline daytime-departure-conflict rate of 2.0 per 100 km decreased by 40 percent during the treatment period.

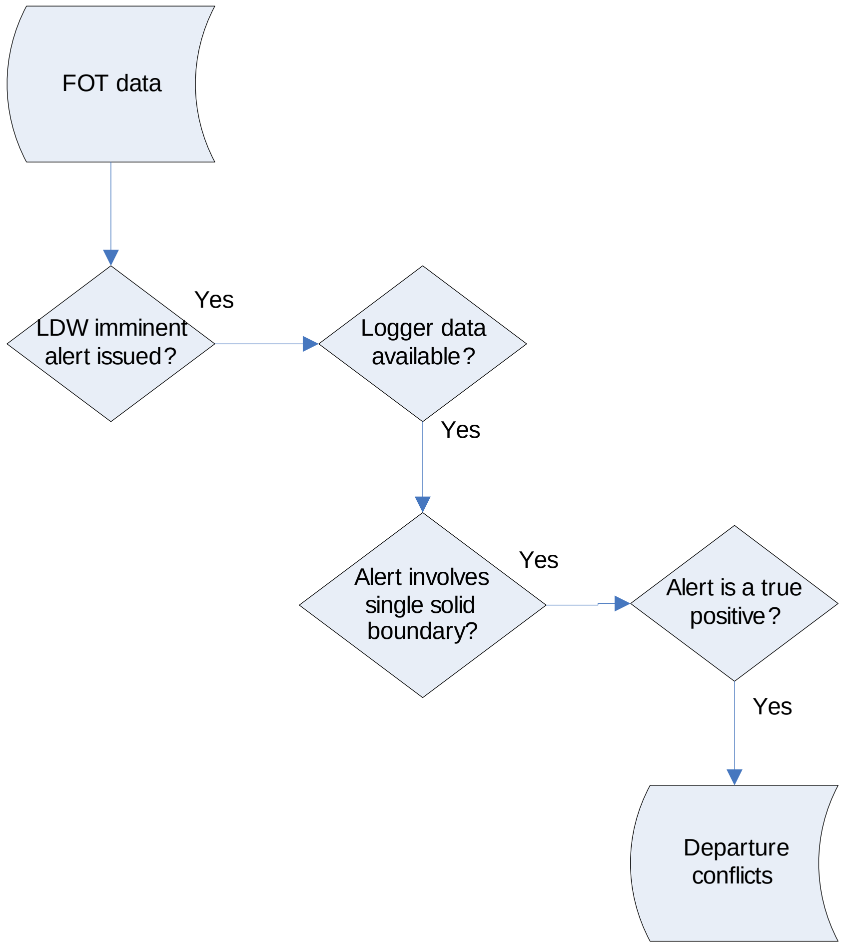


Figure 4-2. Road-Departure Conflict Identification

4.2.1. Overall Rates

The participant pool for the road-departure analysis included participants who had at least one road-departure conflict in each of the FOT periods, baseline and treatment. Participants 34 and 56, as discussed in Section 2, are not included in this pool. Table 4-2 describes the resulting road-departure-conflict analysis pool. This pool contains 49 of the 76 valid FOT participants. The 49 participants had 913 road-departure conflicts with younger males having the most departure conflicts, 236, and older females having the least, 89.

Table 4-2. Road-Departure Conflict Exposure Participant Pool

Gender	Age Group	N	Mean Baseline Conflict Count	Total Baseline Conflicts	Mean Treatment Conflict Count	Total Treatment Conflicts	Total Conflicts
Female	Younger	8	8.9	71	6.8	54	**125**

Gender	Age Group	N	Mean Baseline Conflict Count	Total Baseline Conflicts	Mean Treatment Conflict Count	Total Treatment Conflicts	Total Conflicts
Male		11	13.8	152	7.6	84	**236**
Female	Middle-aged	7	12.3	86	5.0	35	**121**
Male		8	13.0	104	16.6	133	**237**
Female	Older	6	6.7	40	8.2	49	**89**
Male		9	5.7	51	6.0	54	**105**
All Groups		**49**	**10.3**	**504**	**8.3**	**409**	**913**

Conflict exposure data in Table 4-2 reflect counts not rates. Conflict rates, the more safety-relevant measure for a given driver, equal a driver's count divided by the driver's exposure in VDT. The resulting measure is conflicts per km, typically reported in *conflicts per 100 km.* Conflict rates are a repeated measure for the RDCW FOT, because the same participant provided this measure once in the baseline period and once in the treatment period.

A repeated-measures ANOVA study of the road-departure conflict rate, with gender and age group as between-subjects variables and period (baseline, treatment) as the within-subjects variable yielded a single statistically significant[3] effect: period, $F(1,43) = 5.2$, $p = 0.027$. The conflict rate changed from 1.76 conflicts per 100 km during the baseline period to 1.21 during the treatment period, a 31 percent reduction and a result with positive safety-benefits implications.

The ANOVA study only participants who had at least one conflict in both the baseline and the treatment period. A second ANOVA study with all the participants, regardless of their conflict status, showed a *nearly* significant association between period and conflict rate. The p-value is 0.0595, and the baseline rate of 1.18 conflicts per 100 km changed to 0.87 conflicts per 100 km during the treatment period. In this case, the baseline conflict rate decreased by 26 percent.

4.2.2. Overall Severity

The safety benefits approach used in this report (Najm & Burgett, 1997; Najm, 2003) analyzes both conflict exposure and conflict severity. The former quantifies how often FOT participants got into conflicts, and the latter quantifies the danger of these conflicts. The goal of the conflict severity analysis is to determine if there was a change in conflict severity from the baseline period to the treatment period. Several measures are available to help quantify conflict severity. These include:

1. Distance to the lane boundary;

[3] Subsequent use of the term *significant* in this section implies *statistically significant.*

2. Lateral speed; and
3. AMR beyond a lane boundary.

FOT DAS data provided the first two of these, and video analysis provided the last. These measures provide estimates of the distances to the lane boundary and the road edge at several times: when the alert is issued, when the driver reacts to a conflict, or when the vehicle is at the maximum distance beyond the lane boundary. Using distance measures and lateral speed, the time-to-lane-boundary or time-to-road-departure can also be estimated.

Of a number of conflict-severity measures available, a simple distance measurement was chosen as a proxy for departure conflict severity. Considerable variation in the time-to-lane-boundary and time-to-road-departure measures was observed. This variation is due, in large part, to the lateral speed's small magnitude and its use in the denominator of the equation that calculates these measures. The distance to the road edge measure also varies considerably. The RDCW, as determined in controlled testing, appears to use default values for the AMR, rather than actual measurements and by inference provides only an approximate estimate of the AMR. Video analysis also provides an AMR estimate, but only in ranges of 0–1 m, 1–2 m, and >2 m. This quantization level adds variability to the distance from road edge. Given the cited issues with measures such as time to lane boundary, time to road edge, and the distance to the road edge, the distance-to-lane-boundary resulted as the best measure for departure conflict severity.

Table 4-3 lists the participants who fit the criteria for departure-conflict-severity analysis. The criteria comprise:

- at least one departure conflict in each period (since conflict severity, like conflict rate, will be analyzed as a repeated measure)
- a departure conflict with a shoulder width (AMR) less than 2 meters

Only 30 participants met these criteria. Table 4-3 presents their age and gender breakdown.

Table 4-3. Departure Conflict Severity Analysis Pool

Gender	Young	Middle	Old	Row Totals
Female	3	5	4	12
Male	7	5	6	18
All Groups	10	10	10	30

Departure conflict severity data was analyzed using a paired t-test. The dependent variable is the mean of the minimum distance to the lane boundary (during separate baseline and treatment periods) for each participant. Although the minimum distance to the lane boundary increased from 0.066 m during the baseline to 0.098 m during the treatment period (a positive result), the change was not significant. Therefore, the data show no improvement in departure conflict severity during the treatment period.

4.2.3. Road-type Analysis

Because of the variability in travel speed, road quality, and shoulder width between freeways and non-freeways, road-departure conflicts against these two road types were analyzed. The analysis includes only participants with more than 30 km VDT and at least one conflict in each period. The two road types were analyzed separately because an insufficient number of participants simultaneously met the participation criteria for both road types. Table 4-4 lists the participant pool by age and gender for each road type. The most striking observation is the larger number of older participants who did not meet the analysis criteria on freeways due to their low number of conflicts on freeways.

Table 4-4. Road-Type Analyses Participant Pools

Age Group	Female	Male	Totals
Non-freeway			
Younger	5	7	12
Middle-aged	3	6	9
Older	4	8	12
All	12	21	33
Freeway			
Younger	5	10	15
Middle-aged	6	7	13
Older	2	3	5
All	13	20	33

Separate paired t-tests for non-freeways and freeways revealed no significant effect of period on the conflict rate. The data showed a wide dispersion of conflict rates. Although there was a decrease in the conflict rate from the baseline to treatment period for both non-freeways and freeways, the confidence intervals were too wide for this difference to be significant.

The freeway means show a fairly large reduction in the conflict rate, even though the statistical test indicated this reduction was not significant. The difference in freeway conflicts was also analyzed using a non-parametric test. A histogram of this difference in Figure 4-3 shows more participants had a safety benefit than a safety disbenefit using the device. A Wilcoxon matched pairs test, however, indicates no significant difference in the conflict rates between baseline and treatment periods.

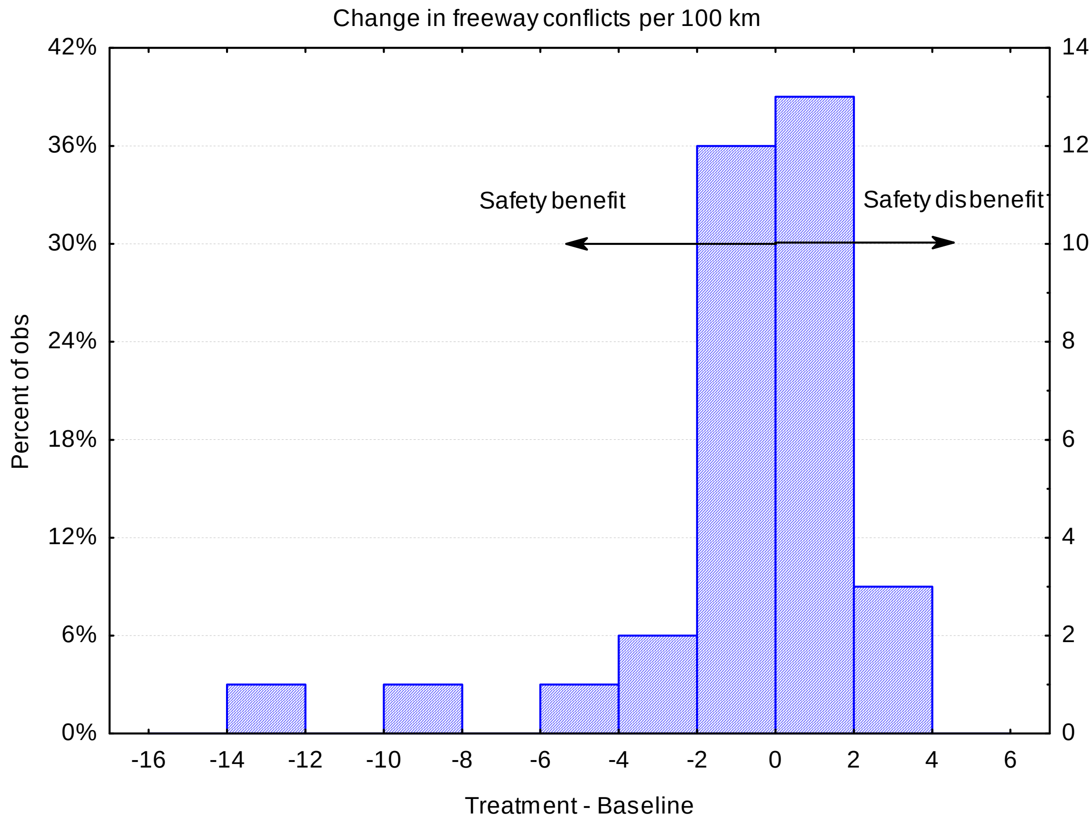


Figure 4-3. Difference in Freeway Conflict Rates From Baseline to Treatment Period

4.2.4. Light-Level Analyses

The light level (night or day) may influence participants' driving and RDCW performance. Similar to the road-type analysis in Section 4.2.3, night and day data were analyzed separately. Only participants with more than 30 km VDT in each period and at least one conflict in each period were included in a given analysis. Table 4-5 lists the participant pool for the night and day analyses. Only 14 of 76 valid participants met the participation criteria for the night-driving analysis, an insufficient quantity to support an analysis. Daytime driving data showed a significant effect of period on the conflict rate, a change from 1.97 to 1.19 conflicts per 100 km, $F(1,45)=7.23$, $p=0.01$.

Table 4-5. Light-Level Analyses Participant Pools

Age Group	Female	Male	Total
Night			
Younger	2	6	8
Middle-aged	0	3	3
Older	1	2	3
All	3	11	14
Day			
Younger	7	8	15
Middle-aged	6	8	14
Older	7	11	18
All	20	27	47

4.2.5. Speed-Bin Analysis

Since the speed of a vehicle just prior to a crash has profound implications for the injuries and damage associated with the crash, an analysis of FOT conflict data over several speed bins was performed. Section 2.3 analyzes VDT over four speed bins, 25–35, 35–45, 45–55, and above 55 mph. The current section analyzes conflict data over three of these bins, ignoring the 25–35 mph speed bin because of insufficient conflict counts.

- At speeds greater than 55 mph, the baseline-departure-conflict rate of 2.64 per 100 km decreased by 43 percent during the treatment period.
- Over the 35 to 45 mph speed range, the mean lane-boundary-violation distance decreased by 0.22 m (8.7 in) with the RDCW.

Table 4-2 lists the participant pool for road-departure conflict exposure. Participants had at least one departure conflict in both the baseline and the treatment period but the inclusion criteria made no reference to speed bin. Table 4-6 lists the participant pool for the departure-conflict rate speed-bin analysis. To be included in the analysis of a given speed bin, participants needed to have at least one departure conflict at a speed within the bin in each period. The partition of departure conflicts into speed bins reduced the number of participants available for this analysis, particularly in the 45–55 mph bin.

Table 4-6. Participant Pools for Speed-Bin Analyses

Age Group	Female	Male	Totals
35 to 45 mph			
Younger	3	4	7
Middle-Aged	1	3	4
Older	4	5	9
All	8	12	20
45 to 55 mph			
Younger	1	2	3
Middle-Aged	2	3	5
Older	2	3	5
All	5	8	13
55+ mph			
Younger	5	10	15
Middle-Aged	6	7	13
Older	2	4	6
All	13	21	34

Conflict Rate

Limited participants were available for the speed-bin analysis; only 20 participants for the 35–45 mph speed bin, 13 for the 45–55 mph bin, and 34 for the >55 mph bin. The limited number of participants in each speed bin precluded an ANOVA study with age and gender as independent variables, and the analysis was limited to performing a paired t-test of conflict rates for each speed bin. The t-test results do not show a difference in baseline and treatment conflict rates for 35–45 and 45–55 mph bins, but they show both a significant and safety significant result for 55+ mph speed bin. The mean baseline conflict rate of 2.64 departure conflicts per 100 km decreased to 1.50 during the treatment period, a 43 percent reduction, $N = 34$, $t = 2.28$, $p = 0.03$.

An analysis of conflict rates associated with severe departure conflicts, in which the vehicle drifted more than 0.25 m beyond the lane boundary, was also performed. Very few participants met the criteria of having a severe conflict in both the treatment and baseline periods (single digits over each speed bin). Despite a general improvement in rates during the treatment period, low numbers of participants led to a lack of statistical significance in the difference of departure conflict rates.

Conflict Severity

As lateral drift causes departure conflicts and the product of longitudinal speed and relative heading angle determine the lateral speed,[4] longitudinal speed may influence the severity of departure conflicts. We analyzed the influence of longitudinal speed on departure conflict severity, using the distance to the lane boundary (this distance is negative when the vehicle crosses a lane boundary) as the dependent variable. As with departure conflict rates, a limited sample pool precluded an ANOVA study, and a paired t-test was used to analyze differences in conflict severity.

Table 4-7 presents the results of these t-tests for three speed bins: 35 to 45 mph, 45 to 55 mph, and greater than 55 mph. The data shows a significant association between conflict severity and period for the 35 to 45 mph bin, where the mean minimum departure distance increased by 0.218 m (8.58 inches) from the baseline to the treatment period. Thus, RDCW alerts resulted in more benign departure conflicts during the treatment period. The data also shows a nearly significant association in the 45 to 55 mph bin, where the mean overshoot improved by 0.084 m (3.31 inches).

Table 4-7. T-Test Results for Departure Conflict Severity Over Different Speed Ranges

Period	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	DOF	p
				35–45 mph				
Baseline	-0.136	0.271						
Treatment	0.082	0.258	10	-0.218	0.223308	-3.083	9	0.013
				45–55 mph				
Baseline	0.052	0.109						
Treatment	0.136	0.140	10	-0.084	0.121372	-2.182	9	0.057
				> 55 mph				
Baseline	0.095	0.200						
Treatment	0.027	0.277	9	0.068	0.391635	0.521	8	0.616

4.2.6. Video-based Analyses

The video logger tool described in Appendix C was used to assign a validity rating to each RDCW LDW and CSW alert. The rating has a five-point scale, ranging from *defi-*

[4] An approximation that assumes a small relative heading angle.

nitely needed to *definitely not needed*. For this safety benefit analysis the *definitely needed* and *probably needed* alerts were grouped into a *true-positive* category, and *definitely not needed* and *probably not needed* alerts were grouped into a *false-positive* category.

The safety-benefits analysis includes examining associations between driver distraction and alert validity, driver attention, and alert validity. The RDCW FOT resulted in some 5,200 LDW imminent alerts for 78 participants. Of these, 4,400 alerts for 64 participants were manually analyzed. Through video analysis, 2,500 alerts from this pool were categorized as true positive or false positive. Table 4-8 lists the participant pool for the LDW video analysis. The pool is approximately evenly split between gender and age group.

Table 4-8. Participant Pool for LDW Video Analysis

	Age Group	Female	Male	Row Totals
Count	Younger	10	11	21
Percent		16%	17%	33%
Count	Middle-Aged	11	11	22
Percent		17%	17%	34%
Count	Older	10	11	21
Percent		16%	17%	33%
Count	All groups	31	33	64
Percent		48%	52%	

Table 4-9 lists the alert pool for the LDW video analysis. Males had 63 percent of the alerts, and middle-aged participants, with 41 percent of the alerts, had almost twice as many alerts as older participants. Collectively, younger and middle-aged males had 51 percent of the alerts.

Table 4-9. Alert Pool for LDW Video Analysis

	Age Group	Female	Male	Row Totals
Count	Younger	312	632	944
Percent		12%	25%	37%
Count	Middle-Aged	378	644	1022
Percent		15%	26%	41%
Count	Older	239	306	545
Percent		10%	12%	22%
Count	All Groups	929	1582	2511
Percent		37%	63%	

Driver distraction has many implications for traffic safety. The video data allows an examination of one association between driver distraction and a safety measure: the odds of an alert being a true positive while a driver is distracted divided by the odds of an alert being a true positive while the driver is not distracted. The corresponding odds ratio describes the strength of the association between distraction and an alert being a true positive, and provides an answer to the question:

When the driver was distracted, was the alert more likely to be a true positive than when the driver was not distracted?

An equivalent question, obtained using the same data in the same manner, is:

When the alert was a true positive, was the driver more likely to be distracted than when the alert was a false positive?

A true-positive alert indicates that the driver needed to alter the vehicle's course to avoid a collision, or that the driver was "in trouble." An odds ratio greater than unity indicates that distracted drivers are in trouble more often than undistracted drivers.

Table 4-10 lists the raw alert validity versus distraction level for the 64 participants used for video analysis, categorized by age and gender. The table also lists odds ratios for these groups and the associated confidence intervals. Other than the interval associated with older males, all odds-ratio confidence intervals exclude unity, indicating a positive association between distraction and alert validity. Participants receiving true-positive alerts were more likely to be distracted than participants receiving a false-positive alert.

Table 4-10. Driver Distraction versus Alert Validity

Age	Gender	Distracted	True Pos	False Pos	Row Totals	Odds Ratio	Min	Max
Younger	Female	Distracted	154	51	205	1.95	1.18	3.22
		Not Dist.	65	42	107			
	Male	Distracted	227	186	413	1.53	1.10	2.13
		Not Dist.	97	122	219			
Middle	Female	Distracted	149	83	232	1.90	1.24	2.89
		Not Dist.	71	75	146			
	Male	Distracted	331	105	436	1.85	1.30	2.65
		Not Dist.	131	77	208			
Older	Female	Distracted	117	43	160	2.52	1.44	4.43
		Not Dist.	41	38	79			
	Male	Distracted	110	61	171	1.24	0.78	1.97
		Not Dist.	80	55	135			
Total			1573	938	2511			

From the data in Table 4-10, the overall driver-distraction odds ratio equals 1.73, with the 95 percent confidence interval in the 1.47–2.05 range. The odds of an alert being a true positive for a distracted driver are 1.73 times the odds for a non-distracted driver. Although the driver distraction data results in a positive association between distraction and true-positive alerts, the driver attention data in Table 4-11 shows a much stronger overall association between attention and true-positive alerts. Here the research questions are:

> *When the driver was inattentive, was the alert more likely to be a true positive than when the driver was attentive?*
> *When the alert was a true positive, was the driver more likely to be inattentive than when the alert was a false positive?*

These questions can be answered using odds ratios.

Table 4-11. Driver Attention Versus Alert Validity

Age	Gender	Attention	True Pos	False Pos	Row Totals	Odds Ratio	Min	Max
Younger	Female	Off road	21	5	26	1.64	0.60	4.52
		On road	184	72	256			
	Male	Off road	25	6	31	4.74	1.91	11.74
		On road	247	281	528			
Middle	Female	Off road	26	2	28	12.34	2.87	53.02
		On road	137	130	267			
	Male	Off road	52	2	54	12.47	2.99	51.99
		On road	269	129	398			
Older	Female	Off road	16	2	18	4.24	0.95	18.96
		On road	134	71	205			
	Male	Off road	15	4	19	2.87	0.92	8.90
		On road	136	104	240			
Total			1262	808	2070			

The odds ratios derived from data in Table 4-11 range from 1.64 (younger females) to 12.47 (middle-aged males). Three groups, younger males, middle-aged females, and middle-aged males had confidence intervals that did not include unity, indicating a positive association between inattention and true-positive alerts. The overall ratio of the odds of an alert being a true positive for an inattentive driver to those of an attentive driver is 5.25, with a 95 percent confidence interval in the range 3.30–8.35. This implies that the odds are five times greater that an alert is a true positive when the driver's eyes are off the road than when they are on the road. Equivalently, the odds of an alert being a true positive for a driver whose eyes are on the road are less than one-fifth the odds of an alert being a true positive for a driver whose eyes are off the road.

4.3 CONTROL LOSS CONFLICTS

- Analysis of control-loss conflict exposure and severity were based on 3,300 FOT conflicts.
- Younger, middle-aged, and older drivers had rates of 6.9, 4.4, and 3.1 conflicts per 100 km.
- Neither control-loss-conflict exposure nor severity changed during the treatment period.

The safety-benefits analysis includes an examination of conflicts in the negotiating-a-curve-and-lost-control pre-crash scenario, listed in Table 4-1. As a first step, corresponding conflicts must be identified in the FOT data. The conflict-identification strategy used was a modification of the original identification strategy, described in (Ayres & Wilson, 2005). The original conflict-identification algorithm searched for excessive speed on curves and flagged a control-loss conflict when a driver needed to brake above 0.11 g to avoid a high lateral acceleration level. This approach provided an acceptable conflict frequency in the pilot data and it made logical sense: either excessive lateral acceleration or an atypical deceleration to avoid excessive lateral acceleration resulted in a conflict.

When applied to the FOT data, the original algorithm had mixed results. It identified many conflicts for some participants and no conflicts for many others, particularly older participants. As the safety-benefits approach in the evaluation requires at least one conflict in both the baseline and treatment periods, the 0.3 g threshold of the original identification algorithm appeared to be too high. To correct this, a simpler control-loss conflict identification approach was adopted, one in which the algorithm searched the FOT data for conditions where the lateral acceleration on a curve exceeded 2.5 m/s^2. The algorithm makes logical sense, is simple to apply, and results in more participants having sufficient conflicts for evaluation purposes.

The control-loss algorithm identified instances of high lateral acceleration on curves, not actual loss of control. The road-departure conflict identification algorithm in Section 4.2 identified instances of solid boundary crossings and sufficient lateral speed to merit an alert. A road-departure conflict, however, does not imply that the vehicle actually departed the road (although it could have). Similarly, a control-loss conflict does not imply that the vehicle actually lost control, although it could have.

4.3.1. Conflict Exposure

As with the departure-conflict analyses in the previous section, a given participant needed sufficient exposure to VDT and conflicts to be included in control-loss conflict analyses. Insufficient VDT exposure for a given participant would introduce considerable uncertainty into any claim that FOT driving observations represent long-term driving. Similarly, insufficient conflicts would introduce uncertainty into any extrapolation of conflict rates from the FOT data.

To be included in the overall conflict exposure analysis, a given participant needed at least 30 km VDT in each period (met by all participants) and at least one control-loss conflict in each period. Table 4-12 summarizes participants who met these criteria by gender and age. Of the original 76 valid participants, 64 met the control-loss conflict exposure criteria. The driver pool shows a slight imbalance between females and males: 45 percent versus 55 percent, and a slight bias toward younger participants of 38 percent. Overall, the control-loss conflict driver pool mirrors the FOT driver pool in Table 2-3.

Table 4-12 Participant Pool for Control-Loss Conflict Analyses

	Gender	Young	Middle	Old	Totals
Count	Female	11	8	10	29
Total Percent		17%	13%	16%	45%
Count	Male	13	11	11	35
Total Percent		20%	17%	17%	55%
Count	All Groups	24	19	21	64
Total Percent		38%	30%	33%	

Figure 4-4 plots individual treatment versus baseline control-loss conflict rates, with a safety-neutral line bisecting the figure. While two points show a clear disbenefit, due to high treatment-period high conflict rates, the remaining points suggest no obvious safety benefit or safety disbenefit.

Control-loss conflicts were analyzed using a repeated-measures ANOVA study with control-loss conflict rates as the dependent variables. The analysis in Table 4-13 shows two significant findings: an association between age and conflict rates and an interaction between period and age in their association with conflict rates. The data does not show a significant association between period and control-loss rates.

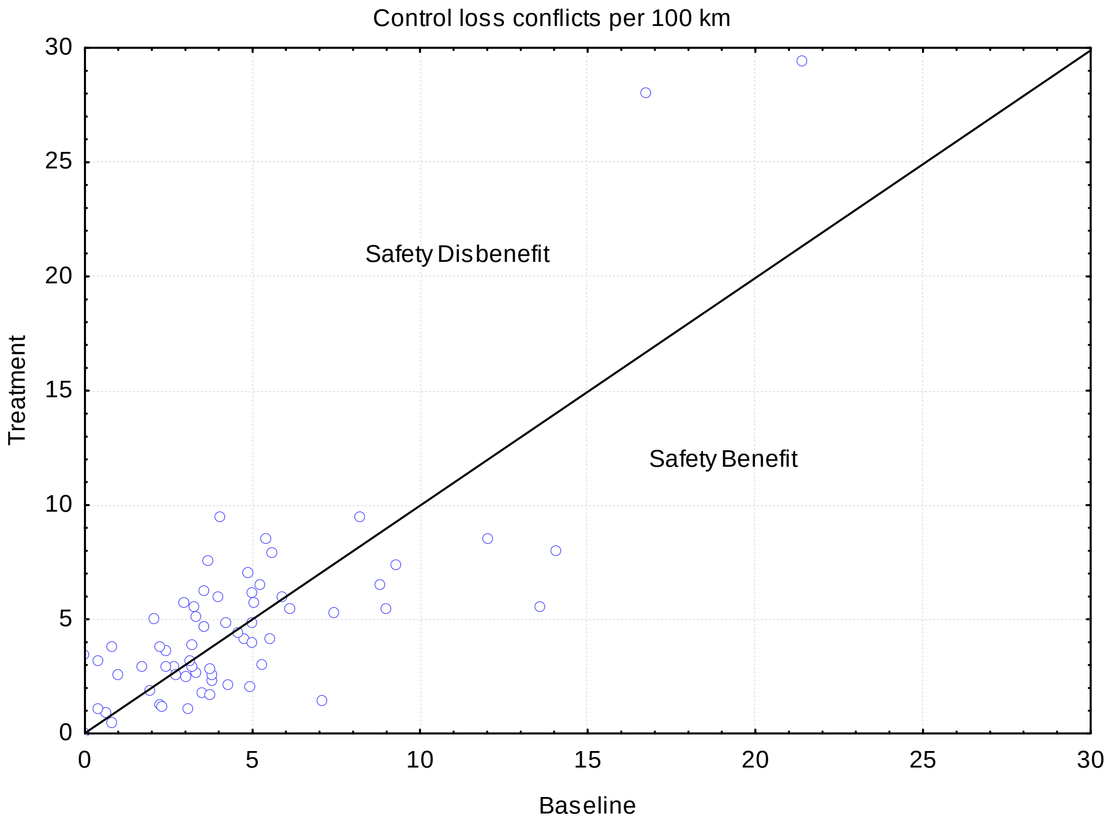


Figure 4-4. Control Loss Conflict Rates During Baseline and Treatment Periods

Table 4-13. Control-Loss Conflicts ANOVA Results

	SS	DOF	MS	F	p
Intercept	2908.6	1	2908.6	95.0	< 0.001
Gender	5.7	1	5.7	0.2	0.668
AgeGroup	336.1	2	168.1	5.5	0.007
Gender*AgeGroup	7.5	2	3.7	0.1	0.885
Error	1776.5	58	30.6		
Period	0.2	1	0.2	0.1	0.812
Period*Gender	0.1	1	0.1	0.0	0.855
Period*AgeGroup	26.5	2	13.3	3.2	0.047
Period*Gender*AgeGroup	1.1	2	0.6	0.1	0.870
Error	239.1	58	4.1		

Over the baseline and treatment periods, younger participants had a mean rate of 6.9 conflicts per 100 km, middle-aged and older participants had respective rates of 4.4, and 3.1 conflicts per 100 km. Each rate was statistically distinct from the other two. This finding indicates that younger participants tended to take curves at higher speeds and older participants at slower speeds, an expected result.

Figure 4-5 shows the interaction between age and period in explaining control-loss conflict rates. Overall, younger participants actually increased their conflict rate from the baseline period to the treatment period, whereas middle-aged and older participants slightly decreased their rates.

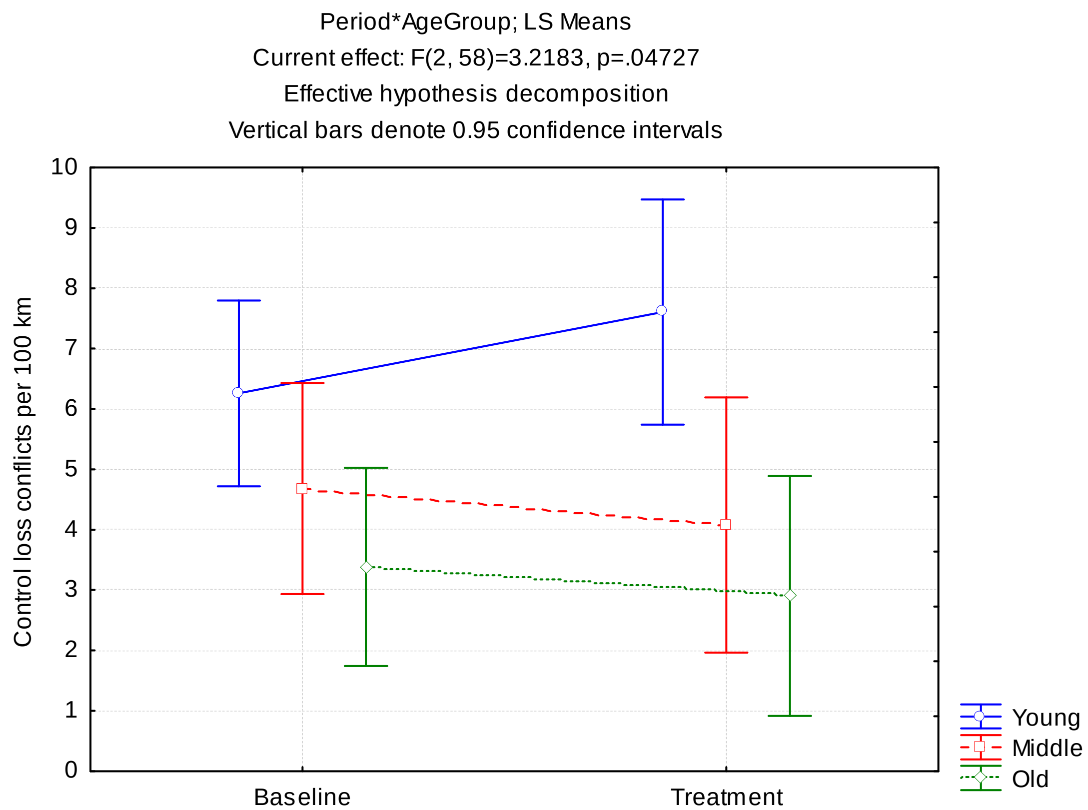


Figure 4-5. Control-Loss Conflict Rates by Age and Period

A separate contrast analysis of control-loss conflict rates by age group showed that younger participants *increased* their conflict rate by 1.21 conflicts per 100 km from the baseline to the treatment period (F(1,50) = 4.06, p = 0.049). A combined middle-aged and older participant group showed no significant change in their rate from the baseline to the treatment period.

4.3.2. Conflict Severity

In addition to the change in control-loss conflict rate, the change in conflict severity from the baseline to the treatment period was also analyzed. Participants who had sufficient VDT and control-loss conflicts, summarized in Table 4-12, composed the pool for conflict severity analysis. The dependent variable is the mean of the maximum lateral acceleration while in a control-loss conflict. Table 4-14 contains the ANOVA results.

Table 4-14. Control-Loss Conflict Severity ANOVA Results

	SS	DOF	MS	F	p
Intercept	1164.47	1	1164.5	32574.79	<0.001
Gender	0.23	1	0.23	6.47	0.014
AgeGroup	0.19	2	0.10	2.66	0.078
Gender*AgeGroup	0.36	2	0.18	5.02	0.010
Error	2.07	58	0.04		
Period	0.00	1	0.00	0.13	0.725
Period*Gender	0.01	1	0.01	0.55	0.462
Period*AgeGroup	0.03	2	0.01	0.61	0.549
Period*Gender*AgeGroup	0.02	2	0.01	0.37	0.689
Error	1.27	58	0.02		

The ANOVA shows a significant association between gender and conflict severity and an interaction between gender and age group in their association with conflict severity. For gender, females' average lateral acceleration was 3.01 m/ s^2 and males averaged 3.09 m/s^2. Although this difference is significant, its influence on safety is minor.

The ANOVA conflict severity study also shows a significant age and gender interaction, as shown in Figure 4-6. The data show that middle-aged males had the most severe conflicts (mean: 3.19 m/ s^2), middle-aged females had the least severe (mean: 2.95 m/ s^2), and gender had no effect on conflict severity for younger and older participants. Indeed, the difference in conflict severity for middle-aged participants appears primarily responsible for the association between gender and conflict severity and the interaction between age and gender. A separate contrast analysis revealed no association between gender and conflict severity for younger and older participants, but did reveal an association for middle-aged participants.

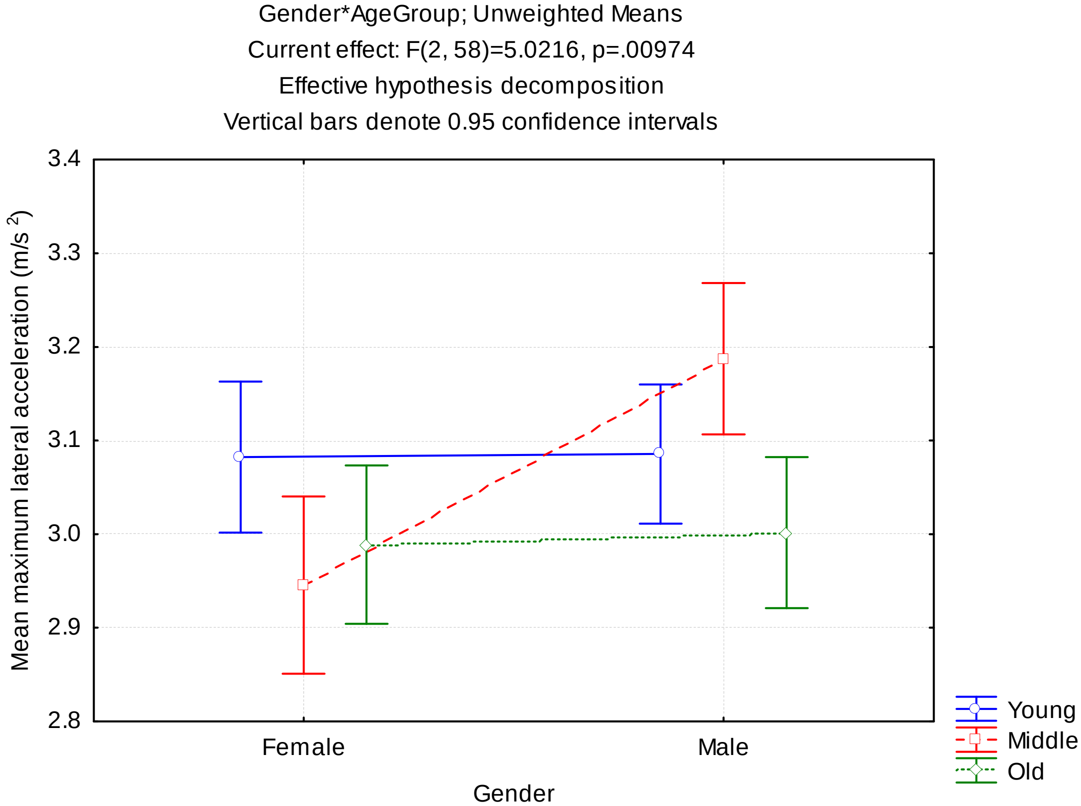


Figure 4-6. Control-Loss Conflict Severity Age and Gender Interaction

The analyses in Sections 4.3.1 and 4.3.2 show no control-loss-related safety benefit associated with the treatment period, meaning neither conflict exposure nor conflict severity decreased when the RDCW issued alerts to the participants. As part of a comprehensive system evaluation and search for possible safety benefits, we also analyzed control-loss conflict exposure by road type, light level, population density, and speed. These results are presented in Sections 4.3.3 through 4.3.5.

4.3.3. Road Type

The same algorithm that assigned an urban or rural code to the FOT data also assigned a freeway or non-freeway road-type code to each sample. Freeways have dividers and posted speeds of 55 mph or greater. Control-loss conflict rates were then analyzed using a repeated-measures ANOVA with road type as the explanatory variable and period as the usual independent variable. Participants were screened for this analysis: by conflict counts of one or more in each of the four combinations of road type and period, and by minimum VDT, with at least 30 km in each of these four categories. Table 4-15 lists participants meeting VDT and non-zero conflict requirements. The resulting participant pool contains 52 of the original 78 participants.

Table 4-15 Participant Pools for Road Type Analysis

	Gender	Young	Middle	Old	Totals
Count	Female	10	7	6	23
Percent		19%	13%	12%	44%
Count	Male	12	10	7	29
Percent		23%	19%	13%	56%
Count	All Groups	22	17	13	52
Percent		42%	33%	25%	

The larger participant count allowed a repeated-measures ANOVA study with both gender and age as explanatory variables and period as the independent variable. Table 4-16 presents the results of this study. Both age and road type have significant associations with the conflict frequency. The age effect is the same effect that has been observed throughout this section, with younger participants having the highest rates and older participants having the lowest rates. The actual respective means for increasing age group are: 5.15, 4.45, and 3.38 control-loss conflicts per 100 km.

Table 4-16 Control-Loss Conflict ANOVA Results for Road Type

	SS	DOF	MS	F	p
Intercept	3665.4	1	3665.4	255.2	<0.001
{1}Gender	1.1	1	1.1	0.1	0.787
{2}AgeGroup	101.9	2	51.0	3.5	0.037
Gender*AgeGroup	15.5	2	7.7	0.5	0.588
Error	660.7	46	14.4		
{3}Period	6.5	1	6.5	1.4	0.251
Period*Gender	3.0	1	3.0	0.6	0.437
Period*AgeGroup	16.8	2	8.4	1.7	0.187
Period*Gender*AgeGroup	5.1	2	2.6	0.5	0.592
Error	222.3	46	4.8		
{4}Road	109.7	1	109.7	11.9	0.001
Road*Gender	1.1	1	1.1	0.1	0.728
Road*AgeGroup	4.3	2	2.1	0.2	0.795
Road*Gender*AgeGroup	0.5	2	0.2	0.0	0.975
Error	425.3	46	9.2		
Period*Road	0.1	1	0.1	0.0	0.858
Period*Road*Gender	0.5	1	0.5	0.1	0.709
Period*Road*AgeGroup	9.8	2	4.9	1.5	0.228

	SS	DOF	MS	F	p
3*4*1*2	2.5	2	1.3	0.4	0.676
Error	147.2	46	3.2		

The association between road type and conflict frequency is understandable: non-freeways have sharper curves than freeways and present more opportunities for control-loss conflicts. The conflict rate on freeways, 3.6 per 100 km, is approximately 30 percent lower than the conflict rate on non-freeways, 5.1 per 100 km.

4.3.4. Lighting Level

Control-loss conflicts were also analyzed by lighting conditions. To be included in this analysis, participants needed at least one control-loss conflict and more than 30 km VDT in each combination of light level (day, night) and period (baseline, treatment). The resulting participant pool, less than half of the original 78 participants, is presented in Table 4-17

Table 4-17 Participant Pools for Light Level Analysis

	Gender	Young	Middle	Old	Totals
Count	Female	9	1	2	12
Percent		26%	3%	6%	34%
Count	Male	13	7	3	23
Percent		37%	20%	9%	66%
Count	All Groups	22	8	5	35
Percent		63%	23%	14%	

Because of the low number of participants in the middle-aged and older age groups, age was not included as an explanatory variable in the repeated-measures ANOVA study. In this case the study had two repeated measures: period and light level, and each eligible participant provided four samples. The results of the study show there was no significant association in this analysis.

4.3.5. Speed Bin

To ensure that driving data used in control-loss conflict analysis had sufficient exposure and sufficient conflicts, we set a minimum VDT threshold of 30 km in a given speed bin and required participants to have at least one conflict in each period in a given speed bin. Table 4-18 presents the participant pools for speed bin analyses over, respectively, the 25 to 35, 35 to 45, 45 to 55, and greater than 55 mph speed bins. In each bin, males are over-represented (57 to 59%). Middle-aged participants consistently provide approximately 30 percent of the pool, and younger participants tend to be overrepresented.

Table 4-18 Participant Pools for Speed-Bin Analyses

	Gender	Young	Middle	Old	Totals
		25 to 35 mph			
Count	Female	9	4	5	18
Percent		21%	10%	12%	43%
Count	Male	12	8	4	24
Percent		29%	19%	10%	57%
Count	All Groups	21	12	9	42
Percent		50%	29%	21%	
		35 to 45 mph			
Count	Female	10	6	7	23
Percent		18%	11%	13%	41%
Count	Male	13	11	9	33
Percent		23%	20%	16%	59%
Count	All Groups	23	17	16	56
Percent		41%	30%	29%	
		45 to 55 mph			
Count	Female	5	7	9	21
Percent		10%	14%	18%	42%
Count	Male	9	7	13	29
Percent		18%	14%	26%	58%
Count	All Groups	14	14	22	50
Percent		28%	28%	44%	
		Greater Than 55 mph			
Count	Female	10	7	6	23
Percent		19%	13%	11%	43%
Count	Male	12	9	9	30
Percent		23%	17%	17%	57%
Count	All Groups	22	16	15	53
Percent		42%	30%	28%	

In both the 25 to 35 and 35 to 45 mph speed bins, the ANOVA study revealed no significant association between the independent variables of age, gender, and period and the dependent variable of control-loss conflict rate. In the 45 to 55 mph speed bin, the analysis revealed a significant association between age and conflict frequency, $F(2,44) = 4.7$, $p = 0.014$. Younger participants had a mean conflict rate (11.2 per 100 km) over twice that of middle-aged (5.0) and older participants (4.6). Separate contrast analyses indicated: (1) middle-aged and older participants had the same conflict rate and (2) younger participants had a higher conflict rate than a combined group of middle-aged and older participants.

For the greater than 55 mph speed bin, the ANOVA results in Table 4-19 revealed two significant associations: age and conflict rate and an interaction between period and age and conflict rate. Younger, middle-aged, and older participants had respective mean rates of 4.67, 3.50, and 2.69 conflicts per 100 km. A separate contrast analysis showed that the only significant difference was that between the younger and older participants.

Table 4-19. Control-Loss Conflict ANOVA Results for Greater Than 55 mph Speed Bin

	SS	DOF	MS	F	p
Intercept	1305.7	1	1305.7	128.4	< 1E-6
Gender	3.6	1	3.6	0.4	0.556
AgeGroup	73.0	2	36.5	3.6	0.036
Gender*AgeGroup	35.2	2	17.6	1.7	0.188
Error	478.1	47	10.2		
Period	0.3	1	0.3	0.1	0.782
Period*Gender	0.1	1	0.1	0.0	0.860
Period*AgeGroup	28.9	2	14.5	4.1	0.023
Period*Gender*AgeGroup	5.7	2	2.8	0.8	0.453
Error	166.1	47	3.5		

Figure 4-7 shows the interaction between age and period and the control-loss conflict rate. Younger participants tended to have more conflicts during the treatment period, perhaps because they felt they could approach curves more aggressively with the system activated. Middle-aged and older participants tended to have fewer conflicts during the treatment period. A post-hoc analysis of the younger participants' data shows that the difference in their mean conflict rate from the baseline to treatment period is significant. The same analysis for middle-aged and older participants shows that the differences in their rates are not significant.

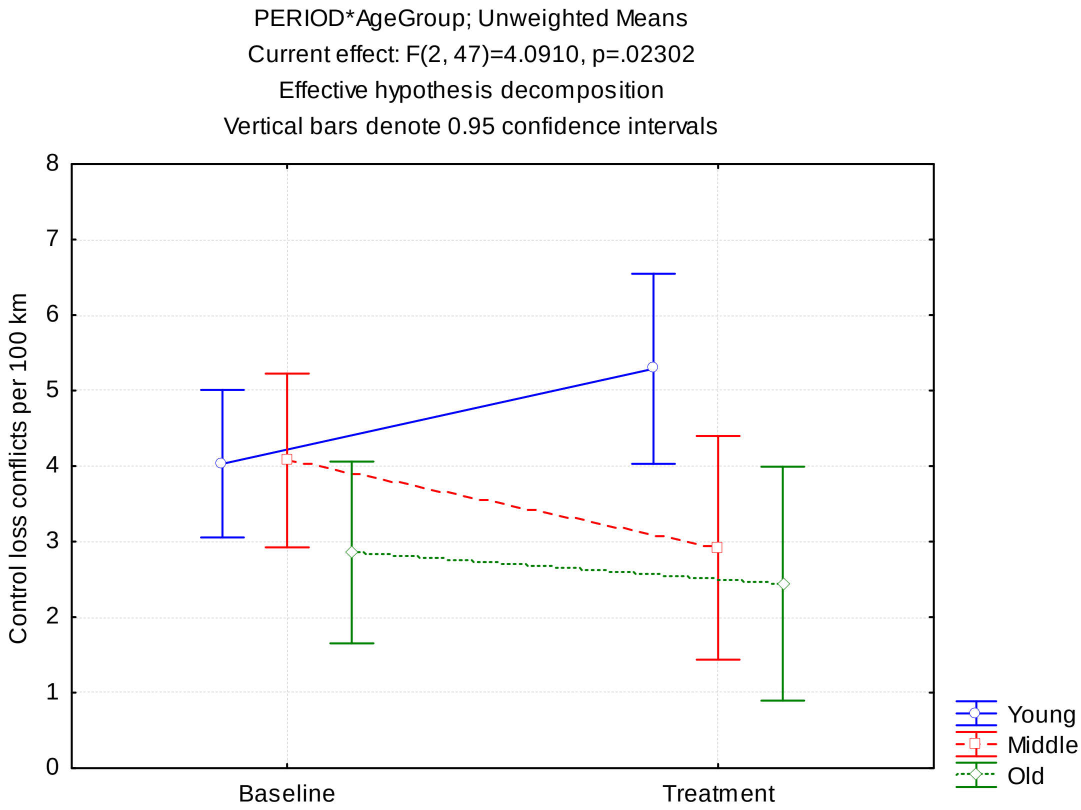


Figure 4-7. Control Loss Conflict Rate by Age and Period for 55+ mph Speed Bin

4.4 CRASH ESTIMATES

The crash estimation model we use follows the safety benefits approach originally proposed by (Najm & Burgett, 1997) and more recently described in (Najm, 2003). The annual number of road-departure crashes RDCW will prevent quantifies the RDCW safety benefit. This safety benefit is the product of current crashes and the RDCW safety effectiveness:

$$C_{\mathrm{A}} = C_{\mathrm{wo}} \times SE, \tag{4-1}$$

where C_{A} is the number of road-departure crashes avoided with RDCW, C_{wo} is the annual number of relevant road-departure crashes, and SE is the RDCW safety effectiveness. The second term in (1) can be expressed using a ratio of crash probabilities:

$$SE = 1 - \frac{p_{\mathrm{w}}(\mathrm{C})}{p_{\mathrm{wo}}(\mathrm{C})},$$

where $p_{\mathrm{w}}(\mathrm{C})$ is the normalized (by VDT) probability of a target road-departure crashes with RDCW assistance, i.e., RDCW treatment, and $p_{\mathrm{wo}}(\mathrm{C})$ is the normalized probability of a target road-departure crashes without RDCW assistance.

The limited scale of the RDCW FOT compels us to determine the safety effectiveness term in (1) indirectly (Najm, 2003). Whereas a large-scale FOT could be expected to yield a sufficient number of crashes to empirically estimate both crash probabilities in the above equation, the RDCW FOT did include any actual road-departure crashes. An alternative approach to estimating safety effectiveness will be employed, one that uses the driving conflicts and conditional crash probabilities.

An analysis of the GES crash database provides the principal road-departure pre-crash scenarios. Table 4-1 lists these scenarios and also highlights the *target* scenarios the RDCW may affect. The safety effectiveness in (4-1) can be calculated by determining the RDCW safety effectiveness over two scenarios: merging going-straight and departing road edge with negotiating a curve and departing road edge, and by negotiating a curve and lost control pre-crash. For each of these scenarios the safety effectiveness is the product of the conditional probability of a conflict given a crash and the safety effectiveness of the device within this scenario:

$$SE = \sum_{i=1,2} p_{\mathrm{wo}}(\mathrm{S}_i \mid \mathrm{C}) \times SE(\mathrm{S}_i), \tag{4-2}$$

where $p_{\mathrm{wo}}(\mathrm{S}_i \mid \mathrm{C})$ is the conditional probability of a conflict of type *i* given a crash without the RDCW (i.e., from current crash statistics) and $SE(\mathrm{S}_i)$ is the safety effectiveness of the RDCW in pre-crash scenario type *i*. This latter term also entails a conditional probability:

$$SE(\mathrm{S}_i) = 1 - \frac{p_{\mathrm{w}}(\mathrm{C}|\mathrm{S}_i)}{p_{\mathrm{wo}}(\mathrm{C}|\mathrm{S}_i)} \times \frac{p_{\mathrm{w}}(\mathrm{S}_i)}{p_{\mathrm{wo}}(\mathrm{S}_i)}, \tag{4-3}$$

where $p_{\mathrm{w}}(\mathrm{C}|\mathrm{S}_i)$ is the probability of a road-departure crash with the RDCW given that a conflict of type *i* has occurred, $p_{\mathrm{wo}}(\mathrm{C}|\mathrm{S}_i)$ is the same quantity without the RDCW, $p_{\mathrm{w}}(\mathrm{S}_i)$ is the normalized probability with an RDCW of a conflict of type *i*, and $p_{\mathrm{wo}}(\mathrm{S}_i)$ is the same quantity without the RDCW.

Still following (Najm, 2003), we can readily determine the conditional crash probability in (4-2) using existing crash statistics. The first ratio in (4-3) is the *crash prevention ratio (CPR)* that quantities the RDCW influence on the conditional road-departure crash probability. A crash prevention ratio of 0.5 indicates that the RDCW reduces the crash probability of this crash type by 50 percent. The second ratio in (3) is the *exposure ratio*, which quantifies the extent to which the RDCW affects the normalized probability of being in a conflict of type *i*. An exposure ratio of 0.5 indicates that the RDCW reduces the probability of being in a conflict of this type by 50 percent.

As the safety effectiveness values in (4-3) approach unity, the RDCW safety effectiveness approaches its maximum theoretical value. As either the CPR or the exposure ratio decreases in (3), the safety effectiveness will increase, with a maximum of unity. Conversely, if the CPR exceeds unity, indicating that the RDCW increased the conditional crash probability, or if the exposure ratio exceeds unity, indicating the RDCW increased conflict frequency, the safety effectiveness will approach zero or even be less than zero, indicating a safety disbenefit.

4.4.1. Road-Departure Crashes

We extend the conflict rate and conflict severity results from Section 4.2.5 to estimate the departure-related safety benefit of the RDCW by analyzing how the RDCW can influence the departure crash statistics listed in Table 4-1 (261,000 going straight and departed road edge crashes and 116,000 negotiating a curve and departed road edge crashes).
We use equations (4-1) – (4-3) to develop this estimate. In the current context, the subscript i =1 in equations (4-2) and (4-3) refers to the departed-road-edge critical event, which includes vehicle movements of both *going straight* and *negotiating a curve*. Since we are analyzing only crashes with a departed-road-edge critical event, we no longer need this subscript. In addition, rather than expressing the crash count in a given pre-crash scenario as the product of $C_{\mathrm{wo}} \times p_{\mathrm{wo}}(\mathrm{S}_i \mid \mathrm{C})$, which is the result expressed in equations (4-1) and (4-2), we will simply use the crash count corresponding to a specific critical event (departed road edge) and speed bin. To distinguish the latter, we add a new subscript j to equation (4-3) that refers to the speed bin, and express (3) as:

$$SE(\mathrm{S}_j) = 1 - \frac{p_{\mathrm{w}}(\mathrm{C}|\mathrm{S}_j)}{p_{\mathrm{wo}}(\mathrm{C}|\mathrm{S}_j)} \times \frac{p_{\mathrm{w}}(\mathrm{S}_j)}{p_{\mathrm{wo}}(\mathrm{S}_j)}, \qquad (4\text{-}4)$$

where j is an index for the speed bin and the conflict category is the departed-road-edge, with vehicle movements of both going straight and negotiating a curve.

Exposure Ratio

The exposure ratio in equation (4-4) is considered first. A significant association between period and conflict rate was found in the 55+ mph speed bin only. The logarithm of the ratio of conflict rates, which determines the exposure ratio in (4), is also significant. The logarithm of the ratio, rather than the ratio itself, was analyzed because this transformation was necessary to achieve normality. The logarithm of the ratio of observed conflict rates, shown in Figure 4-8, is a model for normally distributed data. The 95 percent confidence interval for the logarithm of the ratio is (–0.836, -0.074). The inverse log of this interval, (0.433, 0.929), is the corresponding 95 percent confidence interval of the exposure ratio of the 55+ mph speed bin.

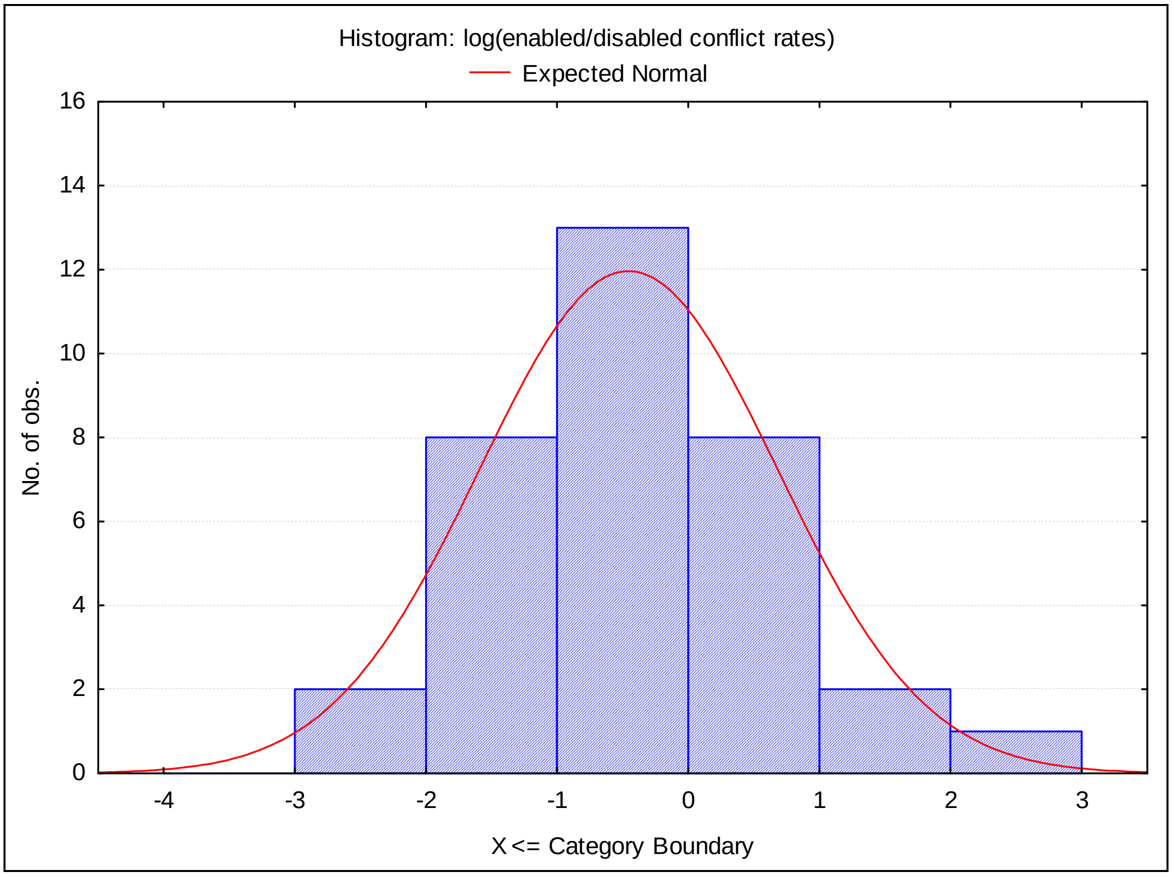


Figure 4-8. Observed Conflict Rates for 55+ mph Speed Bin (Log of Treatment/Baseline)

Crash Prevention Ratio

The CPR in Equation 4-3 is the ratio of two probabilities, the conditional crash probability during the treatment period, $p_{\text{w}}(\text{C}|\text{S}_i)$, divided by the same probability during the baseline period, $p_{\text{wo}}(\text{C}|\text{S}_i)$. While the severity of the departure conflicts influences these probabilities and there is data indicating that departure conflicts were less severe during treatment period (Table 4-7), there is insufficient data to determine a credible estimate of the CPR.

To determine the CPR, many independent road-departure conflicts are needed, for both the baseline and the treatment periods. In addition, accurate estimates of the AMR are required for each conflict, so that the severity of a given conflict can be accurately gauged. Table 4-7 demonstrates that the RDCW FOT data includes only a limited number of cases in which departure conflicts are available for both baseline and treatment periods and different speed bins. These case quantities, 10, 10, and 9 for 35 to 45 mph, 45 to 55 mph, and 55+ mph speed bins, are insufficient to project conditional crash probabilities that would be applicable to a broad class of drivers.

The analysis suggests that the conditional crash probability with the RDCW enabled, i.e., during the treatment period, is likely to be lower than the conditional crash probability during the baseline period. But the actual FOT data does not support a statistically credible prediction of the conditional crash probability and, by extension, the CPR. Thus the CPR in Equation 4-3 will be set at unity for all speed bins.

Crash Reduction

A model for predicting the number of crashes the RDCW will prevent has been formulated in equations (4-1)–(4-4), and numerous parameters for this model have been identified. To predict the reduction in departure crashes using RDCW, the crash data in Table 4-1 must be stratified into speed bins. Table 4-20 lists crash data in Table 4-1 by speed-bin. The table contains crash estimation parameters for only the critical event the RDCW will likely affect, Departed Road, and includes two speed bins.

Table 4-20. Road-Departure Model Parameters for Benefits Estimation

Critical event	Bin	Number of Crashes	Exposure Ratio	CPR
Departed road	35 to 55	125,000	1	1
Departed road	>55	132,000	0.433–0.929	1

The number of crashes column in Table 4-20 equals $C_{\text{wo}} \times p_{\text{wo}}(\text{S}_i \,|\, \text{C})$, in equations (4-1) and (4-2). The exposure ratio and CPR parameterize (3). The resulting quantity of road-departure crashes <u>avoided</u> with departed road edge as the critical event equals the following sum:

$$125,000 \times (1 - 1 \times 1) + 132,000 \times (1 - 1 \times [0.433, 0.929]).$$

This results in an estimated **9,372 to 74,844** fewer road-departure crashes each year**.**

This crash estimate assumes 100 percent device deployment and 100 percent device availability, so it is strictly an approximation of the counts that can be expected in practice. A more nuanced version of this estimate would require a stratification of crash data and conflict rates by availability, i.e., the conditions under which the RDCW's LDW was available and the conditions when it was not available. For example, the FOT data show that LDW availability decreases during the rain, particularly at night. If driver performance with the RDCW improves under these conditions (even though the device is not alerting), the unavailability of the LDW would be mitigated. For the current study, a reconciliation of crash-database statistics and FOT data by availability under different conditions would need to be based on very small samples. This reconciliation would thus introduce additional assumptions and uncertainty into the analysis. At a basic level, the 55 percent overall LDW availability presented in Table 3-3 (Section 3-1, System Availability) reduces the crash estimates presented above to 0.55 * [9732,74844] = **5,155 to 41,164** crashes avoided per year.

The authors wish to emphasize that this range and the range provided in the preceding paragraph are only estimates. They are based on the integration of crash data, system availability, and an observed reduction in road-departure *conflicts* not *crashes* during the treatment period of the FOT, when the RDCW issued audible and haptic alerts to the participants. The estimates, obtained from a limited sample of 34 of 76 subjects, indicate a positive safety benefit with RDCW use. A much larger study –or actual deployment– would be needed to determine that a system with the RDCW's capabilities resulted in an actual crash reduction. One final point: although the estimate is based on the performance of 34 of 76 subjects, it is this group of drivers who had conflicts and, we argue, this group represents the larger population of drivers who are more likely to have road-departure crashes. Thus, it would be incorrect to scale back the projected benefits because not all the participants in the FOT were used to estimate them.

4.4.2. Control-loss Crashes

A change in the crash forecast requires a change in the conflict exposure or conflict severity. Conflict exposure refers to the ratio of treatment to baseline period conflict rate. Conflict severity refers to the ratio of the treatment to baseline period conditional crash probability. For the negotiating-a-curve-and-lost-control pre-crash scenario, the conflict rates analyzed first in Section 4.3.1 and then by speed bin in Section 4.3.3 showed no significant change with Period. The data do not show any safety benefit or safety disbenefit in the conflict exposure.

The conflict severity analyzed first in Section 4.3.1 and then by speed bin in Section 4.3.3 showed no significant change during the treatment period. As a change in conflict severity is required to change the CPR, we conclude that the FOT data do not show any safety benefit or safety disbenefit in the CPR.

The FOT data do not show any change in control-loss conflict exposure or severity. Thus, no change in the crash count associated with the negotiating-a-curve-and-lost-control pre-crash scenario is forecast.

4.5 UNINTENDED CONSEQUENCES

- Driving categories considered for unintended consequences (detrimental changes in driving) included curves, in-lane, lane changes, and turns.
- FOT data contained 38,000 curves, 53,000 in-lane segments, 23,000 lane changes, and 34,000 turns.
- FOT data showed no unintended consequences in any of these categories.

Driver performance was analyzed over the following event categories: curves, in-lane driving, lane changes, and turns. These categories were selected because of the possible influence of the RDCW on driving. Although ANOVA was the appropriate approach to identify differences in performance by age, gender, or period, each event in the FOT data created its own sample for analysis. In general, the data was analyzed with a simple ANOVA, rather than repeated-measures ANOVA. Performance measures associated with the events were the focus, not the frequency of events. Turn-signal usage during lane changes analysis in Section 4.5.2 is an exception, where the percent of lane changes with a turn signal is used as a measure. Since each participant provides this measure for both the baseline and treatment periods, it is a repeated measure.

4.5.1. Curves

Two measures were used to assess driver performance and potential unintended consequences on curves: the mean lateral acceleration over the curve and the minimum acceleration (maximum deceleration) approaching or in the curve. Each measure relates to safety. Mean lateral acceleration describes how a participant negotiates the entire curve. Maximum deceleration is associated with a single instant that occurs while the participant is approaching or negotiating the curve. Larger values of the maximum deceleration (lower values of the actual acceleration) indicate more aggressive braking, either prior to or in the curve.

Mean Lateral Acceleration

The ANOVA results in Table 4-21 reveal numerous significant effects, but no pronounced difference between baseline- and treatment-period data. Furthermore, the differences in magnitudes accounting for the significance are small. This suggests that although the effects are *significant*, they are not *safety significant.*

Table 4-21. ANOVA Results for Lateral Acceleration on Curves

	SS	DOF	MS	F	p
Intercept	10666.0	1	10666.0	63543.6	<0.001
Gender	9.1	1	9.1	54.0	<0.001
AgeGroup	20.0	2	10.0	59.5	<0.001
Period	0.0	1	0.0	0.2	0.6719
Gender*AgeGroup	2.0	2	1.0	6.1	0.0023
Gender*Period	1.5	1	1.5	8.8	0.0031
AgeGroup*Period	0.3	2	0.2	1.0	0.3597
Gender*AgeGroup*Period	1.3	2	0.6	3.8	0.0228
Error	6339.3	37767	0.2		

The ANOVA results in Table 4-21 show five significant effects, gender, age group, an interaction between gender and age group, and interaction between gender and period, and an interaction between gender, age group, and period. For gender, females' average acceleration on curves, 0.55 m/s^2, was slightly lower than that of males, 0.58 m/s^2. For age group, younger participants had the highest mean lateral acceleration, 0.59 m/s^2, followed by middle-aged participants, 0.57 m/s^2, and older participants, 0.53 m/s^2. Again, although these differences are significant, they are not safety significant.

The lateral acceleration by age group and gender plot in Figure 4-9 shows both the gender effect (males took curves faster than females) and age effect (as age increased, drivers took curves more slowly). The plot also shows a curious increase in lateral acceleration for middle-aged males, which is responsible for the interaction between gender and age. This same anomaly is observed in Figure 4-6, where middle-aged males had more severe control-loss conflicts than their female counterparts. Thus for both average and peak lateral acceleration, middle-aged males took curves faster than middle-aged females.

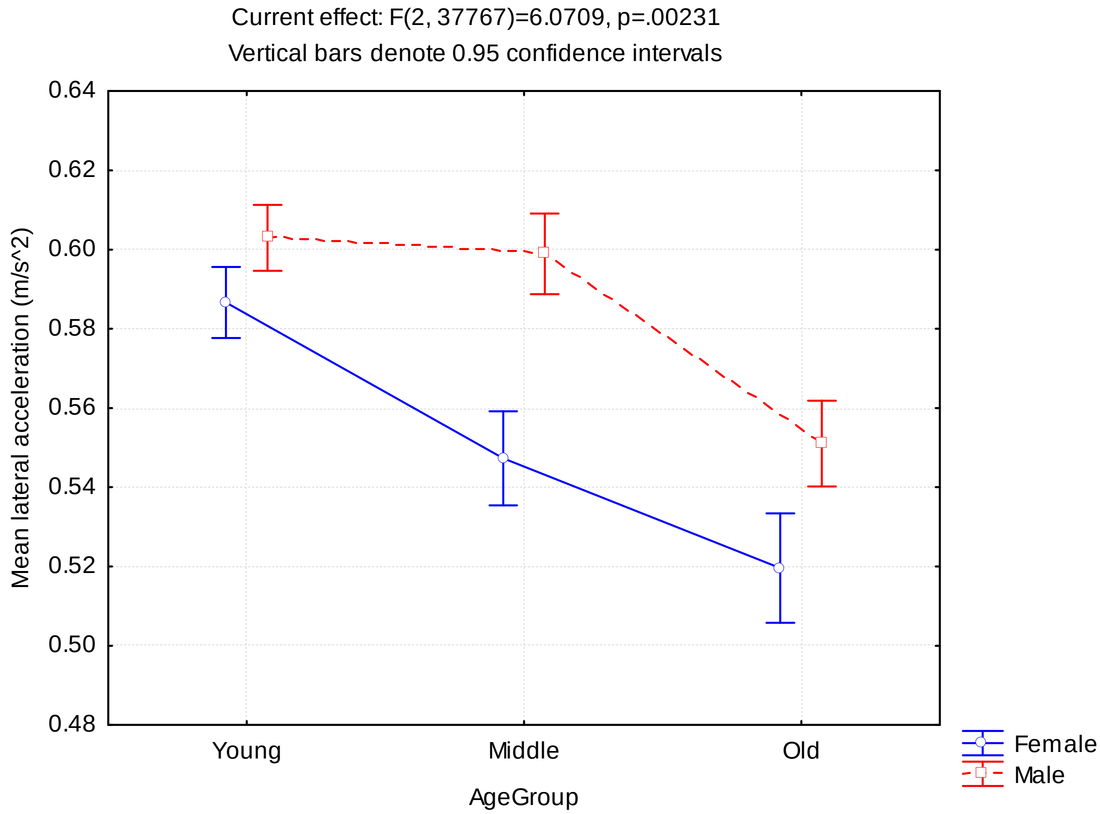


Figure 4-9. Lateral Acceleration by Age Group and Gender

The ANOVA data in Table 4-21 also shows an interaction between gender and period. Females tended to take curves more slowly during the treatment period (0.56 m/s^2 versus 0.54 m/s^2), whereas males tended to take curves more quickly during the treatment period (0.58 m/s^2 versus 0.59 m/s^2). The differences in these levels, although sufficiently large to result in a significant interaction, are very small.

Figure 4-10 plots lateral acceleration and shows the significant interaction of age group, period, and gender. Device activation during the treatment period did not influence lateral acceleration for younger participants or for older males. Activation correlates to an increase in lateral acceleration for middle-aged males and a decrease for middle-aged and older females. This figure also illustrates the overall higher values of lateral acceleration for males, the general decrease in lateral acceleration with age, and the increase for middle-aged males.

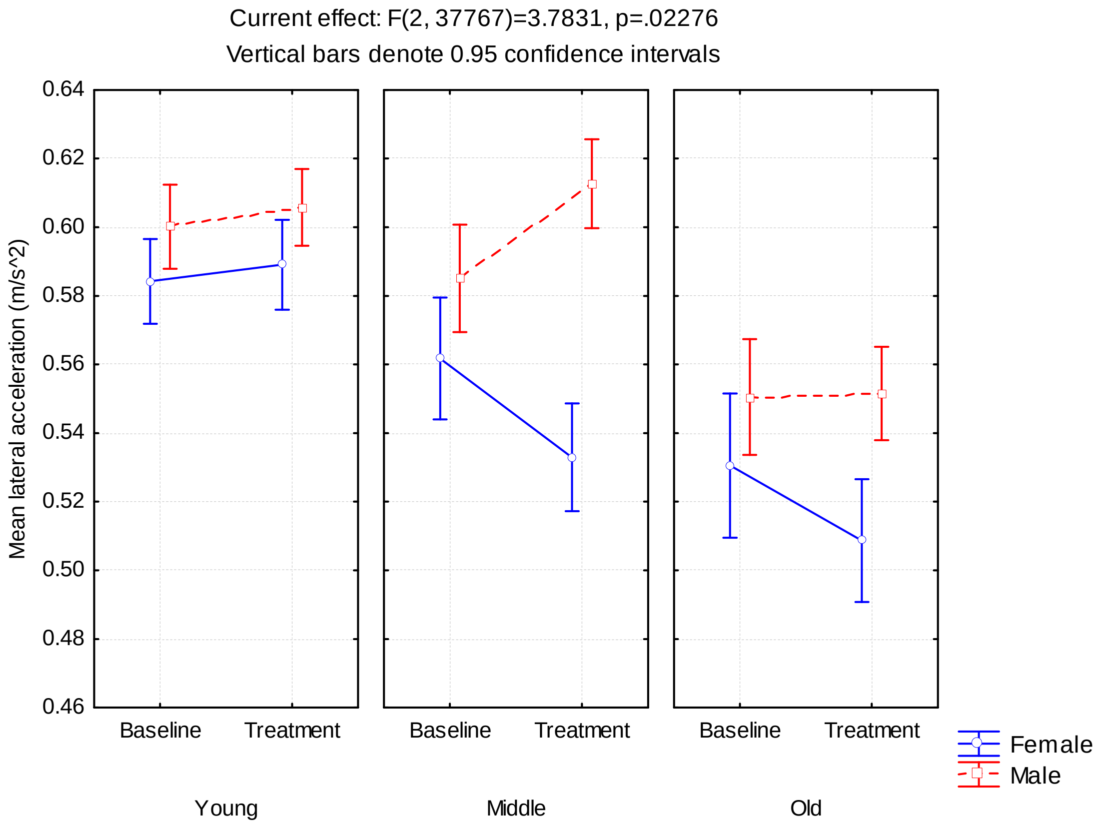


Figure 4-10. Lateral Acceleration by Age Group, Period, and Gender

The analysis in this section shows two period-related effects with the mean lateral acceleration as the outcome measure. The first is an interaction between gender and period. The second is an interaction between age, gender, and period, illustrated in Figure 4-10. Although these interactions show some significant increases in the lateral acceleration, the magnitudes of these changes have essentially no safety significance. The mean lateral acceleration values are modest during the baseline period and their increases (when there is an increase) are miniscule, less than 0.05 m/s^2. We thus conclude that for this measure the RDCW created no unintended consequence.

Peak Deceleration

The ANOVA results in Table 4-22 indicate numerous significant effects, but no pronounced difference between baseline- and treatment-period data.

Table 4-22. ANOVA Results for Curve-Related Deceleration

	SS	DOF	MS	F	p
Intercept	19853.5	1	19853.5	32151.4	<0.001
Gender	16.5	1	16.5	26.8	<0.001
AgeGroup	70.1	2	35.0	56.7	<0.001
Period	0.3	1	0.3	0.4	0.519
Gender*AgeGroup	17.3	2	8.7	14.0	<0.001
Gender*Period	0.7	1	0.7	1.1	0.285
AgeGroup*Period	4.1	2	2.0	3.3	0.037
Gender*AgeGroup*Period	0.9	2	0.5	0.8	0.471
Error	23321.2	37767	0.6		

The ANOVA study indicates that the following variables had a significant association with the peak deceleration drivers applied while approaching curves or while in curves: gender, age, an interaction between gender and age, and an interaction between age and period.

Females tended to brake harder than males while approaching or in curves, with an average peak deceleration of 0.80 m/s^2 versus 0.75 m/s^2 for males. This result supports the lateral acceleration analysis, in which males tended to take curves faster than females. This section shows that females braked harder when approaching curves, which decreases their speed and thereby decreases their lateral acceleration in the curve.

Younger participants braked the hardest, with an average peak deceleration of 0.83 m/s^2, followed by older participants, 0.76 m/s^2, and middle-aged participants, 0.73 m/s^2. Statistically, each of the age group means is distinct from the others. Here, however, the data does not support the lateral acceleration analysis. That analysis showed younger participants took curves the fastest, but the current analysis indicates they braked the hardest. The combined results suggest that younger participants approached curves at higher speeds and braked hard, but still negotiated curves at a higher speed than the other age groups.

Figure 4-11 illustrates the interaction between age group and gender with the peak deceleration as the dependent variable. Younger and middle-aged participants tended to apply the same deceleration levels around curves, with younger participants at a higher level than the middle-aged participants. Older males continued this downward trend of deceleration levels with increasing age, but older females did not. Older females braked at nearly the same levels as younger participants. Figure 4-9 showed older females had the lowest level of lateral acceleration in curves, and the data here indicates they braked nearly as hard as the younger participants to achieve these low levels.

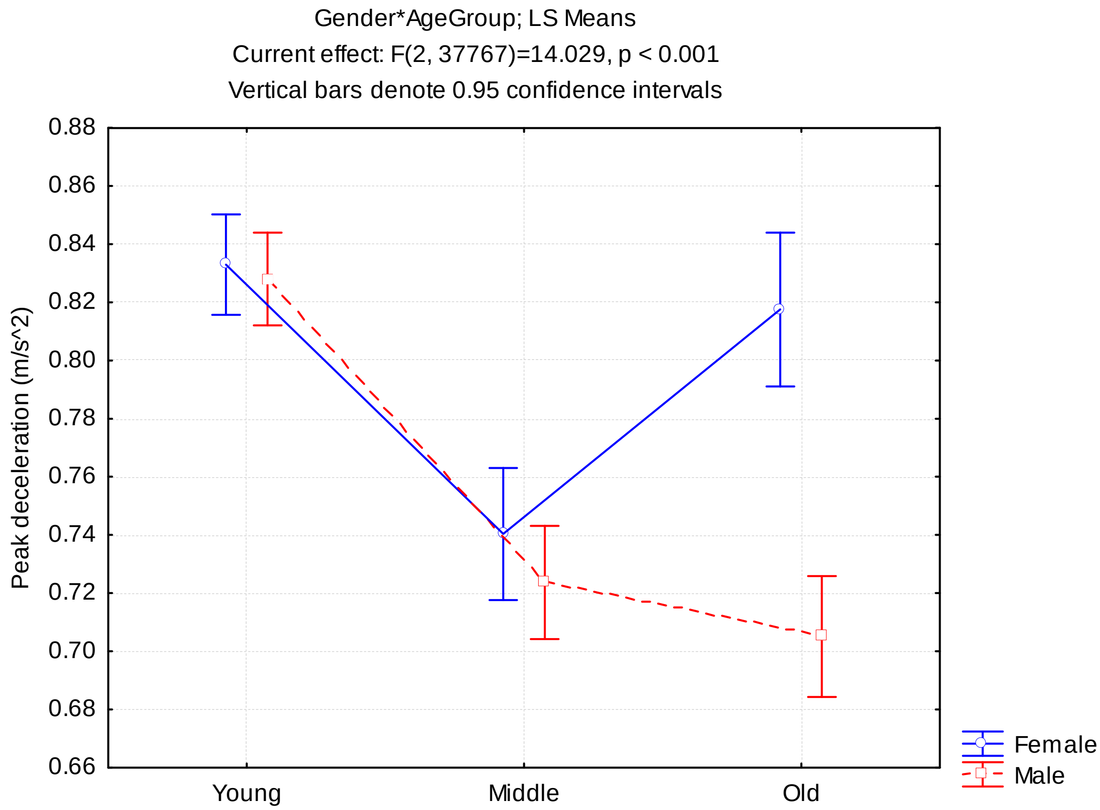


Figure 4-11. Deceleration by Age Group and Gender

Figure 4-12 illustrates the interaction between age and period, again with peak deceleration as the dependent variable. The data shows that younger participants increased their deceleration from the baseline to the treatment period, while the other groups did not change their braking. A separate contrast analysis shows that only younger participants had a significant difference in their braking levels.

The data in Figure 4-12 is the sole period-related effect in this section. Although the younger participants did increase their deceleration during the treatment period, the magnitude of the increase is very small. As this is the only period-related effect for peak deceleration and its change is minor, we conclude that for this measure the RDCW created no negative unintended consequence.

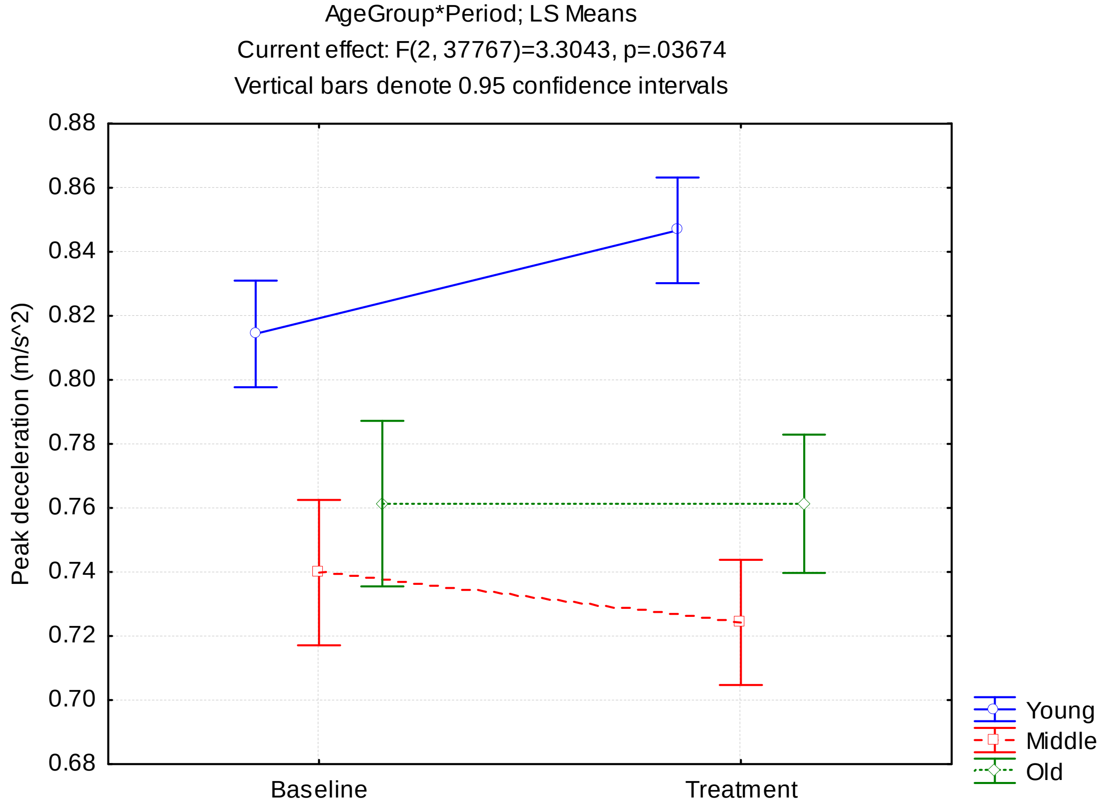


Figure 4-12. Deceleration by Period and Age Group

4.5.2. In-lane Driving

As part of the safety benefits analysis, *in-lane* events, epochs (contiguous time blocks) in which participants stayed completely within the lane boundaries, were identified. For each of these events the mean lane offset and the standard deviation of this offset were tabulated. Lane offset is a fundamental lane-keeping performance measure. The standard deviation of lane offset measures the variability of lane position. A larger standard deviation indicates increased meandering within the lane boundaries.

Lane Offset

The lane offset ANOVA analyses reveal that all variables (gender, age, period) and their interactions have a significant association with the lane offset. This finding is not surprising, because the sample used in this analysis included nearly 54,000 in-lane events. The large number of samples made it more likely that minor differences between the means would be significant. For reporting purposes, only the effects that include period will be discussed.

Lane offset, which is positive to the right of lane center, increased from -0.06 m to -0.04 m from the baseline to the treatment period, a change of 0.79 inch *closer* to the lane centerline. Table 4-23 summarizes the results for the gender by period interaction and the age by period interaction. During the treatment period females improved their lane offset more than males, and younger participants improved more than middle-aged participants. Again, the improvements are minor. The important finding here is that there was no negative unintended consequence.

Table 4-23 Change in Mean Lane Offset by Gender and Age Group

Group	Baseline offset (m)	Treatment offset (m)	Change in inches
Females	-.07	-.04	1.2 closer to center
Males	-.06	-.04	0.8 closer to center
Young	-.07	-.02	2.0 closer to center
Middle	-.09	-.08	0.4 closer to center
Old	-.03	-.03	none

Figure 4-13 plots the significant interaction among age group, period, and gender and their influence on lane offset. The figure illustrates the influence of the RDCW on the various subgroups. Younger participants improved their lane position by almost 5 cm (2 inches). Middle-aged participants not only had the largest baseline-period lane offset, but this offset remained essentially the same during the active period. Older females improved their offset by approximately 2 cm, whereas older males stayed in the lane center during both periods.

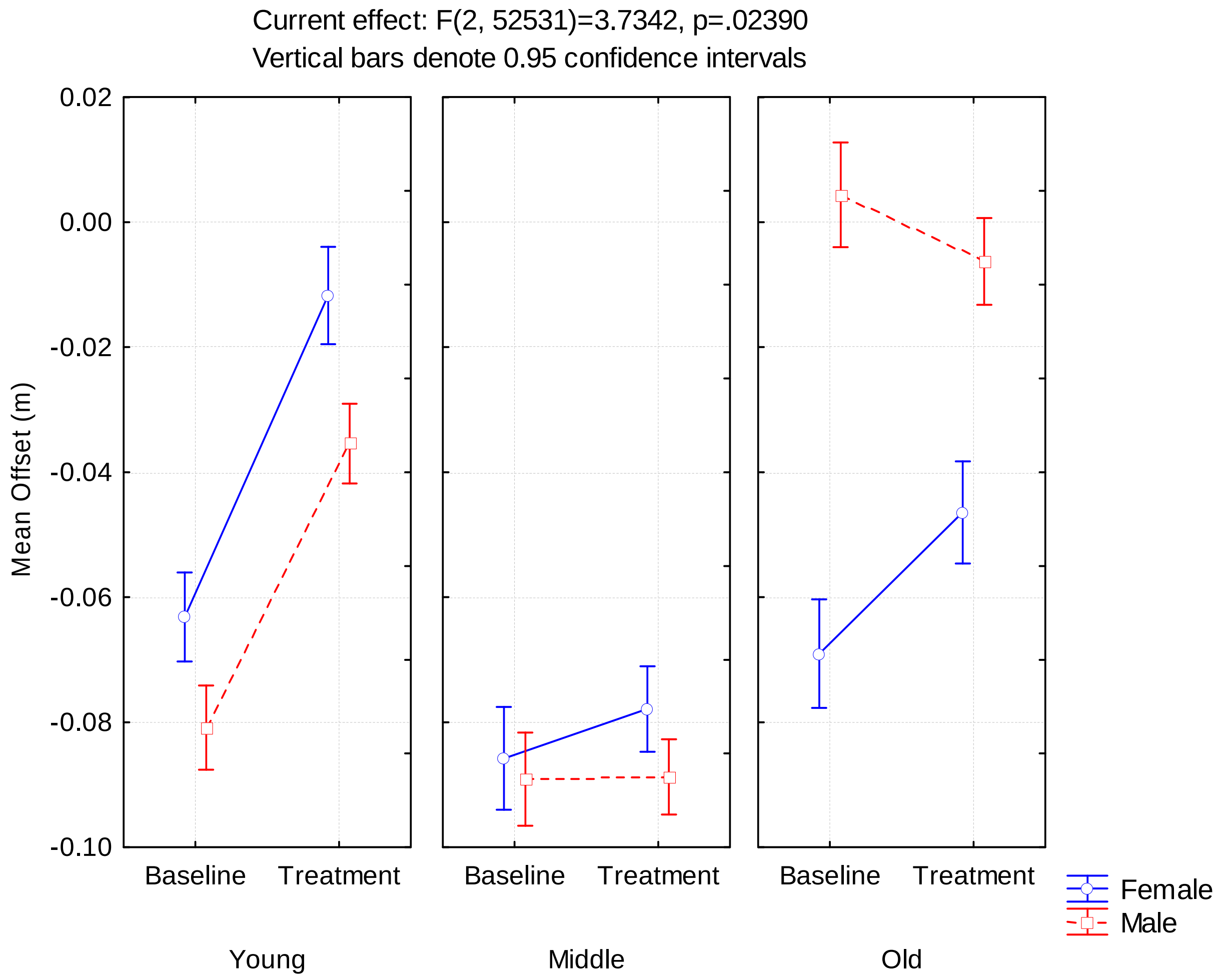


Figure 4-13. Lane Offset by Age Group, Gender, and Period

Lane Offset Standard Deviation

Lane offset standard deviation provides a second performance measure for in-lane driving. This quantity was determined by calculating the standard deviation for *each* in-lane event and then treating this quantity as a distinct measure. The duration of an in-lane event was not used to weigh the standard deviation. As a result, the quantity analyzed here is the unweighted standard deviation of each in-lane event, a surrogate for the actual standard deviation of all in-lane driving.

An ANOVA study was performed with the usual independent variables of gender, age group, and period. The study revealed that all the variables and interactions, with the exception of an age group and period interaction, had a significant association with the LOSD. For reporting purposes, only the effects that include period will be discussed. The LOSD improved from the baseline to the treatment period, changing from 0.22 m to 0.21 m, indicating that participants held their lane position more steadily during the treatment period. The difference in LOSD, however, is very small. Both females and males improved their LOSD from the baseline to the treatment period. Females changed from 0.22 m to 0.21 m, and males from 0.23 m to 0.21 m. Figure 4-14 plots the LOSD by age, gender, and period, illustrating the interaction among these variables. Every subgroup, e.g., younger females, decreased their LOSD from the baseline to the treatment period, but the subgroups were not uniform in their decrease, which accounts for the significant interaction. The magnitude of the improvement is small, and the magnitude of the differences is still smaller. The essential finding for this section is that the data shows no negative unintended consequence with RDCW activation in the treatment period.

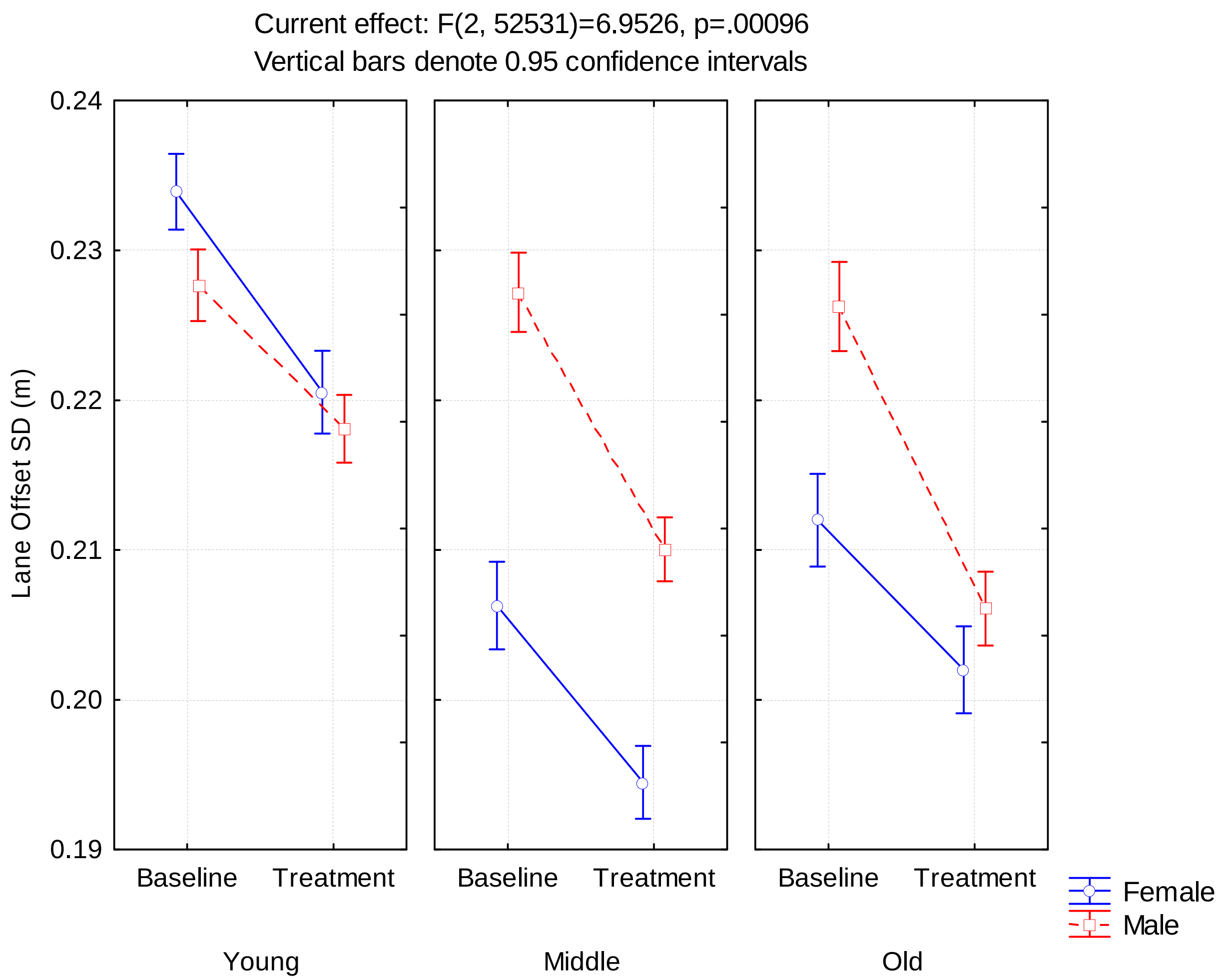


Figure 4-14. Lane Offset Standard Deviation by Age Group, Gender, and Period

4.5.3. Lane Changes

Signaling lane changes is an important part of driving. To assess the influence of the RDCW on turn-signal usage, participant turn signal use during the baseline and the treatment periods was analyzed. Lane changes were identified using a vehicle movement identification algorithm (Ayres & Wilson, 2003), supplemented by RDCW lane-change information.

Table 4-24 lists the number of baseline and treatment period lane changes by participant age group and gender. Of the approximately 23,000 lane changes analyzed, younger participants made 41.9 percent of the changes, middle-aged participants 34.5 percent, and older participants the remaining 23.6 percent. The baseline period is overrepresented in that 43.3 percent of the lane changes occurred during a period that occupied roughly 38 percent of the participants' use of the vehicle.

Table 4-24. Lane Change Analysis Pool

	Age Group	Gender	Baseline	Treatment	Row Totals
Count	Younger	Female	2206	2059	4265
Percent			9.59%	8.96%	18.55%
Count		Male	2508	2854	5362
Percent			10.91%	12.41%	23.32%
Count	**Total**		**4714**	**4913**	**9627**
Percent			**20.50%**	**21.37%**	**41.87%**
Count	Middle-aged	Female	1406	1992	3398
Percent			6.12%	8.66%	14.78%
Count		Male	1658	2882	4540
Percent			7.21%	12.53%	19.75%
Count	**Total**		**3064**	**4874**	**7938**
Percent			**13.33%**	**21.20%**	**34.53%**
Count	Older	Female	1143	1408	2551
Percent			4.97%	6.12%	11.10%
Count		Male	1027	1849	2876
Percent			4.47%	8.04%	12.51%
Count	**Total**		**2170**	**3257**	**5427**
Percent			**9.44%**	**14.17%**	**23.60%**
Count	**Column Total**		**9948**	**13044**	**22992**
Percent			**43.27%**	**56.73%**	

During each period the percent of lane changes in which the driver used a turn signal was determined. This variable served as a repeated measure for an ANOVA study, which included age group and gender as the usual explanatory variables. The analysis in Table 4-25 reveals several significant effects, all with neutral or positive safety implications.

Table 4-25. ANOVA Results for Turn Signal Use

	SS	DOF	MS	F	p
Intercept	646499.2	1	646499.2	1441.9	< 0.001

	SS	DOF	MS	F	p
Gender	1448.2	1	1448.2	3.2	0.077
AgeGroup	2531.6	2	1265.8	2.8	0.066
Gender*AgeGroup	1862.1	2	931.0	2.1	0.133
Error	31386.6	70	448.4		
Period	2166.9	1	2166.9	15.5	< 0.001
Period*Gender	759.9	1	759.9	5.4	0.023
Period*Agegroup	545.4	2	272.7	1.9	0.150
Period*Gender*Agegroup	1036.4	2	518.2	3.7	0.030
Error	9804.7	70	140.1		

The significant effects include period, an interaction between period and gender, and an interaction between period, gender, and age. For period, the percent of lane changes with a turn signal increased from 61.5 (baseline) to 69.0 (treatment).

Figure 4-15 illustrates the period and gender interaction in explaining turn signal use. Males show a much larger improvement in their percent turn-signal use than females, 56.2 to 68.2 for males and 66.8 to 69.9 for females. Females, however, already had a high turn-signal use during the baseline period, so it is not surprising that they improved less than males.

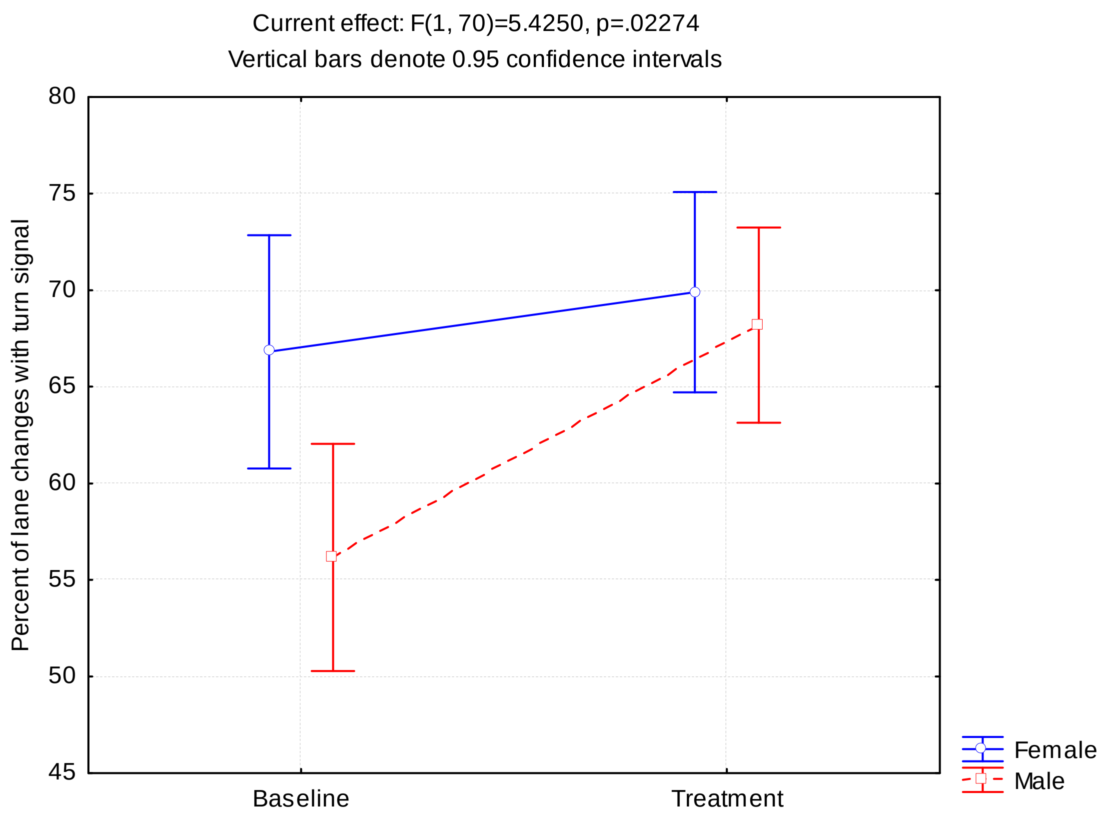


Figure 4-15. Percent of Lane Changes With Turn Signal by Period and Gender

Figure 4-16 illustrates the interaction between period, age, and gender in explaining turn-signal use. Middle-aged and especially older males showed the most improvement in turn-signal use, but they also had the lowest initial (baseline) rates. Younger and middle-aged participants did not change their turn-signal use patterns, but they had high initial rates. The trends in Figure 4-15 and Figure 4-16 suggest that the RDCW motivated drivers with low baseline levels of turn signal use to increase their use, a trend more pronounced among males than females.

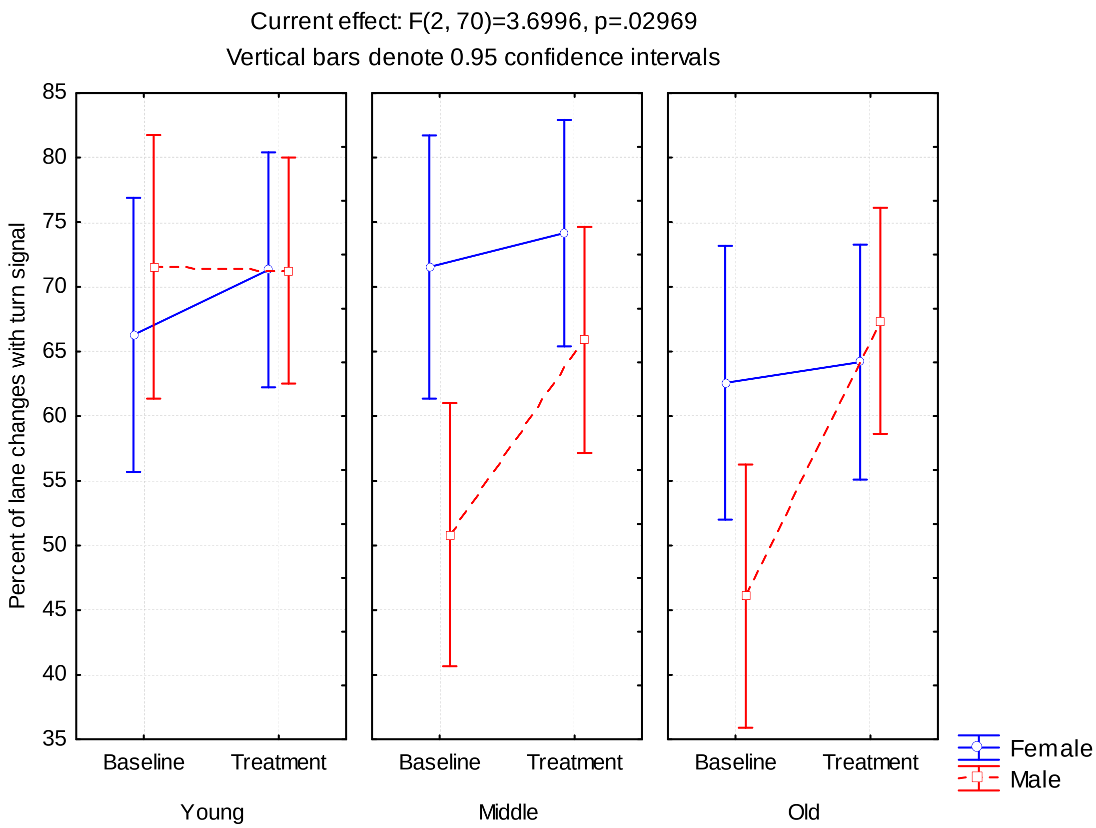


Figure 4-16. Percent of Lane Changes With Turn Signal by Period, Age, and Gender

4.5.4. Turns

Driver performance on turns was analyzed to determine if RDCW use introduced any unintended consequences in this aspect of driving. An ANOVA study was performed with age group, gender, and period as the explanatory variables, and mean and peak lateral acceleration as the dependent variables. Table 4-26 lists FOT turns by period, gender, and age group. There were 34,213 turns during the entire FOT, and these turns make up the sample set for the analyses in this section.

Table 4-26. FOT Turns by Period, Gender, and Age Group

Period	Gender	Young	Middle	Old	Row Totals
Baseline	Female	2966	2111	2185	7262
	Male	3336	2517	2192	8045
Total		6302	4628	4377	15307
		18.42%	13.53%	12.79%	44.74%
Treatment	Female	3076	2583	2834	8493

Period	Gender	Young	Middle	Old	Row Totals
Total	Male	3975	3450	2988	10413
		7051	6033	5822	18906
		20.61%	17.63%	17.02%	55.26%
Column Total		13353	10661	10199	34213
		39.03%	31.16%	29.81%	

Mean Lateral Acceleration

An ANOVA study with the mean lateral acceleration as the dependent variable identified the following significant effects and interactions:

1. Gender;
2. Age;
3. Period; and
4. Gender and period.

For gender, females averaged 0.63 m/s^2 versus 0.65 m/s^2 for males (a trivial difference). For age group, younger participants averaged 0.68 m/s^2, versus 0.66 m/s^2 for middle-aged participants and 0.59 m/s^2 for older participants. For period, the average lateral acceleration on a turn increased from 0.64 to 0.65 m/s^2 from the baseline to the treatment period, a statistically-significant but not safety-significant difference. The gender and period interaction showed that females maintained a constant average lateral acceleration across periods, 0.63 m/s^2, whereas males increased their lateral acceleration from 0.64 m/s^2 to 0.66 m/s^2.

Peak Lateral Acceleration

The ANOVA study with peak lateral acceleration as the dependent variable identified numerous significant effects and interactions. The significant interaction of age, gender, and period is shown first, as this helps explain the other effects and interactions. Figure 4-17 plots the interaction of gender, age group, and period in explaining peak lateral acceleration.

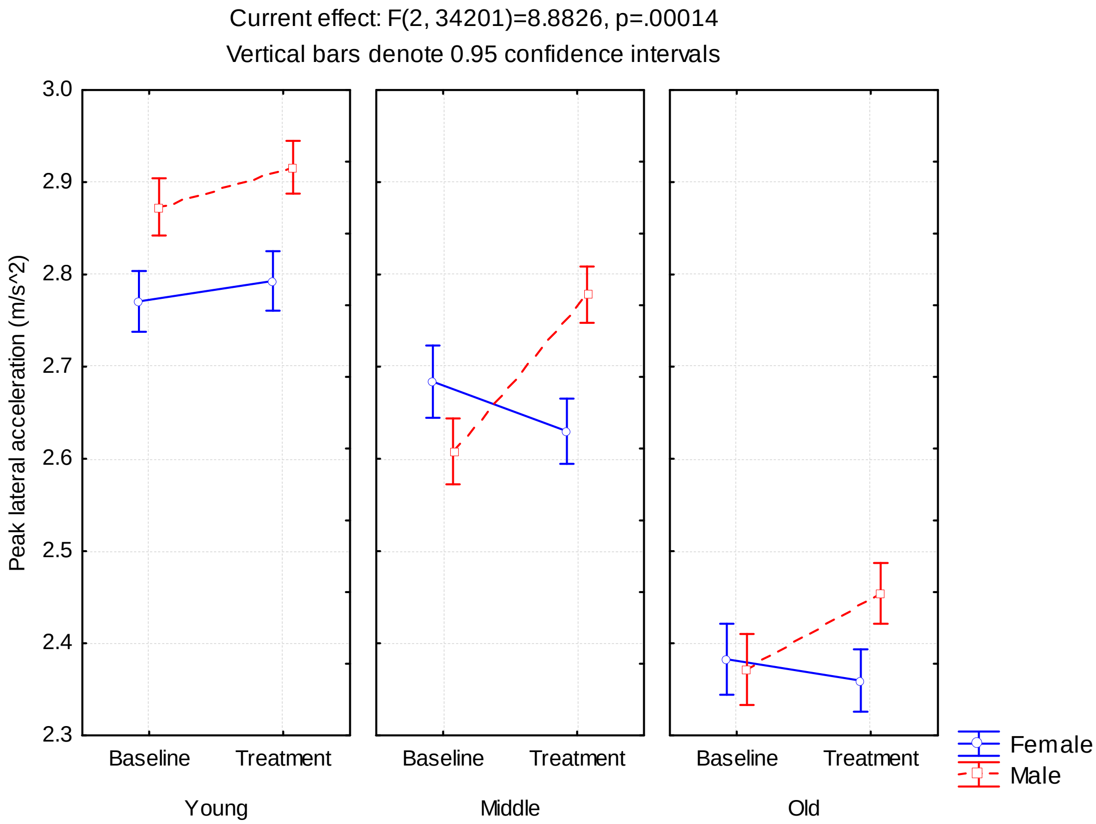


Figure 4-17. Peak Lateral Acceleration by Age Group, Gender, and Period

For gender, males averaged a higher peak lateral acceleration, 2.67 m/s^2, than females, 2.60 m/s^2. The higher values from younger males and increased values during the treatment period for other males account for the gender difference. The data in Figure 4-17 shows a clear decrease in peak lateral acceleration with increasing age. The actual means by younger, middle, and older age groups are: 2.84, 2.67, and 2.39 m/s^2. The peak lateral acceleration increased slightly from 2.61 m/s^2 to 2.66 m/s^2. Although middle-aged and older females decreased their lateral acceleration from the baseline to the treatment period, the other groups increased their values. The small increase from the baseline to the treatment period is not safety significant.

4.5.5. Summary

Analyses of FOT data reveal no negative unintended consequences associated with RDCW use. Although data was analyzed in relation to period, age, and gender, the main concern was identifying if there is a negative change in performance from the baseline to the treatment period. No such negative changes of any consequence were identified; in fact, the changes were primarily positive.

> On curves the data show no change in the mean lateral acceleration with period, nor any change in the peak deceleration with period.

For lane keeping, the data show a modest improvement in lane offset with period, approximately 2 cm, and a modest decrease in the standard deviation of the offset with period.

Signaling during lane changes improved with period from 61.5 to 69 percent of the lane changes accompanied by a turn signal.

On turns the peak lateral acceleration increased slightly from the baseline to the treatment period, approximately 0.05 m/s^2. The mean lateral acceleration also increased, but again, the magnitude was very small, approximately 0.01 m/s^2.

4.6 CONCLUSIONS

This chapter describes the safety benefits associated with using the RDCW. These benefits were determined by methodically and comprehensively analyzing the FOT data. We began by enumerating the most common road-departure pre-crash scenarios and identifying those that the RDCW would most likely affect. These scenarios comprised:

1. going straight and departed road edge;
2. negotiating a curve and departed road edge; and
3. negotiating a curve and lost control.

FOT data was then analyzed to determine the frequency and severity of conflicts corresponding to these pre-crash scenarios. The first two scenarios were grouped into a single *departed-road-edge* conflict category. Conflict frequency was analyzed under a variety of conditions to determine if the RDCW activation (the treatment period) was associated with any significant changes in driver performance. In addition, the conflict frequency and severity for specific speed ranges and crash statistics provided data to predict changes in crash counts that could occur with widespread RDCW deployment. Finally, we analyzed FOT data to determine if there were any unintended consequences associated with RDCW activation.

4.6.1. Road-Departure Conflicts

An analysis of over 900 road-departure conflicts revealed:

1. The baseline conflict rate of 1.76 per 100 km decreased by 31 percent during the treatment period.
2. The baseline daytime-departure-conflict rate of 1.97 per 100 km decreased by 40 percent during the treatment period.
3. At speeds greater than 55 mph, the baseline-departure-conflict rate of 2.64 per 100 km decreased by 44 percent during the treatment period.

A video analysis of 2,500 imminent LDW alerts revealed:

1. The odds of an alert being a true positive for a distracted driver were 1.73 times the odds for a non-distracted driver.

2. The odds of an alert being a true positive for an inattentive driver were 5.25 times the odds for an attentive driver.

4.6.2. Control Loss Conflicts

An analysis of over 3,300 control-loss conflicts revealed:

1. Neither the baseline conflict rate nor conflict severity changed during the treatment period.
2. Conflict rate varied with age: younger, middle-aged, and older drivers had rates of 6.9, 4.4, and 3.1 conflicts per 100 km.
3. Participants had more conflicts on non-freeways than freeways, 5.1 versus 3.6 conflicts per 100 km.

4.6.3. Crash Estimates

An analysis of conflict rates and conflict severity during the baseline and treatment periods and an integration of this analysis with crash statistics revealed:

1. At speeds greater than 55 mph, the RDCW-equipped light vehicles are predicted to have 7 to 57 percent fewer departure conflicts per 100 km than standard vehicles.
2. With full RDCW deployment and full availability, the projected annual reduction is approximately 9,400–74,800 road-departure crashes.
3. With full deployment and the 56 percent LDW subsystem availability observed in the FOT data, the projected annual reduction is 5,200 to 41,200 crashes.

4.6.4. Unintended Consequences

An analysis of participant driving data in curves, lane changes, and turns, and contiguous blocks within the lane markers revealed no non-trivial unintended consequences in the FOT data. Some of the significant effects found in the FOT data include:

1. Although gender and age both predicted mean and maximum lateral acceleration on curves, neither of these measures changed during the treatment period
2. The baseline mean lane offset, -0.065 meter, improved by 0.02 m during the treatment period.
3. The mean baseline percentage of signaled lane changes, 61.5, improved to 69 percent during the treatment period.
4. The baseline peak lateral acceleration during a curve, 2.61 m/s^2, showed a slight increase to 2.65 m/s^2 during the treatment period.

5. DRIVER ACCEPTANCE

The goal of the RDCW is to reduce the number of run-off-the-road crashes. The successful adoption of the RDCW depends on drivers' ability to understand and operate it appropriately and on whether they liked, used, and were interested in purchasing it. The rationale is that if drivers accept the RDCW, they will be more inclined to use it.

> **HIGHLIGHTS**
>
> - RDCW settings and availability indicators are easy to use.
> - Participants stated the RDCW increased safety, because it fostered increased turn-signal use, reduced lane drift, and improved alertness.
> - Most participants want to acquire the RDCW and would pay an average of $725.
> - Older participants are more likely than younger participants to purchase such a system.

The independent evaluation gathered information from the pre-drive questionnaire, post-drive survey, post-drive debriefing sessions and focus groups, which gave insights into driver acceptance of the RDCW. The data includes socioeconomic information, driving experience, post-drive survey and debriefing responses, and, if they elected to attend one of the four focus group meetings, perceptions about use of the RDCW. These driver acceptance measurements estimate participants' interest in eventual purchase and use of the RDCW.

This chapter describes the independent evaluation of driver acceptance of the RDCW. Section 5.1 describes driver acceptance objectives and data collection and analysis. Section 5.2 discusses FOT participants and their driving behavior. Sections 5.3, 5.4, and 5.5 present data analysis results and discussion of, respectively, the RDCW, the LDW (subsystem), and the CSW (subsystem). Section 5.6 provides conclusions.[5]

5.1 FRAMEWORK

The RDCW driver acceptance framework proposed in the independent evaluation plan (Wilson et al., February 2002) and the data analysis plan (Yang et al., November 2004), has the following objectives:

1. *Ease of use* examines participants' understanding of RDCW operation, whether participants feel comfortable with the interface and can adapt to, and understand how to, use the RDCW.
2. *Learning* documents whether participants thought they were able to learn how to become competent users of the RDCW and how long it took them to learn how to operate it.
3. *Driver performance* captures any alterations in driving behavior as a consequence of using the RDCW.
4. *Perceived value* provides information about the participants' rating of the safety of the RDCW, its impact on their driving skill, and their ability to accommodate its alerts.

[5] Appendix D provides information about the conceptual origin of the driver acceptance framework.

5. *Advocacy* measures participants' expressed willingness to endorse and buy the RDCW.

Figure 5-1 illustrates driver acceptance objectives and subobjectives.[6]

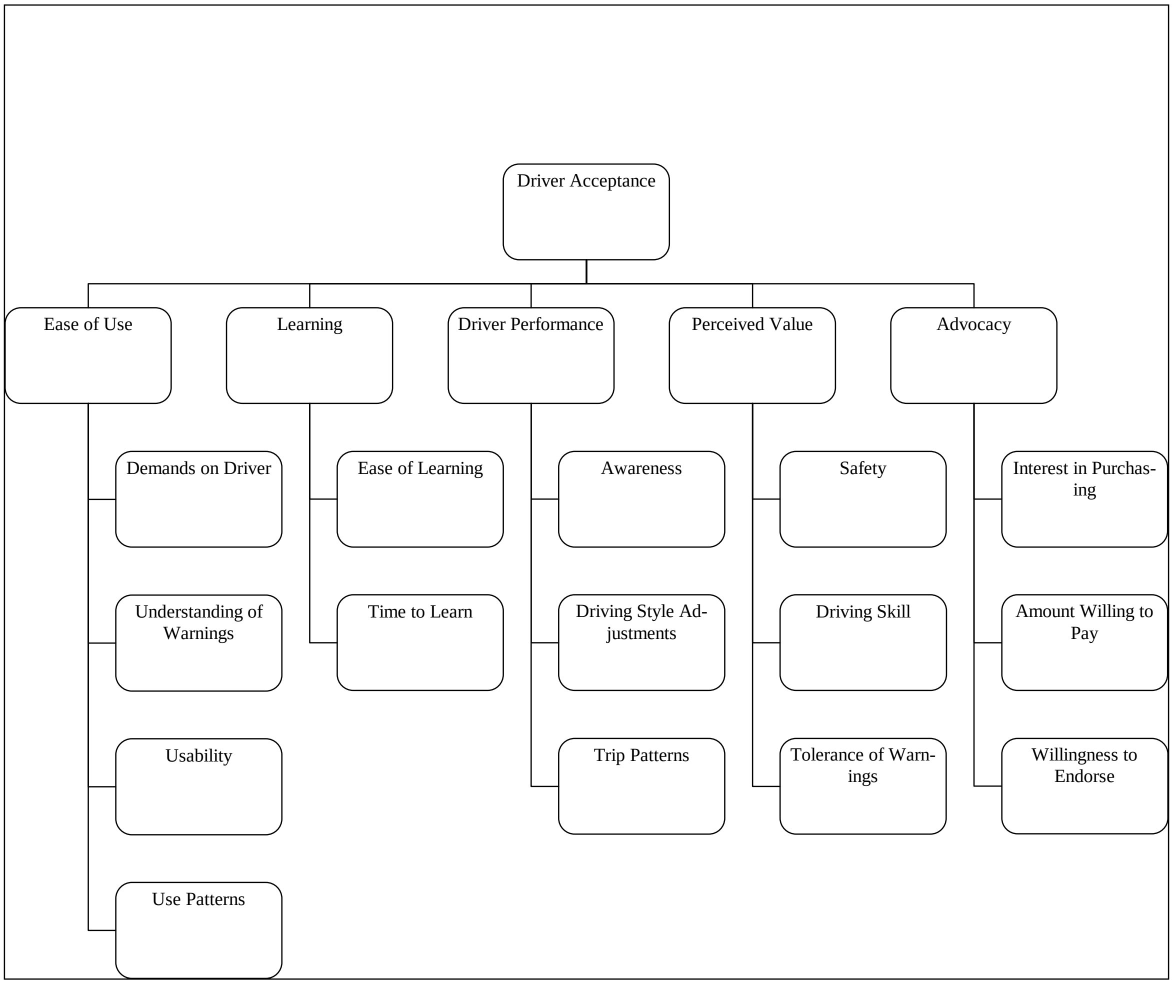


Figure 5-1. Relationship Between Driver Acceptance Objectives and Subobjectives

5.2 FOT DRIVER CHARACTERISTICS

Eighty-seven drivers originally participated in the RDCW FOT[7], but 9 were excluded from the analysis pool.[8] This section presents statistics on the remaining 78 participants.

[6] Appendix D provides definitions of the subobjectives.

[7] Appendix E describes the methodology used to acquire the RDCW FOT driver acceptance data and the quantitative analyses.

[8] Nine participants' data was eliminated from the analyses for the following reasons: (1) struck a deer and crashed the FOT vehicle, (2) FOT vehicle had low LDW availability due to calibration losses, (3) pulled out starter motor fuse and denied doing it, (4) withdrew from the FOT without completing the post-drive survey, (5) drove too few miles during the first and the fourth week, (6) lived outside the mapped area, (7)

5.2.1. Profile of FOT Participants

The participants represent three age groups: 26 younger participants (20 to 30 years old), 26 middle-aged participants (40 to 50 years old), and 26 older participants (60 to 70 years old). Each age group had 13 male and 13 female participants. All participants live in adjacent counties in southeastern Michigan.

- Seventy-eight participants, equally balanced by gender and three age groups provided FOT data.
- Mean participant FOT driving statistics: 116 trips, 1,708 km, 32 hours.
- Mean participant FOT alerts per 100 km:
  - LDW cautionary and imminent: 7.5 and 3.9;
  - CSW cautionary and imminent: 3.3 and 1.0.

Table 5-1 summarizes demographics for the 78 participants. Older participants had more driving experience but had the lowest estimated vehicles miles traveled (VMT). Ten older participants were unemployed (retired or homemakers). All of the middle-aged participants were employed and reported the largest estimated VMT. Ten younger participants were unemployed (homemakers or students). Eighty-of the participants had at least some college education.

Table 5-1. Participant Demographic Information

Demographic Variable:	Group	Value
Mean Age in Years	Younger	24.7
	Middle-Aged	45.3
	Older	64.5
Mean Driving Years	Younger	8.5
	Middle-Aged	29.5
	Older	46.8
	No Response	1 Participant
Mean Annual Mileage Driven (Self-Reported)	Younger	16,581
	Middle-Aged	18,500
	Older	13,479
	No Response	6 Participants
Median Annual Mileage Driven	*****	15,000
Employment Status:	Employed	72.2%
	Retired/Home/Student	27.8%
	No Response	6 Participants
Highest Education Completed:	High School	14.1%

had a CSW outage and data packets were lost, (8) had a DAS malfunction, and (9) drove only 27 miles during the fourth week.

Demographic Variable:	Group	Value
	College	70.5%
	Post-College	15.4%
	Yes	54.1%
Wear Glasses:	No	45.9%
	No Response	4 Participants
	Yes	16.4%
Wear Contact Lenses:	No	83.6%
	No Response	17 Participants

5.2.2. Driving Activity

During the first six days (the “disabled” or “baseline” period), the RDCW operates in the background and will not alert the driver, even if one is required. During the final 20 days (the “enabled” or “treatment” period), the RDCW operates in the foreground and will alert a driver when one is required. To accommodate test schedules, not all 78 participants drove the RDCW-equipped FOT vehicle for 26 days. Seven participants drove for 27 days (Participants 28, 29, 34, 62, 63, 64, and 83), and 6 participants drove for 25 days (Participants 72, 73, 75, 78, 82, and 87). Table 5-2 summarizes driving statistics for the 78 participants using data from the onboard data acquisition system (DAS). These summary statistics show distance and hours traveled during the FOT.[9]

Table 5-2. FOT Driving Summary Statistics

Age-Gender	Total Trips	Mean Trips Per Driver	Total Distance (km)	Mean Distance Per Driver	Total Hours	Mean Hours Per Driver
Younger Female	1,743	134.1	23,418.37	1,801.41	447.63	34.43
Younger–Male	1,746	134.3	27,203.37	2,092.57	491.47	37.81
Middle-Aged Female	1,341	103.2	22,447.54	1,726.73	392.83	30.22
Middle-Aged Male	1,557	119.8	25,070.50	1,928.50	452.78	34.83
Older Female	1,283	98.7	14,951.75	1,150.13	322.80	24.83

[9] Because the realism of FOT driving can be questioned, UMTRI asked participants during the third focus group if they thought they drove differently with the FOT vehicle when their driving data was recorded. Answers were mixed. Some said they drove more cautiously because they did not want to receive an LDW alert and it was not their car and they didn’t want anything to happen to it. Conversely, a younger man said he drove the FOT vehicle more aggressively because it had better acceleration than his car.

Age-Gender	Total Trips	Mean Trips Per Driver	Total Distance (km)	Mean Distance Per Driver	Total Hours	Mean Hours Per Driver
Older Male	1,358	104.5	20,120.44	1,547.73	355.93	27.38
Total	9,028	*****	133,211.98	*****	2,463.45	*****
Mean	*****	115.7	*****	1,707.85	*****	31.58

As the age group increased from younger to older, the number of trips, distance driven, and hours of driving decreased. For each age group, male participants made more trips, drove further, and drove longer than female participants. Appendix E compares participant driving to national data from the National Household Travel Survey. Appendices G and H provide additional participant data.

The total number of trips varied widely by participant. At the low end, Participant 33, a younger female, had 36 trips. At the high end, Participant 34, also a younger female, had 258 trips, 7 times as many trips as Participant 33. Some other notable variation in the trip data includes:

- The average number of trips per day ranged from 1.4 to 9.4, a factor of seven;
- Participant VDT ranged from 280 to 2051 miles;
- Average daily distance ranged from 10.9 to 79.0 miles;
- Total participant FOT hours ranged from 9.5 to 50.4, with an average of 32; and
- Average daily driving ranged from 24 to 114 minutes, with an average of 72.

5.2.3. LDW and CSW Alerts

This section discusses the incidence of LDW and CSW alerts issued to participants during the baseline and treatment periods. A nested repeated-measures ANOVA was performed with alert rate as the dependent variable, gender and age as the between-groups variables, and period, alert type (CSW, LDW), and alert level (cautionary, imminent) as nested within-subject variables. For the latter, alert level is nested within alert type (each alert type has two levels), and alert type is nested within each period. The ANOVA yielded numerous statistically significant associations between alert rate and the aforementioned independent variables, comprising:

1. **Gender**, males had more alerts than females ($F(1, 70)=4.48$, $p=.038$, 3.54 versus 2.69 alerts per 100 km);
2. **Period,** alert rates decreased from baseline to treatment period ($F(1, 70)=19.5$ $p < 0.001$, 3.51 to 2.72 alerts per 100 km);
3. **Gender and Period** interaction, from the baseline to the treatment period, males' alert rates decreased more than females, by 1.20 (males) and 0.38 (females), $F(1, 70)=5.12$, $p=.027$. Males, as indicated, had higher overall rates.
4. **Alert type,** there were more LDW alerts than CSW alerts, 3.90 versus 2.32, $F(1, 70)=27.1$, $p < 0.001$.

5. **Alert level,** there were more cautionary alerts than imminent alerts, 3.80 versus 2.43, $F(1,70) = 34.8$, $p < 0.001$.
6. **Alert type and alert level** interaction, the alert rates shown in Figure 5-2 indicate that FOT participants elicited approximately the same number of LDW cautionary and imminent alerts, but almost 3.5 times as many cautionary CSW alerts as imminent CSW alerts. The difference between LDW and CSW alerts at the imminent level explains both why there were more overall LDW alerts and why there were more cautionary than imminent alerts.

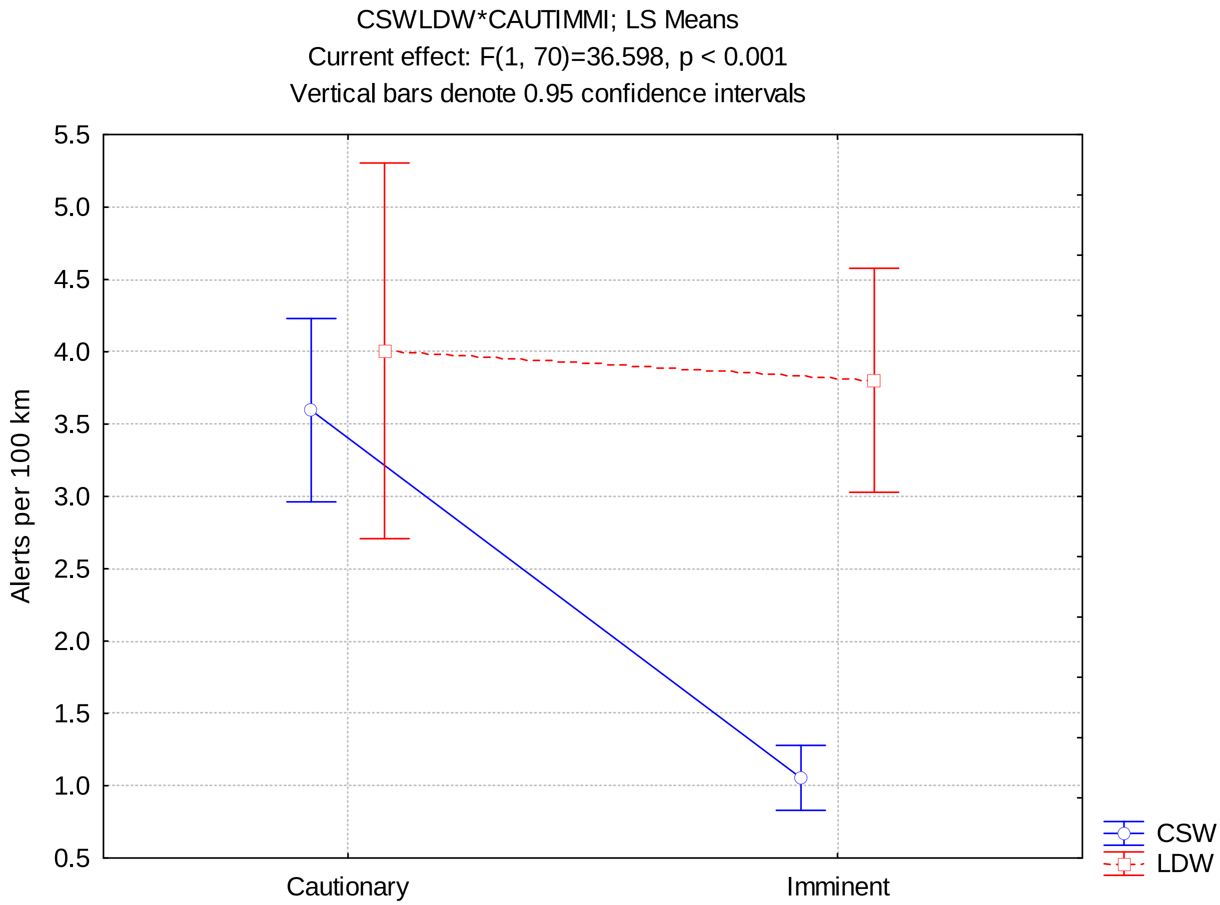


Figure 5-2 Alert Rates Versus Type and Level

7. **Period and Alert type** interaction, from the baseline to the treatment period, LDW alert rates decreased by 1.91 alerts per 100 km, and CSW alert rates *increased* by 0.33, $F(1,70) = 47.1$, $p < 0.001$.
8. **Period and Alert level** interaction, from the baseline to the treatment period, cautionary alert rates decreased by 1.50 alerts per 100 km, and imminent alert rates decreased by 0.08, $F(1,70) = 15.6$, $p < 0.001$.
9. **Period, Alert type, and Alert level** interaction, the alert rates shown in Figure 5-3 explain the previous two interactions. CSW alert rates at both levels increased slightly (but statistically significantly) from the baseline to the treatment period. A separate contrast analysis showed that LDW cautionary alert rates decreased sig-

nificantly from the baseline to the treatment period, but the imminent alert rates did not.

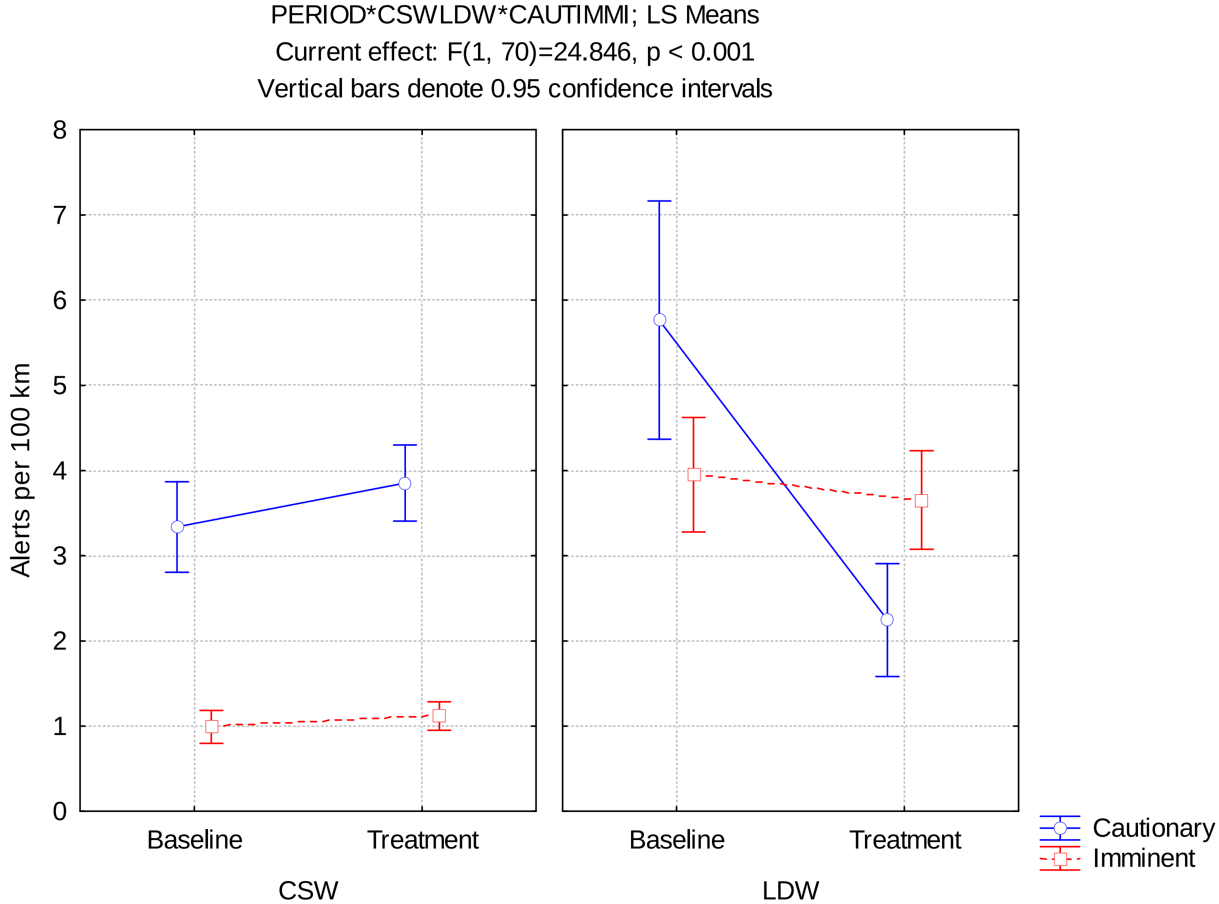


Figure 5-3 Alert Rates by Type, Period, and Level

10. **Alert type, Alert level, and Age** interact, the CSW alert rates on the left side of Figure 5-4 illustrate an age effect with CSW alert rates and an interaction between CSW alert levels and age. Conversely, the LDW alert rates on the right side show no significant effects. The alert rates are the same across age groups and across alert levels. Nor do age and alert level interact in explaining LDW alert rates.

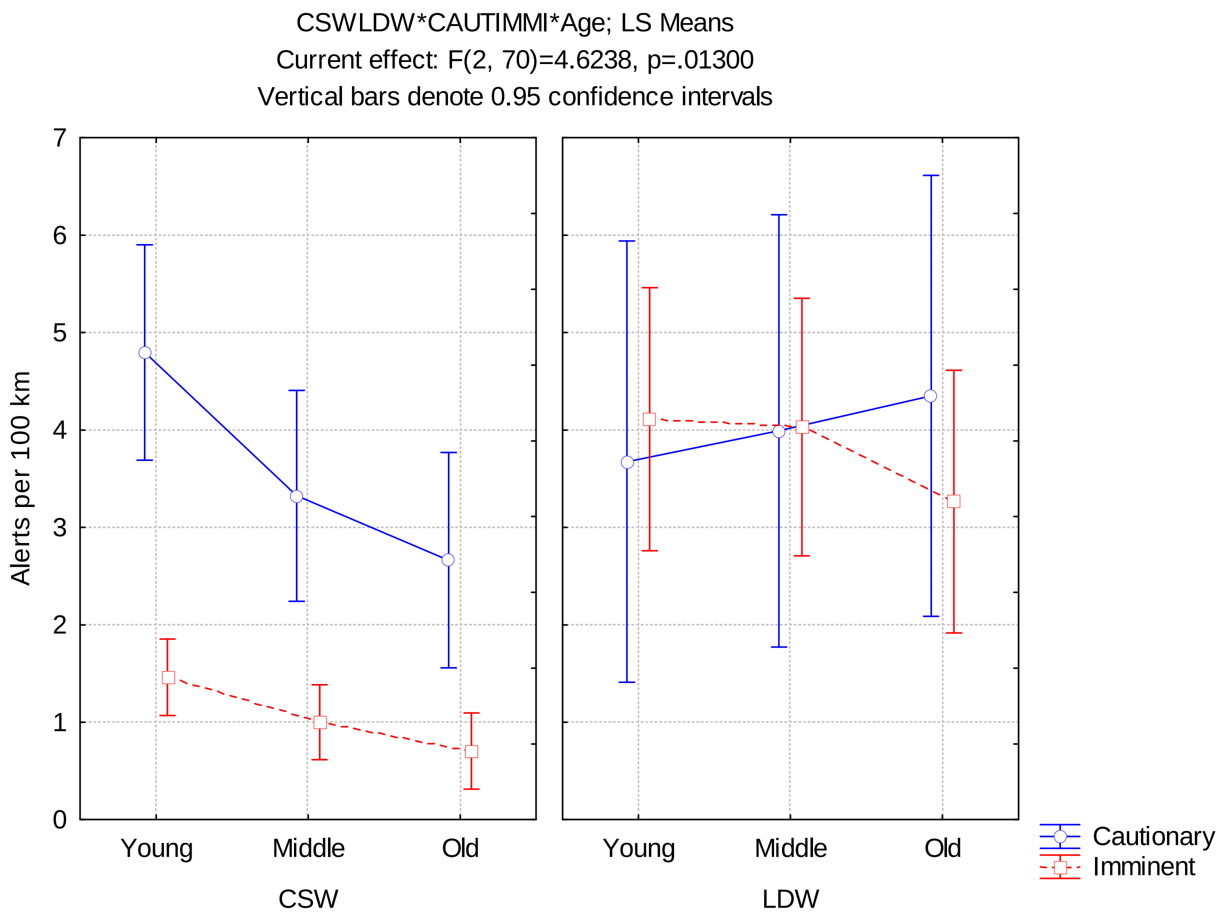


Figure 5-4 Alert Type, Age Group, and Alert Level Interaction

The findings presented in this section will be useful in understanding participants' responses to survey questions. Analyses of these responses make up the majority of this chapter. Appendix D provides more detailed information on CSW and LDW alerts.

5.3 RDCW

- FOT participants rated RDCW ease-of-use positively.
- The RDCW did not distract participants.
- Participants found the display location convenient and the RDCW operation easy to understand.
- Most participants liked the RDCW and thought it would increase driving safety.
- Two-thirds of the participants said they would pay $800 for the RDCW.

This section describes driver acceptance of the RDCW based on post-drive survey responses, debriefing comments, and focus group comments.

5.3.1. Ease of Use

Table J-1 lists, by subobjective, the descriptive statistics for responses to the RDCW *ease of use* post-drive survey questions. The mean scores show that FOT participants considered the RDCW easy to use in terms of demand on driver, understanding of warning, and usability subobjectives. The modal response confirms that most FOT participants rated the RDCW as easy to use.

Participants' responses to questions about the sensitivity settings (Questions 10 and 13) show that participants tended to leave the sensitivity at one setting. The modal response to these two questions is "1" (i.e., strongly disagree), which indicates that participants made few, if any, adjustments to the sensitivity setting. If they do adjust the sensitivity settings, they were most likely to do because of traffic conditions or fatigue.

An analysis of the survey responses in Table J-1 revealed three statistically significant results at the 0.05 level. The mean survey scores for Question 27, I was not distracted by RDCW system components (e.g., alerts, displays or controls), were 5.15, 5.50 and 6.23 for younger, middle-aged, and older participants, ($F(2, 75) = 3.72$, $p = 0.0288$). A separate contrast analysis indicated that the older participants' rating was significantly higher than the younger participants' rating. Thus, most participants were not distracted by the RDCW, and older participants indicated the least distraction

The mean scores for Question 13, I frequently adjusted the CSW sensitivity setting during my drive, were 3.77, 2.64, and 2.57 (younger, middle-aged, and older), $F(2, 71) = 3.74$, $p = 0.0286$. A separate contrast analysis indicated that the younger participants were more likely than other participants to adjust the CSW sensitivity setting. The mean scores for Question 10, the LDW equivalent of Question 13, were 3.96, 2.84, and 2.96 (younger, middle-aged, and older), $F(2, 73) = 3.30$, $p = 0.0425$. As with the CSW, younger participants were more likely to adjust the LDW sensitivity setting. Participants' responses to Questions 10 and 13 complemented results of Question 27. Middle-aged and older participants were less likely to adjust the LDW and CSW sensitivity settings, which may contribute to their agreeing that the RDCW was not distracting. Overall, participants tended to make few changes to the sensitivity settings

In summary, the survey responses indicate that FOT participants found the RDCW easy to use. They were not distracted by it, were able to work with the sensitivity settings, distinguished between the LDW and CSW alerts, understood the meaning of the warnings, and identified the urgency of warnings. They rated the display location as convenient and easy to become familiar with, RDCW operation as easy to understand, and sensitivity adjustment switches as easy to locate and use.

Post-Drive Survey Comments

During their debriefings, some participants volunteered additional comments to their post-drive survey responses or wrote comments on their survey forms. These comments help clarify the post-drive survey responses. The following discussion is drawn from post-drive survey items that generated multiple comments.[10]

Auditory Warnings. Participants said they thought it was easy to distinguish between the auditory warnings. They could tell the difference between the LDW alert, a simulated rumble strip, and a CSW auditory alert, a voice saying "curve, curve." Some participants

[10] The cutoff for review was 15 or more comments per post-drive survey item.

said they were confused and others said they received many false warnings. Specific problems include repeated false warnings on the same road, CSW alerts in the absence of a curve, and a need to receive a few warnings to understand their meaning. Participants liked the auditory warning because it claimed their attention, even though many also described passengers' reactions to the alerts as somewhat annoying.

Vibration Warnings. Most participants readily distinguished these warnings and preferred them to the auditory warnings. A few participants, however, said they lost their ability to distinguish the direction of the seat vibration warning after driving for a long time. One participant confused the seat vibration with cell phone vibration. Another participant asked if the vibration was severe, "is it because I was on a curve or because of a drift to the left?" indicating a lack of understanding of the significance of seat vibration warnings even after completing the FOT.

Visual Warnings. Participants wanted the visual warnings to stay on longer. However, most participants did not pay attention to, or look at, the visual warnings, and those who did thought they "clearly indicated the warning condition."

RDCW Display Location. Most participants did not like the RDCW display location because the steering wheel was in their way. They did not look at the visual display often because they had to take their eyes away from the road. One participant said, "When the lights went off on the visual display, I almost never looked at them because there was no need to. I looked at the visual display to see if the lights were on for system availability."

LDW and CSW Information. Participants located LDW and CSW information easily on the display, but they viewed this information as advisory and did not rely on it. Most could easily distinguish the visual LDW alerts from the CSW alerts, but there were a small number who had difficulty distinguishing between them. A younger woman said she had difficulty making this distinction. An older man said it was hard to see the information.

Sensitivity Switches. The sensitivity switches were easy to adjust, but participants said they did not adjust them often. One participant said she "increased the sensitivity level when driving in unfamiliar places." Another participant said "I didn't do a lot of experimenting because I didn't notice much difference when I did change the sensitivities." Another said he did not adjust the sensitivity much because "I have short arms and the controls were hard to reach." Some participants adjusted the sensitivity settings often, while others did not. Some experienced a difference according to the levels, while others did not. They adjust the sensitivity when they receive false warnings triggered by construction zones and in response to traffic, weather conditions, or fatigue.

RDCW Component Modifications. When asked to suggest changes or modifications to the RDCW subsystems, participants said that the visual display was the least helpful and it should be placed in a heads-up position so they would not have to take their eyes off of the road. The auditory warnings worked well. Most participants thought that the seat vibration warning was the most helpful, but it could use more levels of intensity. All three warnings should stay on until the problem is corrected. For example, the vibration should stay on until the speed or drifting is corrected. At times, participants had difficulty determining if they were being warned about lane departure or approaching a curve too fast. Some wanted an additional warning for exceeding the speed limit.

Focus Group Comments on RDCW Ease of Use

In the focus group discussions, almost all the participants affirmed that they felt comfortable having the RDCW in the vehicle. A middle-aged woman who felt uncomfortable attributed it to “getting [a] shock from somewhere” (referring to a haptic warning) and being unable to identify a source for the warning, leading her to assess it as a false alarm. Two middle-aged women had neutral opinions of the RDCW. The first participant liked the LDW, but was not able to “trust” the CSW, so overall the RDCW was not seen as “beneficial.” The second viewed RDCW “as something to get used to.”

In probing what “feeling comfortable” with the RDCW meant, participants said it helped them to maintain, or return, their attention to the road. They described distraction due to passengers, mental preoccupations, cell phone use, or fatigue, and viewed the RDCW as having helped them return their attention back to the road.

Participants cited having more information as another reason to feel more comfortable with the RDCW. Some participants categorized the added information from the RDCW as “feedback” and said “you don’t usually get feedback from your car as to how you are actually doing in driving conditions.” Participants also indicated that the system made it possible to learn more about their driving. For example, one older woman said she learned that she pulled to the left more than she realized.

Participants became used to the RDCW. They said that when they drove home in their own vehicle, having completed their FOT, they remembered thinking as they were doing a particular maneuver, “the system will warn me” but then realized that they no longer had the RDCW. A middle-aged woman said that she went through an adjustment to get used to not having the RDCW.

Participants were asked what they thought about how the information was conveyed. Interpreting this topic as referring to the warning modalities, participants said they concentrated on the road and, by the time they looked at the visual display, the warning had ended. Several wanted the visual warning to illuminate for a longer duration. At times they were not sure what the auditory warning was for unless it said, “curve.” Participants said that they could feel the seat vibrating and one added “but I couldn’t always tell which side or if it was in the middle and what it was for.”

5.3.2. Learning

Table J-2 provides the descriptive statistics for responses to the RDCW *ease of learning* post-drive survey questions. Almost all the participants thought the RDCW was easy to become familiar with and had a good understanding of how it works. The mean responses given to RDCW Questions 25 and 26 are almost identical, 6.4 and 6.5, respectively. Participants who felt that it was easy to become familiar with the RDCW also developed a good understanding of how the RDCW worked. Statistical analyses of these responses revealed no association between age and the responses, nor one between gender and the responses.

Focus Group Comments About RDCW Learning

When asked if the RDCW was intuitive to use, most participants said it is self-explanatory, straightforward, and user friendly. They estimated they needed one hour to one day to understand the alerts. A participant who rated its intuitiveness as neutral said he reviewed the instruction manual for a refresher and had to travel far to make the availability icons for the LDW and CSW subsystems illuminate. He had availability problems, reducing his ability to rate RDCW on intuitiveness. Two respondents who did not rate the RDCW as intuitive said they watched the instructional video repeatedly to remember how it worked. One respondent said he tended to shift position while driving for long durations so his leg was placed alongside the door for relief rather than on the driver's seat; as a result he did not receive the haptic warnings as intended.

When asked how easy it was to remember what each warning meant, only the older men and women offered comments. An older woman said she drove alone most of the time, wanted more audio warnings, and had difficulty understanding the seat vibration warning. An older man suggested moving the CSW seat vibration to the back of the seat to make it more distinct. Another older man said he received alerts but was unsure if they were LDW or CSW when there was no reason for them. He said UMTRI (the FOT conductor) told him that the warning came from driving under an overpass. An older woman said she always understood what the auditory warning was for, but was not sure what the seat vibration meant.

5.3.3. Driver Performance

The driver performance objective has three subobjectives: awareness, driving style adjustments, and trip patterns. Table J-3 lists the descriptive statistics for first two subobjectives. Participants indicated that the RDCW made them more aware of the position of their vehicle on the road and of the upcoming curves. Most participants did not rely on the RDCW to operate their vehicles safely. Statistical analysis revealed no significant associations between age group and responses.

The trip patterns subobjective used DAS trip data to understand driver performance with RDCW, focusing on participants' number of trips, total hours, and total distance. In each these cases, the data revealed a statistically significant association between age and the corresponding measure. The mean number of total trips, by age group, was 134.2, 111.5, and 101.6 (younger, middle-aged, and older), $F(2, 75) = 3.71$, $p = 0.0291$. A separate contrast analysis showed younger participants having significantly more trips than older participants. The mean number of total hours, 36.1, 32.5, and 26.1 (younger, middle-aged, and older), $F(2, 75) = 6.92$, $p = 0.0017$, showed younger and middle-aged participants having significantly more hours than older participants. The same pattern held for participants' mean total distance in kilometers, 1947.0, 1827,6, and 1348.9 (younger, middle-aged, and older), $F(2, 75) = 5.69$, $p = 0.0050$, with younger and middle-aged participants having significantly more distance than older participants. Although younger and middle-aged participants drove more, they did not rely on the RDCW more than the older participants, as the responses to Question 28 in Table J-3 indicate. Use of the RDCW made participants more aware of their vehicle position on the road and of upcoming curves, but they did not rely on it.

Focus Group Comments about Driver Performance

A focus group participant said that using the RDCW had an impact on driving her own vehicle. The driver performance consequence was captured because the focus groups were conducted after participants completed their FOT participation. This driver commented:

> "When I took the survey after I dropped the vehicle off, one of the questions was 'did you kind of rely on the system in your driving?' And I said, no, I didn't think I did. It was a good system, but I don't think I used it to help me in my driving. It wasn't until after I was driving home the next day and I was doing something in the car, and I was going off the road, and I was thinking, this is going to warn me, but I didn't have the system. If I took that questionnaire again, I would change my answer. I had a little bit of an adjustment to get used to not having RDCW."

5.3.4. Perceived Value

Perceived value is the fourth objective in the RDCW driver acceptance framework. Table J-4 lists the descriptive statistics for responses to the RDCW perceived value survey questions. Most FOT participants had positive perceptions of the RDCW and thought the RDCW would increase driving safety. An analysis of the survey response data did not show a statistically significant association between responses and age group.

The debriefing comments showed that participants thought that the RDCW improved driving safety because it increased turn-signal use, reduced lane drifts, and improved their alertness on long distance drives, but they did not rely on it, recognizing that it would not always be available.

Focus Group Comments about Perceived Value of RDCW

Three quarters of the focus group participants said they felt safer using the RDCW, with the most frequent reason being they were more alert. Comments included:

> "(RDCW) made me think I was paying more attention than usual."
>
> "(RDCW) kept me more attentive to my surroundings."

> "I felt safe in the vehicle. I reached down to do something but I was approaching orange barrels along the side and all of sudden I was out of my lane…It let you know how easily you become distracted from the road by looking down."

Some participants said that the RDCW taught them more about their driving. "(RDCW) made me notice the drift thing…that I ride my lane to one side …"

A minority of focus group participants who were neutral about the safety provided by the RDCW indicated that the system assisted driving but did not improve safety. One driver based his reaction on his CSW experience. "I never felt it was working. I got more false readings than I ever did positive readings."

5.3.5. Advocacy

The advocacy objective has three subobjectives: interest in purchasing, amount willing to pay, and willingness to endorse. Two post-drive survey questions related to interest in purchasing the RDCW and two to the amount willing to pay for RDCW. Table J-5 lists the descriptive statistics for the responses to these RDCW survey questions.

Almost three-quarters, 73 percent, of participants said they might purchase new cars in the next two years (Question 33). Almost two-thirds, 64 percent, expressed interest in acquiring the RDCW in a new car (Question 34). Fourteen percent did not answer RDCW Question 36 that asked the maximum amount they would pay for the RDCW.[11] For the remaining 67 people who answered, the mean amount they are willing to pay to acquire the RDCW is $729. The amounts range from $4,000 to 10 percent saying that they would pay nothing. At a given price of $800, almost half, 47 percent, would consider purchasing the RDCW, and one quarter had a neutral opinion. As for statistical analyses, there was no association between age and interest in purchasing a vehicle with the RDCW as an option (Question 34).

Van der Laan and colleagues developed a scale to assess acceptance of new technology (van der Laan et al., 1997). The following driver acceptance scale, made up of nine pairs of contrasting words, assesses perceptions of RDCW. Respondents checked 1 of 5 squares to rate the RDCW on each pair of words. A score of -2, -1, 0, 1, or 2 was assigned to each of five squares. Table 5-3 lists the word pairs.

Table 5-3 Driver Acceptance Scale Word Pairs

Useful	2	1	0	-1	-2	Useless
Pleasant	2	1	0	-1	-2	Unpleasant
Bad	-2	-1	0	1	2	Good

[11] One of 7 participants was not able to answer because they buy used cars, have not purchased a vehicle in many years, or estimate vehicle cost by the monthly payment. They said the following: "I haven't bought a new car in more than 10 years and am uncertain about what accessories cost." "I have to drive used cars." "The extras are only a couple dollars more per month. The bottom line is $3 to $4 more per month on a payment. If RDCW cost $4-5 more per month, it would be worth it."

Nice	2	1	0	-1	-2	Annoying
Effective	2	1	0	-1	-2	Superfluous
Irritating	-2	-1	0	1	2	Likeable
Assisting	2	1	0	-1	-2	Worthless
Undesirable	-2	-1	0	1	2	Desirable
Raising Alertness	2	1	0	-1	-2	Sleep-Inducing

Van der Laan et al. validated the responses to these nine pairs of words into two scales: *usefulness* and *satisfaction*. The responses to rows beginning with useful, bad, effective, assisting, and worthless construct the usefulness scale. The responses to rows beginning with pleasant, nice, irritating, and undesirable construct the satisfaction scale. Table J-6 shows the descriptive statistics for the RDCW scores on the driver acceptance scale. The mean usefulness score is 1.2, compared to a mean satisfaction score of 0.6.

An analysis of participants' responses to the usefulness scale revealed no significant association between age and this measure. In contrast, the satisfaction score increased with age, $F(2, 75) = 3.37$, $p = 0.0397$, with mean ratings of 0.30, 0.59, and 0.90 (younger, middle-aged, and older). Indeed, 84 percent of the older participants had positive satisfaction scores, compared to 69 and 54 percent of the middle-aged and younger participants, respectively. A separate contrast analysis showed a significant difference between the satisfaction ratings of older and younger participants

RDCW Purchase Intent

The "weighted box" method was used to estimate the percentage of participants willing to purchase the RDCW and to forecast acceptance.[12] RDCW Question 34, self-reported purchase intent, provided the data. Urban and Hauser (1993) translate subjective scale responses into purchase predictions or an estimate of future purchase. Market researchers use the weighted box method because positive correlations have been found between stated purchase intentions and purchase behavior (Juster, 1966) (Morwitz & Schmittlein, 1992). Participants responded to Question 34 as follows: 1=definitely would not consider (6%), 2 (6%), 3 (2%), 4 might or might not consider (21%), 5 (18%), 6 (20%), and 7 definitely would consider (27%). The weighted box method predicts that 41 percent of the FOT participants would purchase the RDCW.

[12] The procedure to calculate purchase prediction, given intent level and probabilities of actual purchase, is the probability of purchase for given intent level multiplied by the number of respondents at that intent level. In this case, 90 percent of "definites," 40 percent of "probables," and 10 percent of "mights" were summed. Marketers multiply this result by the expected "awareness-availability" percentage to predict what percent of the population will make an actual purchase. The awareness-availability percentage refers to the population segment that is both aware of the product and finds it available. The awareness-availability percentage value for RDCW was not available for calculations as it is proprietary. Therefore, by default, 100 percent availability and awareness of the system was assumed.

When asked for the primary reason for their answer to Question 34, most participants said they thought the RDCW would increase safety and they would purchase if it was not too expensive. Some participants would rather buy the LDW because it was more helpful than the CSW. Sample comments included:

> “Safety - even with the false warnings, RDCW made me more aware.”
>
> “Could use some help to improve the safety of my driving because of my age.”
>
> “Would be helpful with passing or drifting to the middle but less helpful on curves.”
>
> “If you were driving in an unfamiliar place, the curve warning, in particular, would be useful.”
>
> “I use my cell phone while driving and LDW was useful because it made me keep my eyes on the road.”
>
> “I felt safer driving at night.
>
> “I think this system made me more alert about my driving and how often I cross the line without putting my blinker on. I became a more conscientious driver.”
>
> “I have problems driving long distances. I have dozed off behind the wheel while driving.”

5.4 LDW SUBSYSTEM

- Participants rated the LDW ease-of-use positively.
- Participants knew how to respond to an LDW alert.
- Most participants stated the LDW made them more aware of their lane position.
- As an independent system, participants would pay an average of $500 for the LDW.

This section describes FOT participants' perceptions of the LDW (subsystem). Post-drive survey responses, debriefing comments, and focus group results provided the source material to evaluate the LDW.

5.4.1. Ease of Use

Table J-7 lists the descriptive statistics for responses to the LDW ease of use survey questions, by subobjective. The mean and modal responses to these survey questions (all “7” or Strongly Agree) confirms that participants considered the LDW as easy to use. Participants did not find the LDW alerts distracting and knew what to do when warned.

A statistical analysis of the response to these questions revealed only a single statistically significant finding: a relationship between age and the distraction of LDW auditory warnings, Question 13, $F(2, 73) = 5.77$, $p = 0.0047$. The mean scores by age group were 4.96, 5.52, and 6.40 (younger, middle-aged, and older). A separate contrast analysis found that older participants agreed more strongly than younger and middle-aged groups that the warnings were not distracting. In percentage terms, all the older participants agreed that the LDW auditory warning was not distracting compared to 75 and 58 percent of the middle-aged and younger participants. As for the seat vibration warnings, older participants were uniformly not distracted these, compared to 75 and 80 percent of the middle-aged and younger participants.

Figure 5-5 contains two images of the RDCW visual display, which shows device availability and alert status. The left image shows a right cautionary LDW alert. The right image shows a right imminent alert. The arrow direction corresponds to the direction of the lane drift or departure.

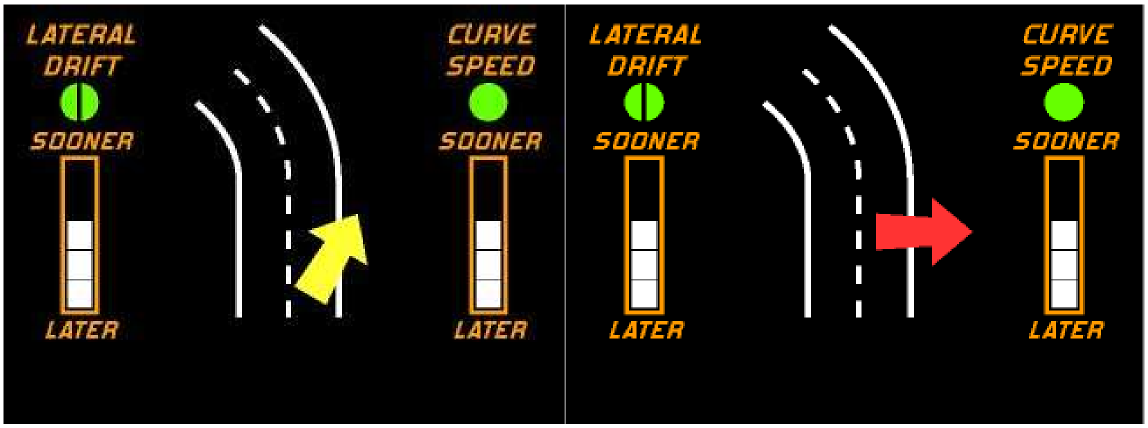


Figure 5-5. RDCW Display Showing LDW Cautionary and Imminent Alerts

During their debriefings, participants said they did not find the LDW visual display distracting, in part because they did not use it much. The few participants who were distracted by the LDW display said they were distracted initially as part of learning how to use it. When they knew how to interpret an LDW alert, they looked at the road and glanced at the visual display for confirmation.

Participants said they are not distracted by the auditory LDW alerts. Several people characterized the auditory warning as "a little startling" but it got their attention. They estimated that the LDW auditory warnings are correct 80 to 90 percent of the time, contributing to its widespread acceptance. A few people said initially they were slightly distracted by the LDW seat vibration, but became accustomed to it.

Participants commented on their passengers' reactions to the auditory LDW alert. Reactions ranged from affirming that the LDW alert is a good idea, to asking for an explanation of the sound, expressing concern about the vehicle's safety, triggering hilarity sometimes at the expense of the driver, and expressing annoyance.

Focus Group Comments on LDW Ease of Use

Participants liked the range of settings for the warning timing. Some participants selected settings to support their physical state. For example, a middle-aged man said if he felt fatigued, he made the timing more sensitive. An older man said he increased the LDW sensitivity setting if the road had faint lines. A younger man turned the sensitivity to its lowest setting because he wanted to touch the lines without setting it off. "I found that by keeping it down it did allow me a bit of leeway to just kind of briefly touch a line and when it went off, it had a pretty good reason." Some participants did not adjust the sensitivity settings; others changed them but then returned to the default setting.

Participants experienced false LDW alerts but tolerated them. They received false-positive LDW alerts due to the effect of weather on the road surface. Some participants received LDW alerts in close succession, as many as 40 per hour, in heavy rain or snow. Reflective surfaces due to wetness and following the cleared path behind a plow straddling lane markings provoked multiple repetitive warnings, making these false warnings particularly annoying. Some participants found the repetitive false LDW alerts so annoying they altered their route. A younger man became so annoyed that he left the road and took side streets, and other participants recalled deliberately trying to stay in the center of their lane.

Construction zones triggered false LDW alerts. Participants recalled that UMTRI staff warned them that they might receive false LDW alerts in construction zones, which tempered their annoyance. A middle-aged woman said, "It wasn't really that annoying because I knew why it was happening."

There were accounts of false LDW alerts even with turn-signal use or proper lane position. Some participants realized that they moved their vehicle before they activated the turn signal. Others said that they knew that they had used their turn signal and still received a LDW alert. A middle-aged woman said this occurred while making left turns, raising the possibility of confusing the CSW alert with the LDW alert. Several participants received false LDW alerts while driving in the middle of the lane and recalled slowing their vehicle, checking their lane position, and checking their speed again, suggesting confusion with a CSW alert. A middle-aged man said he deliberately crossed a lane to make room for a bike and classed this alert as false because it was his deliberate choice for safety reasons. He also mentioned that this occurred in the country with no other vehicle around, suggesting he ignored turn-signal use in the absence of threats.

Participants accepted the false LDW alerts. A younger man said "it's a prototype, there are obviously going to be bugs in it." A middle-aged woman said she paid more attention to the road as a result of false alerts and a younger man reduced the LDW sensitivity to its lowest setting.

One participant distinguished between unnecessary and false alerts. An older woman said she received unnecessary, not false, alerts, when she drove two-lane roads and had to hug the side: "I was on a two lane highway and I was hugging toward the right and I knew that the side of the road was there and so it was an unnecessary alarm, not a false alarm, and I was not really annoyed by it. "

Participants discussed whether there "were situations when you did not get an alert when you felt one was required." This was difficult to assess because it was contaminated by LDW availability and participants varied in their awareness of it. Only a few participants explicitly referred to LDW availability as a factor in missed alerts.

In discussing LDW alerts, a younger man asked UMTRI to confirm his observation that that it took LDW 4 to 5 seconds to relock on the lane markings. He described his regular route to work, in which he had to quickly cross several lanes to reach his exit. He generally made this maneuver without activating the turn signal and believed the LDW was unable to track his motion.

Other participants said that they did not get LDW alerts on the right side. An older woman overcompensated by pulling to the right and thought that the LDW should have give her an alert on the right side. An older man said that the LDW always worked in reference to the left lane but, if there was no white lane on the right, the LDW did not work. In addition, participants asked if the LDW works on dirt or gravel roads.

5.4.2. Learning

Table J-8 lists the descriptive statistics for responses to the LDW-learning survey questions. Most participants rated the LDW easy to learn and had a good understanding of how LDW worked shortly after starting to use it. Almost 85 percent of participants became comfortable driving with LDW within two to three days. One FOT participant said he never became comfortable with LDW operations (Participant 32, male, 29 years old).

There were no statistically significant differences in the responses to these post-drive survey items by age group. Almost all the participants rated the LDW as easy to learn.

Focus Group Comments on Learning

Although none of the focus group topics explicitly address learning, the transcript contains comments describing participants' experience learning to use the LDW. A colorful example involves an older man who said that he assumed LDW did not work because he never had an LDW alert. As a result, he drove faster to provoke an alert, including in a school zone. He said "it (LDW) came on at 55 mph about the same time as the siren of motorcycle cop, for a $125 ticket." This anecdote shows that participants want to test LDW to understand how it works. It also raises the question of how LDW alerts intersect with speed. From this example, it is clear that some participants incorrectly believed that speed triggered an LDW alert.

Focus group comments suggest some participants misinterpreted LDW alerts as CSW alerts and vice versa. While discussing false LDW alerts, a middle-aged woman said she received five false alerts and became annoyed after the third one. She thought they were lateral-drift warnings and "when I came back and dropped off the car I found out they were all curve warnings," associated with passing an exit ramp. A younger man said he took long drives in unfamiliar rural areas and he "thought it helped me a lot when I was coming around curves and I slowed down when I felt it vibrate." He said this in response to a question asking whether the LDW will help keep participants from leaving their lane.

5.4.3. Driver Performance

Table J-9 lists the descriptive statistics for responses to the LDW driver performa*nce* survey questions. Most participants said that the LDW made them more aware of the position of their vehicle on the road. Participants were neutral regarding their reliance on the LDW, Question 36, a finding consistent with their reliance on the RDCW. Participants felt slightly comfortable carrying out additional tasks while using the LDW.

Survey data showed an association between only the age group and the level of comfort in performing additional tasks, Question 42, $F(2, 75)=5.36$, $p = 0.0067$. With mean response levels of 4.96, 3.35, and 4.54 (younger, middle-aged, and older), younger and older participants felt more comfortable performing additional tasks using the LDW than their middle-aged counterparts.

During the debriefings, participants said that using the LDW made them both more aware of their car's position on the road and more attentive to the road. Although they indicated they did not rely on the LDW, their enhanced awareness of the road allowed them to feel more relaxed and comfortable performing additional tasks.

Focus Group Comments on Driver Performance

During the focus groups participants discussed their responses to the LDW alerts and how they affected their driving. Participants said they liked the seat vibration warning. A middle-aged woman liked the cautionary LDW alert because she could respond quickly without having to look down. A middle-aged man said he liked cautionary seat vibration warnings because his passengers were unaware. An older man said that "seat vibration forced me to look at my lane position," and another older man said he was better able to distinguish the orientation, right or left, from the seat vibration than from the auditory tone. A younger man said he was startled by the seat vibration warning but in a good way. He admitted that he was lost in the scenery or distracted but that, in that situation, "startling is a very good thing."

A middle-aged woman said that she would focus on staying in the lane for the next 5 to 10 minutes after she received the cautionary alert. A few participants had difficulty distinguishing between the cautionary LDW and the CSW alerts, which were issued by vibrating the left or right side of the seat (for LDW) or front of the seat (for CSW). An older man said he could distinguish right and left for the LDW alert but, when the CSW issued a haptic alert, he was not always able to distinguish it from the LDW alert.

Participants described their responses to imminent LDW alerts. They said they received many false LDW alerts compared to a few "real" ones but very few were startled by the imminent alert. A middle-aged man said he was startled by the imminent LDW alert while trying to pass a tractor-trailer on a two-lane highway. He signaled and moved out but received a LDW alert, aborted the maneuver, and returned to following the truck. He said, "It panicked me so much that it senses another car down there that I don't see." A younger woman said she was startled by an imminent LDW alert when she was falling asleep or “zoning out.”

After receiving an LDW alert, most people said they assumed they must be doing something wrong, checked their lane position and repositioned, if necessary. An older woman said that after she checked her lane position she looked at the visual display but it disappeared too quickly. A few people said that they took their foot off the accelerator. Several participants said they lowered the LDW sensitivity setting after an alert.

When asked if their response to the LDW changed with more experience, some said their responses remained the same but many others described how their responses changed. A middle-aged woman said she became more relaxed using LDW as she become more familiar with it. A younger man said that, with time, LDW did not go off as much because he “made a conscious effort to use my turn signal when I change lanes.” Another younger man said that it took him a week to get used to having LDW and to learn to hold a “steady line in the middle” to hear fewer alerts.

Participants thought LDW alerts would prevent them from leaving their lane. The principal benefits of the LDW were to make participants pay attention and remind them to use their turn signal. Participants acknowledged a carry-over of learning from the LDW. An older woman said “I find myself using the blinkers driving my own car now and being very careful about the lane.” Several people noticed LDW was missing when they resumed driving their own vehicle. An older man said that “the first time you didn’t have it (LDW) then suddenly you realize how much you used it.”

Participants volunteered that LDW provided additional benefits because it supported fatigued or stressed participants. An older woman recounted that when driving home after working all night she could have used LDW. “All of a sudden I felt myself almost going to sleep for a minute but that vibration would have alerted me quickly.” A middle-aged man mentioned his long drives to Florida and said that if LDW were available, it would prevent him from getting too close to the edge of the road. A middle-aged woman said that LDW makes you more attentive, and that, in itself, should prevent accidents.

Participants said they became more aware of how well other drivers keep to their lanes as a result of using LDW. They noticed more when other drivers don’t stay in their lanes or use their turn signals. An older woman said that she noticed that the “person in front of me was driving over the line; being in the study made me notice that.”

Participants became habituated to using LDW and maintained their increased use of turn signals. Several participants recalled that when they returned to their own vehicle they expected to be alerted to lane departures. A middle-aged man said using LDW made him a more courteous driver and more likely to signal lane changes even in his own car. Another participant said “LDW does affect your driving and make you more conscious and more aware.” An older man said that he had thought his incidence of lane departures was very low until he drove the FOT vehicle. Another older man said that he found out that “I leave my lane a lot more than I thought I did.”

5.4.4. Perceived Value

Table J-10 lists the descriptive statistics for responses to the LDW perceived value items. The responses suggest that participants were not certain whether LDW alerts could effectively prevent vehicle collisions, but believed the technology would increase driving safety. The LDW made participants use turn signals more frequently when changing lanes. Participants indicated it was somewhat useful to have the device in vehicles for various traffic conditions, but not during adverse weather conditions. The frequency of auditory and seat vibration warnings are not annoying. Some participants report that they received unnecessary or false warnings but most said that their frequency of LDW alerts is acceptable.

The responses to two related questions had statistically significant associations with the age group. Question 35, regarding attentiveness to turn signals during lane changes, $F(2, 75) = 4.42$, $p = 0.0153$, had mean response values for younger, middle-aged, and older participants of 5.88, 5.12, and 6.58. A separate contrast analysis showed that older participants believed that LDW made them more attentive to use turn signals than middle-aged participants. The analysis in Section 4.5.3, Lane Changes, supports the findings from this survey question. Question 14, which asked participants about their lack of annoyance to LDW alerts, $F(2, 72) = 5.79$, $p = 0.0047$, had mean response values of 5.00, 5.13, and 6.33 (younger, middle-aged, and older). A contrast analysis showed that older participants agreed more strongly than younger and middle-aged drivers that the frequency of LDW auditory alerts was not annoying.

Question 30, which addressed the frequency of the LDW alerts, did not have a statistically significant association between the response and age or gender. The responses, however, do show strong agreement across most participants regarding the LDW alert frequency. The responses, plotted in Figure 5-6, show the vast majority of participants (96% of the older and 88% of the middle-aged and younger participants) selected responses in the optimal range of 3 to 5.

LDW Question 30: Overall, I received LDW warnings …

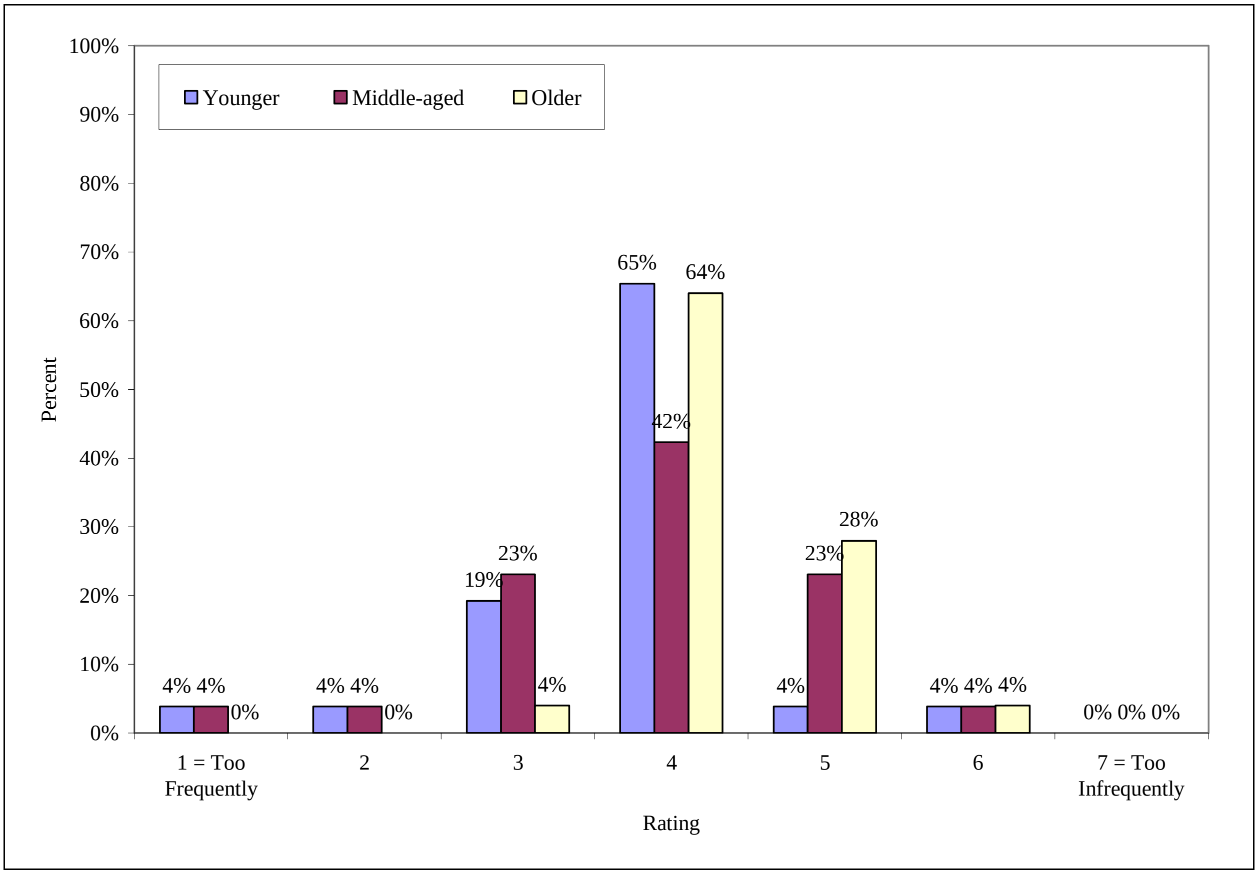


Figure 5-6. Distribution of Driver Responses to Regarding LDW Alert Frequency by Age Group

The correlation between participants' LDW alert counts and their opinion regarding alert frequency was analyzed. We determined that the number of LDW alerts, both cautionary and imminent, is not significantly related to participants' subjective opinion of frequency of LDW alerts.

Post-Drive Survey Comments

Although participants received many cautionary and imminent LDW alerts, they tolerated the frequency. A participant said, "The warnings were good, they made me more aware of using the turn signal but I was a bit annoyed by the fact that these warnings pointed out my mistakes." Another person said, "I am fine with the frequency of the warnings; the system was supposed to increase my driving safety and safety of others, hence, I don't mind if I receive frequent warnings."

Participants described unnecessary or false LDW alerts. Sometimes they came to realize the warning had a purpose despite their initial opinion. One participant initially described an example of an unnecessary warning but amended it. “A couple of times, but they were probably not false because I had crossed the line and I was doing it to pass a car and didn’t use my turn signal because there was no one behind me.” Reasons for unnecessary and false LDW alerts include road narrowing due to construction, trucks on both sides of the vehicle, skid marks or old faded lane markings, proximity to the side boundary but position not threatening; another vehicle entering lane; drifting onto, or close to, boundaries with no traffic around, positioned in the middle of the lane; briefly close to a solid line but not crossed; changing lanes with nothing nearby; and rainy conditions.

During debriefings, participants were uncertain whether the LDW would reduce collisions because they said they did not have any close calls. One participant recalled occasions when he was about change lanes and LDW alerted him to cars in his blind spot.

LDW alerts made participants more conscious of turn-signal use. Being able to suppress an LDW alert motivated their use of the turn signal. A participant said, “I think encouraging people to use their turn signals is the biggest benefit of this system.” Another participant admitted, “I always have been lax on turn signals. I am probably better now. It is better than having my wife telling me to use them.” Participants think that that LDW will improve driving safety because it fosters alertness and encourages them to use their turn signal. LDW alerts make participants more aware of road conditions as well as their own driving.

After participants completed the post-drive survey, they reviewed video replays of selected LDW cautionary and imminent alerts they received. Typically they viewed three clips each of the LDW cautionary and imminent alerts. They rated each warning as "useful" (yes or no) and ranked the usefulness of each warning on a 5-point scale. (1=not at all useful, 2=slightly useful, 3=somewhat useful, 4=fairly useful, 5=quite useful).

Figure 5-7 shows the screen used for video replay of selected LDW and CSW cautionary and imminent alerts. The screen displays the map location of the alert, driver’s forward view and face, status of the visual display, vehicle parameters, and the alerts received.

Figure 5-7. Split Screen for Video Replay of Selected LDW and CSW Cautionary and Imminent Alerts

With the dichotomous response (useful, not useful), participants rated 74 percent of the cautionary and 76 percent of the imminent LDW alerts as useful. With the more nuanced response, the 1-to-5 scale, participants' responses were more distributed, although 50 percent of the cautionary and imminent alerts were rated as fairly or quite useful. At the other end, 31 (33) percent of the cautionary (imminent) alerts were rated as not at all or slightly useful.

Participants were asked the reason for rating an LDW cautionary alert as 1 or "not at all useful." The reasons are, in order of importance, turn signal not used, or changing lanes. The most frequent reasons for rating an LDW cautionary alert "quite useful" are drifting from the lane, not using the turn signal, and driver inattention. Reasons for rating an imminent alert "not at all" useful are false warning and a deliberate lane change. The reasons for rating an LDW imminent alert "quite useful" are drifting from the lane and driver inattention.

Focus Group Comments about Perceived Value

Focus group participants discussed the usefulness and safety provided by the LDW and described situations when LDW was useful. They value the LDW alert because it notified them they were drifting from their lane, cars were drifting toward them, or they were in their blind spot. An older man said, "I encountered a blind spot, being a big person in a small car, and the mirrors were not as effective as the two mirrors I got in my van… and, at least on one occasion, there was a car in my blind spot and I didn't see it." A younger woman said she received an LDW alert when someone was about to hit her and she said she didn't even see him because he was in her blind spot and coming into her lane.

Participants cited useful warnings around distraction, construction zones, a tendency to overcorrect toward one side, and challenging road conditions. An older man said, "whenever I was slightly distracted talking on the cell phone or late at night, those were useful LDW alerts." A middle-aged woman said that when she drove in construction zones, the LDW alerts were useful because she did not pay enough attention to how close she was to the side. A middle-aged man said that the LDW alert was useful when he forgot to use his turn signal in changing a lane the LDW alert caused him to check his mirror to ensure there was no one in the receiving lane.

Some participants had difficulty differentiating between LDW and CSW alerts. A middle-aged woman said her speed was too fast for the area due to exit ramps. When told she was referring to CSW alerts, she said her speed was so high that she would drift across lanes, suggesting that the two types of warnings merged in her mind.

Participants said they felt safer driving with LDW, in part because they used their turn signal more frequently. An older man said he was a safer driver because he "did not like hearing the LDW so I was trying to avoid setting it off." Other participants were safer because they became more aware and less aggressive. An older woman said her sister told her she had become a less aggressive driver. As a result, her sister also appreciates LDW. A younger man said he became less aggressive using LDW and attributed it to realizing that drivers, including him, "do dumb things." He said, "You realize you are doing things that you didn't even know you did."

Another younger man admitted that using LDW made him more aware of his surroundings but he also was concerned that "people could use the system as a crutch because now they could drive a little faster." This raises the possibility of risk compensation with LDW use. A middle-aged woman suggested a similar thought by saying that when she used the cell phone, took something out of her purse, or ate while driving, she felt she had a "little bit more support" doing these activities.

When asked "if there were situations when you got an alert when you were not paying enough attention," many participants mentioned using a cell phone. A middle-aged woman who uses her car for work said "I drive all day…and it (LDW) taught me a lot about not to do that (talk on the cell phone) so much or at least to pay attention and I pull over more now and stop" to make a cell phone call. Another older woman said that a LDW alert made her want to pull over instead of trying to dial a number that was not loaded on her phone. A middle-aged man said he gained self-awareness of his driving, saying "I didn't realize that, if I have my cell phone to my ear, I don't use my signal to change lanes." His response was to tell himself "now you have to stay off the phone when you are driving." Comments show that cell phone use is important to many participants. An older woman estimated she spent 900 minutes a month on her cell phone.

5.4.5. Advocacy

Table J-11 lists descriptive statistics for responses to measures of the advocacy objective. Participant response to LDW Question 47 indicates that "cost aside" participants would consider purchasing the LDW with a new vehicle. The mean amount for participants who indicated how much they were willing to pay for the LDW (10 did not answer) was $500. Eleven participants would pay $1,000 or more and 7 participants would pay $0. At a price of $300, the tendency to purchase the LDW sub-system is similar to when cost is not considered (LDW Question 50). Most participants would not have turned off the LDW if an on/off switch had been provided.

Responses to only this last question (LDW Question 43), regarding turning the device on and off, had a significant association with age, $F(2, 75) = 6.39$, $p = 0.0027$. The response means by age groups were 3.65, 2.19, and 1.88 (younger, middle-aged, and older). A contrast analysis showed that had there been an on/off switch, younger participants would have been more likely to turn off the LDW than middle-aged and older drivers.

Participant response to the Driver Acceptance Scale (van der Laan, Heino, & de Waard, 1997) was used to assess LDW acceptance (LDW Question 46). The mean usefulness score was 1.4 (on a scale of -2 to 2) and the mean satisfaction score was 0.8. These scores, shown as a scatter plot in Figure 5-8, indicate that almost all participants rated the LDW positively.

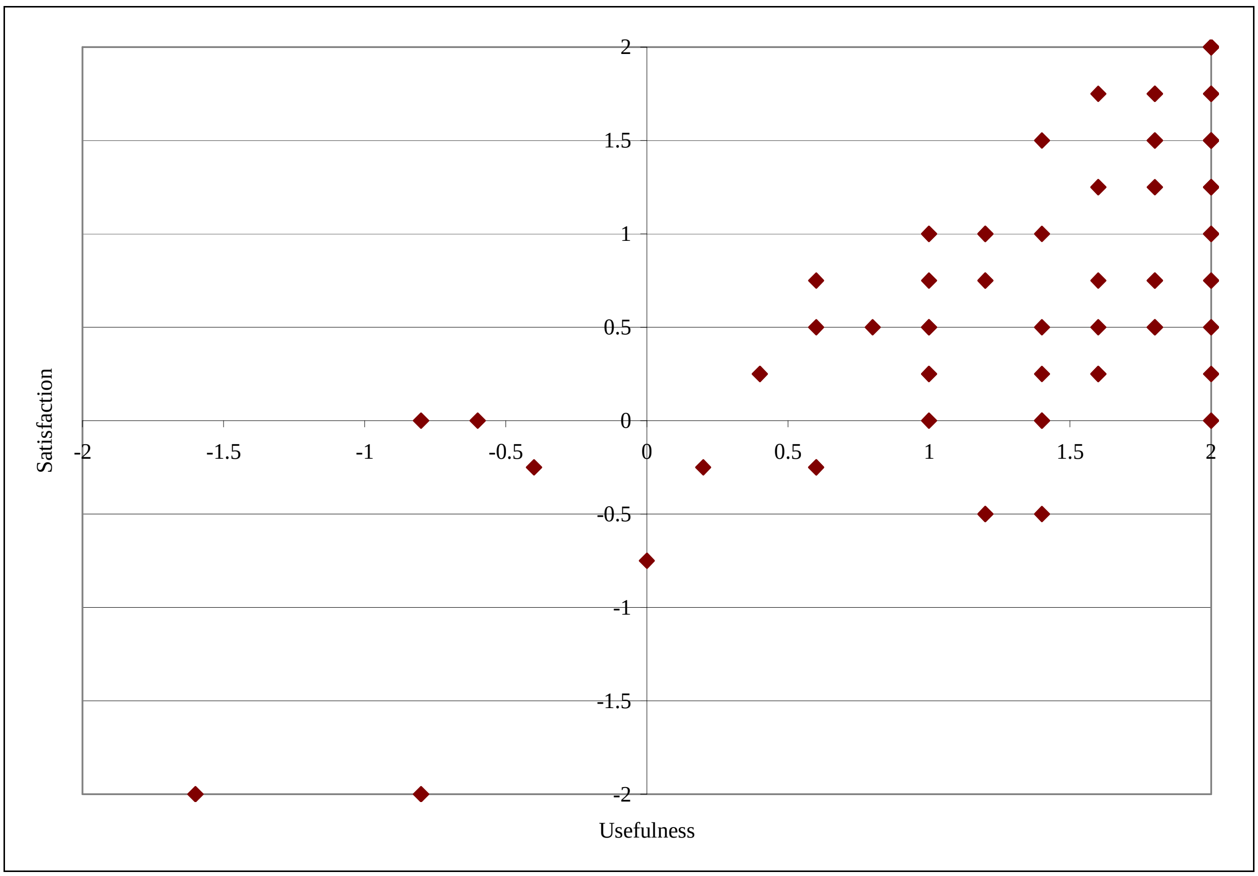


Figure 5-8. Driver Acceptance Scale Scores for LDW by "Usefulness" and "Satisfaction" Quadrants

Participants had positive opinions of the LDW and perceived it as easy to learn and use. The LDW encouraged participants to use turn signals more when changing lanes. As a result, participants thought this technology had the potential to improve their driving safety and was useful. Almost all the participants liked the LDW, particularly the older age group.

Estimating LDW Purchase Intent

Two methods were used to estimate the proportion of people who might purchase the LDW. During the focus groups, participants were asked, “would you buy an LDW and their responses were recorded as “yes” or “no.” Eighty-six percent of the participants said they would purchase the LDW; this number is higher than the results from a post-drive survey question, but may be an artifact of the self-selection in focus group participation. FOT participants were invited to participate in focus groups and one-third, 32 percent, attended.

For comparison, the frequency distribution on the “purchase intent” post-drive survey item, (LDW Question 47 of “cost aside, how likely are you to purchase LDW") shows that 64 percent of the responses were in the 5 to 7 range, degrees of “would consider,” on the 7-point Likert scale. The interest in the LDW expressed at the focus groups show it is enduring and may have increased after participants returned to using their own vehicle and realized they missed the LDW alerts.

The longitudinal data (FOT, surveys, focus groups) shows that participants generally maintained their interest in purchasing the LDW. In the post drive survey, FOT participants were asked if, cost aside, they would like to purchase the LDW; participants returning for a focus group were asked this question again. The time between their answers ranged from the same day to 11 weeks, so it was possible to see if attitudes toward LDW changed over time. When asked again if they would purchase LDW, 18 percent answered differently than they did in the post-drive survey. Of those whose responses changed, three-quarters moved from a “might or might not” consider purchasing a LDW to affirming that they would purchase LDW, and one-quarter shifted from a neutral to negative opinion.

As in Section 5.3.5, the weighted-box method was used to estimate the percent of participants willing to purchase the LDW and to forecast acceptance. Intent is gauged by responses on a 7-point Likert response scale (1 = definitely not to 7 = definitely would) to the survey item: “Cost aside, if you were purchasing a new vehicle, how likely would you be to consider purchasing the CSW system?” Participants answered as follows: 1 = definitely would not consider (4%), 2 (8%), 3 (2%), 4 might or might not consider (23%), 5 (8%), 6 (26%), and 7 definitely would consider (29%). The weighted box rule resulted in a prediction that 42 percent of the FOT participants would purchase the LDW.

During debriefings when asked for the main reason for their response to the “purchase intent” question, participants cited safety, enhanced driving alertness, reminder to use turn signals as well as the need to improve the LDW accuracy by reducing false warnings or late warnings and upgrade it for bad weather.

Focus Group Comments on Advocacy

Focus group participants agreed strongly that the LDW was useful and described how it helped them to drive in challenging conditions. These ways include: “LDW is helpful to have when driving home after working late”; “It ensures safer driving while using a cell phone”; “I no longer talk on the cell phone while driving as a result of using LDW”; “LDW helps keep my attention on the road since my mind wanders because I drive the same roads repeatedly”; “LDW forces you to be alert, to use your turn signals because if you don’t, it will beep at you”; “LDW makes you more aware of turn-signal use, even though you think you use them frequently”; “LDW points out how much you don’t use them”; “Increasing LDW sensitivity provides reassurance at night.”

The focus group transcript shows that some participants confused the LDW and CSW and the meaning of cautionary and imminent alerts. For example, when asked what they did after receiving an imminent LDW alert, a middle-aged woman said, “I thought it was too loud and it didn’t need to say ‘curve.’” She assumed the voice saying “curve, curve” was an imminent LDW alert.

There is evidence of confusion between the significance of cautionary and imminent alerts. Participants tended to describe warnings in terms of their modality and intrusiveness instead. Participants appreciated the seat vibration because it was silent and did not alert the passengers. A younger woman asked if the LDW could offer the option of selecting either the auditory or the seat vibration alert, implying she viewed them as equivalent warnings rather than as indicating cautionary and imminent conditions.

When asked if they would have turned the LDW off, only a few people said they would have and only in adverse weather conditions when its operation was impaired. A middle-aged woman said she would have turned the LDW off in a rainstorm because she didn’t think it was working properly but would turn it on again. Other participants said they would turn the LDW off in snow because it issued too many false alerts.

The auditory tone for an LDW imminent alert could be disruptive, particularly to passengers. Some participants suggested reducing the LDW sensitivity to reduce its passenger discomfort with the tone. Carpoolers need an “on-off” switch because members “mock the system.” Other suggestions for the auditory alert include the use of different tones for the right and left sides and to make it possible to silence the tone if there is a sleeping passenger or a baby.

Focus group participants identified aspects of the LDW that need to be improved or changed before it becomes a product; these include:

Reduce the incidence of false alerts by 75 percent.

Improve availability - LDW is unavailable when there is salt on the roads and road markings need to be bright and fresh to use LDW effectively.

Reduce the noise associated with the LDW computer because it interferes with the radio.

Increase geographic availability.

Move the visual display toward the vehicle center. Consider putting the visual display on a heads-up display because “that way your eyes are much closer to the road instead of dropping all the way down to the dashboard so it is in the same field of vision.”

Focus group participants would consider purchasing the LDW despite its false alerts. They were positive toward the LDW and willing to overlook its problems. Some comments were. “I think it is a fantastic system and there some things that need to be tweaked…but I can see this as something that is very helpful to everyone, it could save lives.” “With the bad experiences that I had, the good far outweighed the bad.”

5.5 CSW SUBSYSTEM

- Participants rated the CSW ease-of-use positively.
- Participants stated they knew how to respond to a CSW alert, but some evidence suggests they did not understand CSW alerts.
- Participants had mixed reactions about the CSW improving their awareness of upcoming curves.
- Numerous participants stated the CSW issued too many false alerts.
- Most drivers who participated in focus groups found the CSW useful on unfamiliar roads.
- Sixty-eight participants who responded would pay an average of $400 for the CSW.

This section describes the FOT participants’ views of the CSW. The post-drive survey responses, debriefing comments, and focus group results provide the source material to evaluate the CSW.

5.5.1. Ease of Use

Table J-12 lists the descriptive statistics for participant responses to the CSW ease of use survey questions by subobjective. The mean scores suggest that participants evaluated the CSW as easy to use in terms of the demand on driver, understanding of warning, and usability subobjectives. The modal response to the CSW ease of use survey questions (all “7” or Strongly Agree) confirms that participants considered the CSW easy to use. Participants did not think that CSW alerts were distracting and they knew what to do when the alerts are issued.

The responses to two questions in Table J-12 had a significant association with age. Question 13, which concerned the distraction of the CSW alerts, had mean responses of 4.88, 5.58, and 6.27 (younger, middle-aged, and older), $F(2, 73) = 4.85$, $p = 0.0105$. A contrast analysis showed that older participants agreed more strongly than younger participants that the alerts were not distracting. Question 5 concerned the appropriate action following a CSW visual warning. The mean scores were 5.77, 4.42, and 5.19 (younger, middle-aged, and older), $F(2, 73) = 3.26$, $p = 0.0440$. A contrast analysis showed that younger participants felt more confident than middle-aged participants regarding the response to a CSW visual warning.

During debriefings, several participants mentioned aspects of the CSW implementation that bothered them. They disliked the use of the static arrow in the CSW visual display, which does not change direction with the orientation of the curve. A participant said “it boggled my mind when the curve was in the other direction.” Other participants said they are unable to discriminate the direction of the seat vibration. Figure 5-9 illustrates the CSW visual display: the left display shows the LDW cautionary alert and the right display shows the CSW imminent alert. The arrow’s orientation is static and does not indicate the curve’s direction.

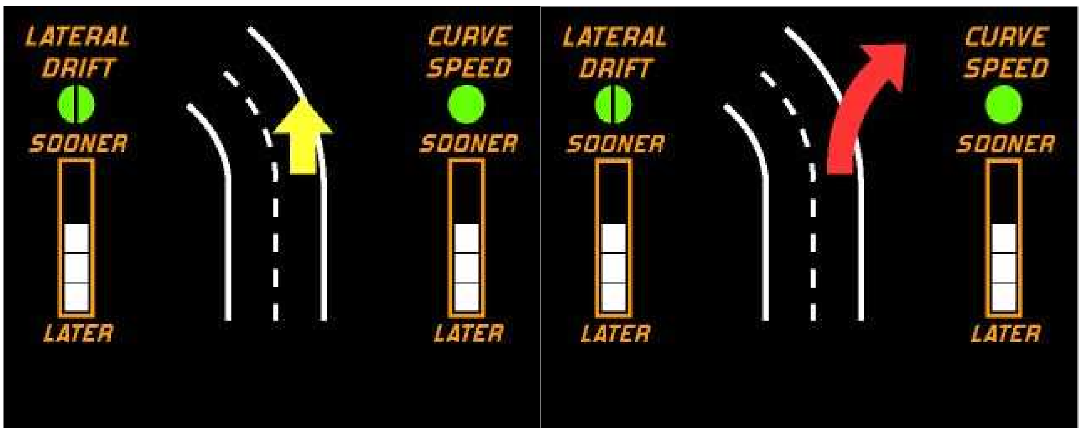


Figure 5-9. RDCW Display Showing CSW Cautionary and Imminent Alerts

Participants mentioned that passengers react to the auditory CSW alert of a male voice saying “curve, curve.” Reactions ranged from laughter, attempts to imitate the voice used in the warning, being startled and annoyed, or to asking the driver to turn it off. They find these warnings are annoying when trying to converse. Passenger reaction is significant because their awareness of a warning issuance raises questions about the driver’s control of the vehicle, causes passengers to assess their safety, and could undercut their perception of the driver’s competence. The statistical tests run to determine if age group influenced CSW learning shows no significant relationships.

Focus Group Comments on CSW Ease of Use

Many FOT participants categorized their driving in terms of “familiar” and “unfamiliar” roads and emphasized that the CSW was useful on unfamiliar roads. The CSW prevented drivers from approaching curves too fast only on unfamiliar roads. Many participants drove regular routes and knew to decelerate for upcoming curves. Thus, they were unlikely to receive CSW alerts on these routes. An older woman said “we are pretty well programmed in how we approach curves in our familiar areas.” In contrast, they consider a CSW alert useful when driving an unfamiliar road.

Numerous participants said they did not have enough time to test the CSW and referred to their insufficient experience in several ways. When the appropriateness of the CSW alert timing was discussed, almost half of those responding said that they did not have enough driving time to evaluate it. An older man said that most of his CSW alerts were false so he could not judge the appropriateness of the timing. He also said that the roads he drove were generally straight, so there were few opportunities for CSW alerts. A younger woman said that she found it hard to assess CSW alerts because she didn't know what was right or wrong.

Several participants had no opinion about whether the CSW would prevent drivers from approaching curves too fast because CSW is too "buggy" and unreliable. A middle-aged woman said, "They need to get rid of all the false alarms with the exit ramps." Another middle-aged woman said, "I found it too unreliable so I would just not take it seriously." She added that she "did not have an opportunity to have a real warning."

Participants had concerns about the CSW imminent alert timing. There were issues related to road geometry. An older man said that he would prefer to receive a CSW alert before he enters a curve rather than when he was in the curve. There was also a concern that drivers responding to CSW alerts issued too early could disturb the traffic flow and thereby impair driving safety. A middle-aged man said that he set the CSW sensitivity at its lowest setting because he thought the CSW imminent alert told him to "slow down so early that you would impede the flow of the (freeway) traffic." A younger man said that, even though he set the sensitivity as low as possible, CSW told him "…way too early that I'm going too fast even though I am applying the brake." A minority of focus group participants said the timing of CSW alerts was correct.

Participants recommended better integration of the CSW functionality with other automotive features. For example, vehicle braking could extinguish a CSW alert. The use of CSW and cruise control can be discordant. One cited a need for coordination between cruise control activation and CSW alert issuance relative to the onset of a curve. An older man said his cruise control practice does not synchronize with the CSW alerts. He does not release cruise control until he starts up a ramp and lets the car coast as long as possible before braking.

5.5.2. Learning

Table J-13 lists responses to CSW survey questions measuring the learning objective. Most participants thought it was easy to become familiar with the CSW. They developed a good understanding of how the CSW worked shortly after they began to use it; more than 80 percent said that they became comfortable driving with the CSW within 2 to 3 days. However, four participants or 5 percent (two younger men, a middle-aged woman, and older man) said they never were comfortable driving with the CSW.

Focus Group Comments on Learning

Although post-drive survey responses suggested that the CSW is easy to learn, focus group comments suggested that many FOT participants found it challenging to learn. Participants described the limits of their knowledge of CSW operation. A middle-aged woman admitted that she did not understand how the CSW was supposed to work and, as a result, wondered if some of the faults she attributed to the CSW were actually due to her lack of knowledge. She said she “should have stopped and reread the literature that was sent with the car, but did not have the time or take the time to do that. So I felt my perception of CSW was my misunderstanding or being uneducated about it.” Two older men had an extended discussion of how the CSW alerts trigger in relation to curve geometry. They wanted to clarify when a driver should receive the CSW alerts, prior to curve entry or when already in it, and whether there should be multiple alerts for a sequence of curves.

Anecdotal evidence suggests that many participants did not understand how the CSW functioned. For example, an older man asked the focus group leader to clarify the sequence between CSW alerts and vehicle response. A middle-aged woman recalled driving in a rural area and said that lines were not clear on the road surface (suggesting she was confusing the LDW with the CSW). An older man’s comments suggested that he was not able to distinguish between the LDW and CSW alerts. He said that, when he drove a particular freeway, “CSW would think you are going to get off unless you turn that turn signal on.” Several participants said that they needed time to learn the meaning of the cautionary CSW alerts. An older woman said it took her several days to understand the significance of the seat vibration as a cautionary CSW alert.

A number of participants said that they did not receive sufficient CSW imminent alerts to comment. Variations in road geometry, routes traveled, and familiarity with roads all influenced how well participants learned to use the CSW. When asked if their responses to CSW alerts changed with experience, participants described several techniques they developed for responding to the CSW alerts. Several middle-aged and younger men turned CSW issuance into a game. One man would try to say “curve, curve” before the CSW would. Another tried to make “one clean run all the way to work,” meaning that he did not receive any CSW alerts, and he usually failed. Others said they learned to ignore CSW alerts but still checked the road to identify a reason for the issuance. Finally, several participants said that they checked the speedometer when they received a CSW alert. One middle-aged man said that he wanted to make sure he “wasn’t going 55 or 60 on a curve that he should have been doing 45.” This last response suggests that CSW alerts caused participants to evaluate their driving performance against road conditions.

5.5.3. Driver Performance

Table J-14 lists post-drive survey responses to measuring CSW driver performance. Participants rated the CSW as somewhat useful for information about upcoming curves. This result needs to be examined together with responses about reliance on the CSW (CSW Question 36). Participant scores show they tended to not rely on the CSW. The mean and modal responses as to whether participants feel comfortable carrying out additional tasks while driving have a neutral rating.

The responses to two questions in Table J-14 had a significant association with age. Question 36, which concerned the reliance on the CSW, had mean responses tending towards the negative, 3.23, 2.54, and 3.77 (younger, middle-aged, and older), $F(2, 75) = 3.15$, $p = 0.0486$. A contrast analysis showed that middle-aged participants disagreed more strongly than older participants that they relied on this subsystem. Question 42 concerned the comfort while performing additional tasks. The mean scores tended towards neutral, 4.54, 3.12, and 4.04 (younger, middle-aged, and older), $F(2, 75) = 3.76$, $p = 0.0277$. A contrast analysis showed that middle-aged participants felt less comfortable performing additional tasks than younger participants. Participants thought the CSW was somewhat useful in that it notified them about upcoming curves. They did not, however, rely on it operate their vehicles safely, in particular the middle-aged group. Debriefing comments clarify responses to the post-drive survey item asking about reliance on the CSW. Participants said, “I thought the CSW alerts were not very consistent, hence I did not depend on it,” “did not really rely on CSW but it was helpful,” “in my own car I tend to go over the speed limit going into a curve and CSW made me slow down,” and “after many false CSW alerts, I turn off to such warnings.”

Focus Group Comments on Driver Performance

When asked, “How many times a month do you approach a curve too fast?” responses ranged from once or twice a month to daily. These responses revealed that some participants learned more about their driving from the CSW. A middle-aged man described himself as a “lead foot” and attributed his incidence of CSW alerts to his tendency to drive too fast. Another middle-aged man said that he would have answered that he never approached a curve too fast but that the “car said I did.” Another middle-aged man said that he approached a curve too fast every six months but based his estimate on the times when he drove unfamiliar roads. An older woman said that she would have said she never approached curves too fast but, when she received CSW alerts she realized she was distracted by talking with passengers and that this happened even on familiar roads.

When asked what they typically did when they received an imminent CSW alert, almost half of the focus group participants responding said they ignored it. Some people reacted to imminent CSW alerts initially, but ignored them with time. They reduced their speed in response to a cautionary CSW alert, particularly if the road was unfamiliar, but tended to ignore the cautionary CSW alerts on familiar roads. Most people said that they would release the accelerator but prefer not to use the brake. One quarter of those discussing this topic said that they did not get enough CSW imminent alerts to be able to report what they did in response. When asked if the CSW cautionary alert (seat vibration) affected their speed as they approached a curve, almost all said that they reduced their speed in response to a cautionary CSW alert, particularly if the road was unfamiliar.

When asked if they thought that the CSW would prevent them from approaching curves too fast, most limited their positive response to unfamiliar roads. An older woman said "we are pretty well programmed in how we approach curves in our familiar areas." An older man said that CSW will prevent drivers from "approaching a curve they are familiar with and don't realize how much they have to slow down in that sort of situation." One third were not able to provide an opinion as to whether the CSW would prevent drivers from approaching curves too fast because they said that the CSW was too "buggy" and unreliable.

Several participants said that the CSW changed the way they drove. A middle-aged woman became more aware and cautious on curves so as not to set off the CSW alert. An older man said he became more aware of entrance ramps and ramp traffic. A younger man said he avoided certain roads and lanes in roads so as not to trigger CSW alerts due to "Michigan lefts." (A Michigan left is an automobile traffic maneuver in which a U-turn and a right turn replace a prohibited left turn. The term comes from the fact that the arrangement is quite common along Michigan roads and highways and extremely rare anywhere else in the United States.) A middle-aged man stopped using a particular very short exit ramp with a sharp exit. People who altered their driving, as a result of using the CSW, did so to avoid setting off a CSW alert.

5.5.4. Perceived Value

Table J-15 lists descriptive statistics on participants' responses to the CSW post-drive survey questions for the perceived value objectives. Participants have a neutral to positive opinion that the CSW can issue alerts to effectively prevent vehicle collisions. They became more aware of the need to slow down for curves using the CSW. The usefulness of CSW alerts in stressful traffic or challenging weather conditions is neutral to slightly positive. Participants are not annoyed by the CSW cautionary and imminent alerts and have neutral to slightly negative opinions about unnecessary and false CSW alerts.

An analysis of the perceived-value survey questions revealed four significant associations between the age group and responses. These associations, listed in Table 5-4, pertain to CSW: seat-vibration alerts, unnecessary alerts, false alerts, and alert frequency. Separate contrast analyses revealed:

- Older participants felt more strongly that the seat-vibration alerts were not annoying
- Middle-aged participants disagreed more strongly than older participants regarding not receiving unnecessary alerts
- Younger and middle-aged participants disagreed strongly more than older participants regarding not receiving any false alerts
- Younger and middle-aged participants indicated that CSW alerts were slightly too frequent, while older participants indicated they were slightly infrequent

Table 5-4. Statistical Comparison of CSW Perceived Value Measures by Driver Age Group

Sub-Objective	Survey Question	Age Group	Mean	Result from ANOVA
Safety				
Question 21, The frequency with which I received CSW seat vibration warnings was not annoying.				
	1 (Strongly Disagree) – 7 (Strongly Agree)	Younger	**5.12**	**F(2, 75) = 3.46, p = 0.0366**
		Middle-aged	**4.96**	
		Older	**6.19**	
Question 28, I did not receive any unnecessary CSW warnings.				
	1 (Strongly Disagree) – 7 (Strongly Agree)	Younger	**3.85**	**F(2, 75) = 4.87, p = 0.0103**
		Middle-aged	**2.85**	
		Older	**4.73**	
Question 29, I did not receive any false CSW warnings.				
	1 (Strongly Disagree) – 7 (Strongly Agree)	Younger	**3.62**	**F(2, 75) = 3.22, p = 0.0455**
		Middle-aged	**3.00**	
		Older	**4.62**	
Question 30, Overall, I received CSW warnings				
	1 (Too Frequently) – 7 (Too Infrequently)	Younger	**3.23**	**F(2, 75) = 9.80, p = 0.0002**
		Middle-aged	**3.65**	
		Older	**4.81**	

A separate analysis of the actual frequency of cautionary and imminent CSW alerts in relation to participants' opinions regarding CSW alert frequency was performed. The number of CSW alerts relates to the opinion regarding alert frequency in a proportional manner. That is, participants who received more cautionary or imminent CSW alerts indicated they received CSW alerts too frequently.

With the dichotomous response (useful, not useful), participants rated 58 percent of the cautionary and 49 percent of the imminent CSW alerts as useful (compared to 74% and 76% ratings for LDW alerts). With the 1 to 5 scale, participants' rated only 27 (21) of the cautionary (imminent) CSW alerts as fairly or quite useful (compared to 50% of the LDW alerts). At the not-useful end, participants rated 55 (62) percent of the cautionary (imminent) alerts were rated as not at all or slightly useful (compared to 31% and 33% of the LDW alerts). The reasons for rating a CSW imminent alert "not at all useful" are, in order of importance: false alert, speed not excessive, and not taking exit. The reasons for rating a CSW alert as “quite useful” were: driving too fast, made aware of upcoming curve, and driver inattention. The reasons for rating a CSW alert as “not at all useful” were: false alert, speed not excessive, and familiar with the road.

Post-Drive Survey Comments

During the debriefings, some participants said that the frequency of the auditory CSW alerts was not annoying. Others said that they received too many auditory CSW alerts, especially when entering freeways. Representative comments about the imminent CSW alert included:

- The auditory warning was annoying and it was loud but it was not bad because, if I were asleep, it would wake me up.
- The auditory sound stops everything in the car, i.e., conversations.
- The auditory warning distracted passengers.
- I drive by a lot of curves to work but I know the route well and the warnings were not necessary.
- I would receive a warning after I had applied the brakes and was slowing down for a curve, quite often.

Participants considered the CSW as a speed limit reminder and an indicator of the appropriate speed for driving in a curve. Representative comments showing how participants substituted CSW for a speed limit reminder included:

- There were times I felt I wasn’t going too fast, but got a warning.
- It is difficult to say that I was driving too fast. But for some drivers it would have been too fast. (Note: This type of opinion has been encountered in other FOTs.)

Participants took exception with the road geometry where CSW was issued. Representative comments included:

- I got some unnecessary CSW alerts while driving on freeway due to passing exit ramps and lane changes into turnaround lanes.
- On the freeway, CSW seemed to warn for every curve, even if it was a gentle, normal curve with no danger.
- CSW warned on straight-aways, near overpasses, when I was moving out to pass.

Focus group participants’ experience with false CSW alerts reduced their comfort using it. They received false CSW alerts on straight roads, driving over a bump in the road, changing lanes, and on small curves. When they drove a regular route that included a false-positive alert, they received it repeatedly.

Focus Group Comments about Perceived Value

When focus groups participants were asked “How often did you encounter situations where you felt the CSW was useful,” most of the comments were positive. Participants said that CSW is valuable when driving on unfamiliar roads or in more challenging conditions such as snow. The few dissenting opinions were due to lack of success trying to provoke a CSW alert or having had insufficient time to experience the operation of CSW.

An older woman said she was unable to provoke a CSW alert even though she thought her testing exceeded her "comfort level." A middle-aged man said that CSW did not activate often and that he would like twice as much driving time to experience CSW. Another older man wanted more time to test CSW operation because he only drove familiar roads during the FOT and wanted to see how CSW could help on less familiar roads.

One out of 8 of the focus group participants described situations when the CSW might have prevented them from having an accident. A middle-aged man and a younger woman described receiving a CSW alert when they drove on curves in snowy conditions. Although they were driving familiar roads, they valued the alert because it made them drive more slowly in the challenging road conditions.

When asked if CSW alerts were useful, most of those responding agreed and added that CSW was useful when they drove unfamiliar roads. An older woman said CSW alerts were useful when she was not paying attention to her driving.

When asked if they thought that CSW made them safer drivers, all of those responding agreed. A younger man said, "I must admit as much as I hated it, it did make me a little bit more conscious of speed and I did look at the speedometer a lot more often when it went off." A younger and an older woman both said that using CSW made them drive less aggressively in curves.

Almost all the focus group participants found false-positive CSW alerts annoying. They added that, with time, they became accustomed and their annoyance decreased. The following are examples of false-positive CSW alerts that focus group participants describe as annoying. A younger man received false CSW alerts at the same spot on a freeway he drove regularly. He didn't consider it to be a curve but rather a "road correction with a bridge across the top of it." A younger woman received false CSW alerts repeatedly at one location that she had to drive regularly. A middle-aged woman received repeated false CSW alerts passing a wide ramp on a freeway. A middle-aged man received false CSW alerts on a ramp between two freeways. He was leaving a ramp and entering a freeway and needed to speed up but the CSW warned him to slow down. He thought that the traffic flow was about 45 mph on these ramps and wanted to keep to the traffic flow. Several participants mentioned false CSW alerts due to a road geometry known as a Michigan left. These occurred when CSW picked up the turn lane.

Focus group participants were asked if they experienced missed alerts with the CSW. A younger woman said she never received a CSW alert at an exit onto an interstate, which she described as a "big curve" where "everyone goes fast." Similarly an older man mentioned a hard curve off an interstate where he would have expected to receive an alert, but did not.

The consequence of unmet expectations of a warning is that participants became uncertain about CSW. When CSW did not work according to their expectations, they were puzzled. This suggests that drivers need more tools to interpret how the CSW reads a curve. The issue of CSW availability may have contributed to the incidence of missed alerts. Participants were probably unaware of the CSW availability status when they expected a CSW alert.

Focus group participants were asked if they received CSW alerts when they were not paying enough attention to the road. Four women mentioned situations and their examples refer to driving with extra workload. One woman said she was trying to follow a lead vehicle that was driving too fast. Another woman was driving in a construction zone on an unfamiliar interstate. An older woman recalled a situation of night driving on a curvy "parkway" and another woman said she was talking with her passenger.

5.5.5. Advocacy

The advocacy objective examines participants' interest in the CSW by asking if they would purchase a CSW, what they would pay to acquire it, would they recommend it to others, and how would they rate it using standardized measures. Table J-16 lists the descriptive statistics for responses to the CSW advocacy post-drive survey questions. In addition, this section presents debriefing and focus group comments about advocacy of CSW.

The results in Table J-16 reveal that aside from cost, participants have a mid-range or neutral interest in considering purchasing the CSW with a new vehicle. At a price tag of $500, participants have a neutral propensity to purchase the CSW. Ten participants, 13 percent, did not answer the survey question asking for the maximum amount they would pay for the CSW. The remaining 68 were willing to pay a mean amount of $402 to acquire a CSW. Nine participants, 13 percent, said that they would pay $1,000 or more for the CSW. One quarter of the participants or 16 said they would pay $0 for CSW. A majority of participants indicated that they would not turn off the CSW if an on/off switch were provided.

Data were analyzed to determine if the number of cautionary and imminent CSW alerts was related to interest in purchasing the CSW. There was no statistically significant correlation between the frequency of cautionary or imminent CSW alerts and participants' interest in purchasing the CSW or paying $500 to obtain it. As with the LDW, responses to only CSW Question 43, regarding turning the device on and off, had a significant association with age, $F(2, 75) = 4.22$, $p = 0.0183$. The response means by age groups were 3.81, 2.65, and 2.19 (younger, middle-aged, and older). A contrast analysis showed that younger participants were significantly more likely to have turned off the CSW, the same finding observed with the LDW.

As with the LDW, participant response to the Driver Acceptance Scale (van der Laan, Heino, & de Waard, 1997) was used to assess CSW acceptance (CSW Question 46). The mean usefulness score was 0.89 (LDW was 1.4) and the mean satisfaction score was 0.41 (LDW was 0.8). These scores, shown as a scatter plot in Figure 5-10, illustrate a mixed approval of the CSW. A separate statistical analysis revealed no association between age and driver acceptance.

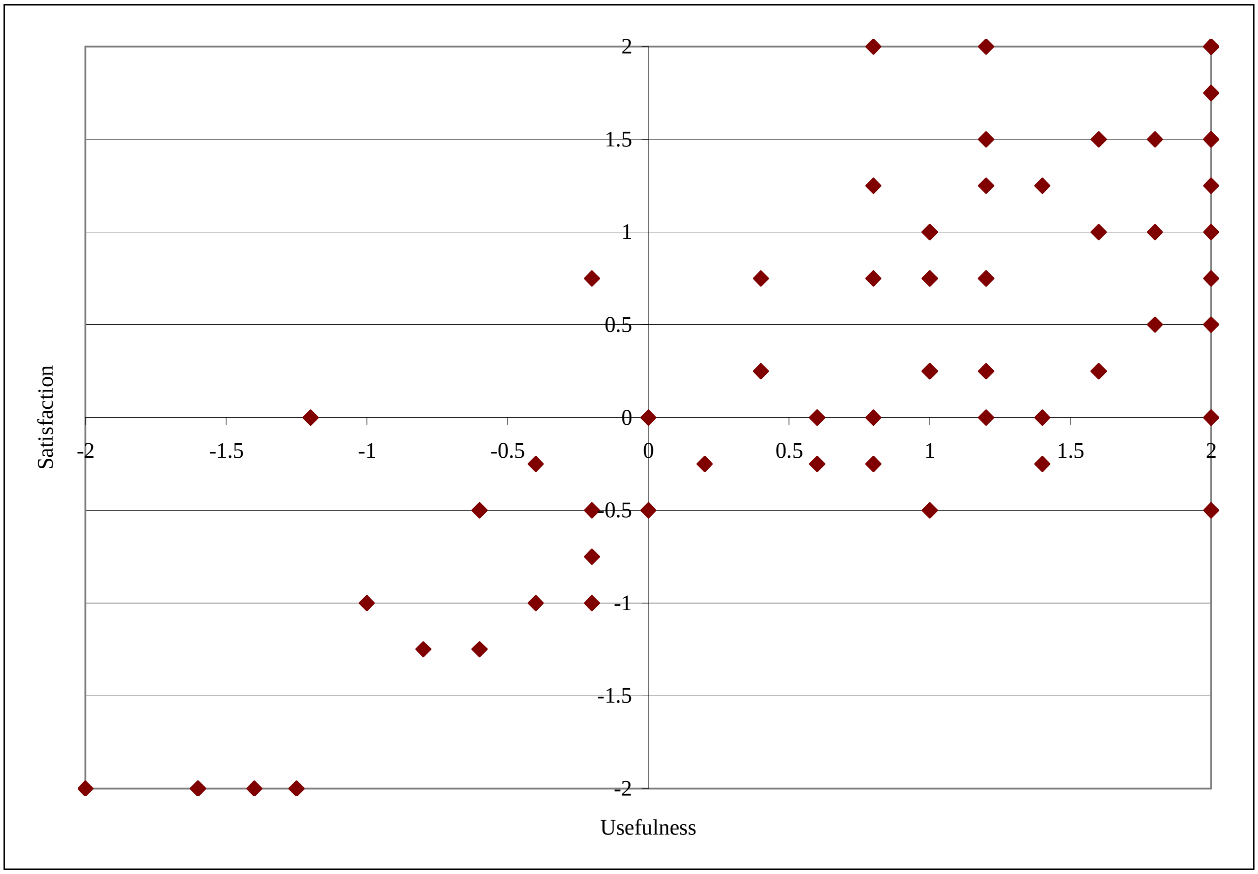


Figure 5-10. Driver Acceptance Scale Scores for CSW by Usefulness and Satisfaction

Estimating Purchase Intent

Two methods were used to estimate the proportion of people who might purchase the LDW. During the focus groups, participants were asked if they would buy a CSW, and their responses were recorded as yes or no. Sixty-one percent of the focus group participants said they would purchase a CSW; this estimate is similar to the results of a similar question on the post-drive survey. The frequency distribution of responses to the CSW Question 47 ("cost aside, how likely are you to purchase CSW") shows that 47 percent of the responses were in the 5-to-7 range on the 7-point Likert scale. Assigning half of the responses on the CSW 47 neutral midpoint to the positive category makes this total approximately 60 percent.

Using the same participants, it is possible to see how robust participants' interest in purchasing the CSW is over time. In the post drive survey FOT participants were asked if, cost aside, they would like to purchase the CSW. The gap of time between their answers to this question and focus group participation ranged from the same day to 11 weeks so it is possible to see if attitudes toward the CSW change with time. When asked in the focus group if they would purchase the CSW, 17 percent answered differently and now said they would purchase the CSW. Of those whose responses changed, 75 percent moved from a "might or might not" consider such a purchase to affirming that they would purchase the CSW. Twenty-five percent went from “would not” consider purchasing the CSW to “yes.”

As in Sections 5.3.5 and 5.4.5, the weighted-box method was used to estimate the percent of participants willing to purchase the CSW and to forecast acceptance. We gauged buying intent using responses to a 7-point Likert response scale (1 = definitely not) to the survey item: “Cost aside, if you were purchasing a new vehicle, how likely would you be to consider purchasing the CSW? Participants responded as follows to CSW Question 47: 1=definitely would not consider (17%), 2 (7%), 3 (7%), 4 might or might not consider (22%), 5 (12%), 6 (17%), and 7 definitely would consider (18%). The data indicate that 30 percent of the FOT participants would purchase the CSW.

Post-Drive Survey Comments

During the debriefings, participants gave the primary reason for their response to CSW Question 47, “Cost aside, if you were purchasing a new vehicle, how likely would you be to consider purchasing the CSW?” Comments include the following. “Need CSW on unfamiliar roads,” “I like the idea of being warned in some unfamiliar situations and locations,” “The false CSW alerts need to be fixed,” “CSW enhances driving safety,” “I would buy CSW if everything works properly,” “I fell asleep while driving,” “Too many false warnings. “If false warnings were somehow corrected, I would definitely consider buying,” “CSW needs to be more accurate,” and “CSW needs more accurate detection of upcoming curves.” One participant said “I found few situations where I was unaware of upcoming curves and I do not need it.” Several people mentioned their lack of experience with CSW, such as "most of my driving is city driving,” “Did not use CSW enough to assess,” and “I don’t feel as knowledgeable about CSW as I do with LDW.”

Focus Group Comments on Advocacy

Focus group participants were asked whether they would have turned off the CSW. Two-thirds said they would not have turned it off. Participants who would not have turned off the CSW often said they lowered the CSW sensitivity setting to reduce unnecessary alerts. They want the CSW functionality because “in theory it seems like a good enough idea to leave it on.” A middle-aged female said she would not turn off the CSW because she didn’t think she had adequately tested that piece of the system because “my driving didn’t cover a whole lot of curves.” This comment raises the issue of variation in driving experiences and the need for sufficient time and varied conditions to become accustomed to new features.

A younger man would have turned off the CSW because he received CSW alerts only when he passed an exit ramp on the highway and when he got on and off freeways. A younger woman wanted to turn off the CSW because she said there were “certain spots where it went off like crazy” but she added that she would turn it on again eventually.

When asked if the CSW performed in the way they would expect it if they bought this feature, only one person, a middle-aged man, agreed that the CSW performed in the way he would expect if he bought it. Many participants said that the CSW issued too many false alarms. Others said the CSW needed to be more reliable and have “fewer false readings.” A few participants suggested the CSW needed to “take more information into account” such as brake pressure and turn-signal use to predict better driver intention. A younger man said the CSW became annoying when he received false CSW alerts but it was helpful because it let him know when he entered a curve too fast. A middle-aged man suggested the CSW might be good on rental cars because drivers of rental cars drive on unfamiliar roads.

When focus group participants were asked what needs to be different before the CSW becomes a product, many comments referred to the imminent alert and its use of a voice saying “curve, curve”. Two younger women described their passengers’ reactions to the voice alert. One said that “her kids loved it” and the other said it became a joke with her passengers. Other suggestions include the following: use a female voice, do not say “curve, curve,” intersperse “curve, curve” with another message saying “slow down” every third issuance, and provide the option to select a preferred message.

When asked if they would buy the CSW, cost aside, 59 percent, said they would. Younger participants said they would purchase the CSW but the middle-aged and older participants had split opinions. They wanted the CSW to be more accurate, “fine tuned,” and fix the false alerts. Other participants said the CSW is useful in unfamiliar areas. Some participants’ assessments were limited due to insufficient opportunity to use the CSW.

Participants who said they would not buy the CSW did so because of excessive false-positive and missed alerts. An older man had situations when he thought it should have alerted him and he tried to make the CSW “go off and it didn’t go off.” A middle-aged man said that if the CSW “doesn’t go off when you think it should, then when you need a warning and it doesn’t go off when you’re approaching way too fast, that could be a problem.” A middle-aged woman said that “after a while you start not paying attention to it if you get too many false alarms.”

The most frequent suggestions to improve the CSW were to make it more accurate and to eliminate false alerts. Other suggestions are to move the display to the center of the dashboard and teach it to read speed signs.

5.6 CONCLUSIONS

The RDCW was intended to warn drivers of lateral drift, either into an adjacent lane or off the road, and excessive speed for an upcoming curve. Participants accepted it because they recognized that using it made them drive more safely. The LDW and, to a lesser extent, the CSW provide new information about driving performance in terms of lateral road position and appropriateness of vehicle speed during curve handling. Participants accept these subsystems because they consider the added information useful.
The following summary of the independent evaluation assessment of the driver acceptance of RDCW and its LDW and CSW subsystems is based on analyses of the partici-

pants' subjective opinions from survey responses, debriefing comments and focus group input.

5.6.1. RDCW

The RDCW settings and availability indicators were easy to use. The display location was convenient, system operation was easy to understand, sensitivity adjustment switches were easy to locate and use, sensitivity settings were easy to understand, and the display layout was easy to learn. Two-thirds of the participants found the directional haptic alerts easy to understand. A minority of participants did not like the location and short duration of the visual display. Younger participants adjusted the RDCW sensitivity settings more than middle-aged and older participants. Participants understood how changes to the sensitivity settings affected alerts, could distinguish between the LDW and CSW alerts, and understood the alerts' meanings.

Participants learned the RDCW operation quickly but some comments, at the conclusion of the FOT, suggested that they did not understand the differences between the LDW and CSW functionality. Furthermore, they understood the difference between seat vibration and auditory tone, but some did not understand that the former corresponded to a cautionary alert and the latter an imminent alert.

Despite being easy to learn to use, the LDW and CSW alerts, with two levels of gravity and common modalities, confused some participants. Some participants did not discriminate between LDW and CSW alerts. Others did not make meaningful distinctions between the cautionary and imminent alerts. This raises the question of whether drivers using such a system need to know the reason for an alert or does its value rest in refocusing their attention on the immediate road situation.

The RDCW evoked a "carryover" effect, based on comments of focus group participants after completing their FOT participation. They tended to assume they had RDCW capability after leaving UMTRI in their personal vehicle. They experienced situations when, expecting to receive a RDCW alert, realized they no longer had this feature.

Even though the RDCW made participants more aware of their vehicle position on the road and upcoming road challenges, participants did not rely on the RDCW and assumed responsibility for operating their vehicle. Participants thought that RDCW use would increase their driving safety because it fostered increased turn-signal use, reduced lane drift, and improved alertness.

Most participants wanted to acquire the RDCW and would pay an average of $725 for it. Older participants were more likely than younger participants to purchase such a system.

5.6.2. LDW

The LDW was easy to use. Everyone, especially the older age group, recognized the urgency of the alerts. The alerts were not distracting and participants knew what to do when the RDCW issues an LDW alert. Participants did not change the LDW sensitivity setting often.

Although some participants said they received unnecessary or false LDW alerts, most found the LDW alert frequency acceptable. Weather conditions, particularly rain, caused LDW errors and repetitive alerts. LDW availability varied and may account for some portion of the reported missed alerts because participants did not always consider the system availability status.

The LDW was easy to learn. Participants reported more turn-signal use when they drove their own vehicle after the test, evidence of a carry-over effect. At times, participants had difficulty discriminating between LDW and CSW alerts, but did not find it annoying. When participants mentioned that they checked their speed when receiving a LDW alert, it suggests they confused the alerts, which may have contributed to some reports of false alerts. It is important that participants distinguish between the alerts because speed is a factor in triggering the CSW, but not the LDW. They needed to distinguish between the alert categories to provide the appropriate remedy.

The LDW made participants more aware of their vehicle position, more relaxed when driving, and more skilled in maintaining their position in the center of the lane. The LDW encouraged more turn-signal use when changing lanes, even after completion of the FOT.

The LDW improved self-awareness of driving performance, based on comments about noticing lane drifts during cell phone use. Some participants referred to the LDW as a de facto ‘blind spot detector’ because it issued an imminent alert if an adjacent lane was occupied. The younger and older age groups said that they were more likely to perform additional tasks when driving with the LDW. Participants, however, recognized that their cell phone use affected their lane position and described accommodations to their phone use.

Participants appreciated the information provided by the LDW and thought it made them safer drivers. The LDW improved driving safety because participants responded to its feedback about their lateral road position and used their turn signal more often. Some participants said that the LDW alerts pointed out their driving mistakes and led to changes in driving practices.

The incidence of LDW alerts was not related to participants’ tolerance of their frequency. Participants rated three-quarters of both their cautionary and imminent LDW alerts “useful” because they learn about their lane drifts, lack of turn-signal use, and lack of attention. FOT participants had a positive reaction to the LDW. They rated the LDW as useful and most of them, especially older participants, were satisfied with it. Participants wanted to acquire the LDW to increase driving safety, enhance driving alertness, and as a reminder to use the turn signal. They would like it to work better in poor weather and would not turn it off if an on/off switch were provided. Participants were interested in purchasing the LDW and would pay an average of $500 to acquire it.

5.6.3. CSW

Participants found the CSW easy to use and knew what to do when they received an alert. The alerts did not distract participants. Many said that because of infrequent curves they did not have sufficient exposure to the CSW to have an informed opinion of it. A sizable minority of FOT participants said they received too few alerts, particularly imminent alerts, to be able assess the CSW. Finally, many focus group participants made comments that revealed that they did not understand the CSW. Participants tested the CSW and, if they had difficulty triggering an alert, become uncertain about its operation.

Participants discriminated between the CSW utility in relation to familiar and unfamiliar curves. Participants appreciated CSW alerts on unfamiliar curves, when they were distracted, and when conditions made driving more challenging (i.e., snow, rain, night). Participants said they did not need the CSW alerts on familiar curves because they drove them regularly and knew how to handle them.

Passenger reactions to alerts affected participants. The auditory imminent alert, a voice saying “curve, curve,” was found by some to be provocative and caused some passengers to question their safety and mock the driver’s performance. An older man suggested that the haptic alert should be placed in the passenger seat where his wife sits because "she tells me what to do." This humorous comment reveals an important component of driver acceptance, which is how passengers react to the vehicle enhancement. If the passengers find the enhancement amusing, silly, threatening, or not understandable, it can affect the driver.

CSW implementation produced problematic situations when alerts were issued but participants did not consider them appropriate. There were inconsistencies between participants’ opinions and the CSW’s judgment of a curve when the geometry was complex, i.e., “S” and multiple curves. In addition, participants cited false alerts for Michigan lefts and for ramps entering or exiting freeways. Participants did not like receiving CSW alerts when they entered ramps or exit freeways because they feel a conflict between the CSW advising deceleration while they needed to match the speed of traffic flow they were entering.

There were issues with the CSW alert modalities. Some participants were annoyed by the visual representation of the CSW, which did not match the direction of the curve generating the alert. A minority of participants had difficulty discriminating the directionality of the seat vibration used for the cautionary alert due to heavy clothing or seating posture.

The CSW was easy to learn, and more than 80 percent of participants learned to use it within two to three days. However, there is a distinction between learning to use the CSW in the sense of operating it, and understanding how it works.

Participants rated the CSW as somewhat useful but did not rely on it to operate their vehicles safely. The middle-aged group was least likely to say that they rely on the CSW. Similarly, the middle-aged group was less likely to say they would perform additional tasks using the CSW. Half the participants said they ignored the CSW alerts: they reacted initially and, with time, tended to ignore them. Younger participants received more cautionary and imminent alerts than middle-aged and older participants.

CSW alerts made participants more aware of the need to slow down for curves. Some participants said that receiving CSW alerts, even when false, reminded them to check the suitability of their driving for the road conditions. The CSW helped participants observe speed limits and assume appropriate speeds for upcoming curves. Participants had neutral to positive opinions that the CSW will prevent crashes and rated the utility of these alerts in stressful traffic or challenging weather conditions as neutral to slightly positive.

Overall, participants had negative opinions about unnecessary and false CSW alerts. The incidence of false CSW alerts interfered with their ability to become comfortable using the CSW. Younger and middle-aged participants were more likely to say they received too many unnecessary and false CSW alerts, in keeping with their higher incidence of CSW alerts. They were particularly annoyed by repeated false CSW alerts on regular routes.

Based on a review of selected CSW alerts, participants classified three-fifths of the cautionary CSW, and one-half of the imminent CSW, alerts as useful. They considered CSW cautionary alert to be quite useful when they warn about driving too fast and on unfamiliar roads, and CSW imminent alerts quite useful for calling attention to an upcoming curve. A middle-aged woman said, “In theory it seems like a good enough idea.” Overall, participants would not turn off the CSW if an on/off switch were provided. Participants had a neutral response to the idea of purchasing the CSW in a new vehicle. Slightly less than one half, 47 percent, of the participants would consider purchasing the CSW and would pay an average of $400 for it.

6. CONCLUSIONS

This chapter highlights key findings related to the three principal evaluation topics of system performance, driver acceptance, and safety benefits. The chapter also presents recommendations for a future RDCW, the additional data needed for the related FOT, and enhancements to the FOT experimental design and procedures.

HIGHLIGHTS

- Out of every 100 km, the LDW was available 55 km and the CSW 95 km.
- FOT participants rated most alert characteristics positively.
- The LDW improved lane keeping and turn signal use.
- The RDCW resulted in fewer road-departure conflicts.
- Assuming 100 percent device deployment and the availability observed during the FOT, an annual decrease of 5,200 to 41,200 road-departure crashes is forecast.

6.1 FINDINGS

6.1.1. System Performance

System availability indicates if the subsystem is capable of issuing an alert. FOT data show that road type and the combination of lighting and precipitation influence LDW (subsystem) availability. Table 6-1 summarizes the LDW availability at speeds when the subsystem was capable of alerting the driver. Road type strongly influenced availability. The LDW availability on freeways, 76 percent, dropped to 36 percent on non-freeways. Light and weather also strongly influenced availability. The daytime, dry LDW availability, 56 percent, dropped to 4 percent during the rain at night. CSW availability was consistently high, 99 percent on freeways and 94 percent on non-freeways.

Table 6-1. LDW Availability Summary

Conditions	Percent Available
Overall	55
<u>Road type</u>	
Freeway	76
Non-freeway	36
<u>Light and weather</u>	
Day and dry	56
Night and wet	4

One thousand three hundred kilometers of on-road characterization test-driving, when the RDCW was supplemented with an independent measurement system (IMS), provided a wealth of data to quantitatively evaluate RDCW performance. In comparing the AMR in a shoulder, a key LDW measure, with the actual AMR, i.e., the one measured by the IMS, we found that the LDW often overestimated the width of narrow shoulders and underestimated the width of wide shoulders. A comparison of CSW and IMS estimates of the distance to an upcoming curve and the curve radius revealed differences, but no clear trend, in these measures.

The characterization data indicates that inaccurate AMR estimates caused numerous missed and false-positive alerts. When there were solid markers and the situation required an alert, the LDW failed to issue an alert in approximately 1 of 8 cases. An overestimate of the AMR likely caused the LDW to not issue an alert. When there were solid markers and an alert was issued, approximately half were false positive, with corresponding TTCs greater than 5 seconds, and approximately one-third had TTCs less than 1.5 seconds. The large TTCs occurred because the LDW underestimated the AMR, and the small TTCs occurred because the LDW overestimated the AMR.

The LDW side and forward radars enabled the RDCW to detect adjacent and forward objects and alert accordingly. When the test vehicle drifted toward an adjacent vehicle and an alert was required, the RDCW issued an LDW alert in 4 of 5 cases. Even though a malfunctioning radar during one test run was responsible for most of the missed alerts, 1 of 4 alerts was a false positive. The LDW detects stationary roadside objects, particularly parked vehicles, well. In 9 of 10 cases, the RDCW issued an alert when the test vehicle drifted toward a parked vehicle.

The FOT, with its pool of participants and its diverse roads and conditions provides a rich set of data to analyze the RDCW LDW-alert performance. The FOT provided two orders of magnitude more data, 130,000 km versus 1,300 km, than the characterization testing. A manual video analysis of FOT alerts indicates that 1 in 3 alerts was a false positive. Further analysis revealed that the weather conditions that influenced LDW availability also influenced LDW performance. In particular, the FOT data show:

- The odds of an alert being a false positive for nighttime driving were 1.8 times the odds for daytime driving.
- The odds of an alert being a false-positive alert on wet surfaces were 3.0 times the odds on dry surfaces.
- The odds of an alert being a false positive when driving in the rain were 3.6 times the odds when driving under dry conditions.

Construction zones, with barrels, barriers, and poor or no lane markings, degrade visual conditions and make it difficult for the LDW to correctly sense its surroundings. Of the alerts issued in construction zones, almost half were false positive. Inaccurate AMR estimates caused most of the false-positive and missed alerts in construction zones.

Characterization testing provided a comprehensive set of RDCW and IMS data to analyze CSW performance. When the test vehicle approached a curve at an excessive speed, the system missed 1 of 4 alerts. When the system did alert, 93 percent of the alerts provided a driver with sufficient time to brake and negotiate the curve safely. When the vehicle approached a curve or passed a ramp, 1 of 10 alerts was a false positive. Underestimates of the distance to the curve or the curve radius caused the false positives, and overestimates of the same measures caused the missed alerts.

Participants rated the RDCW DVI in their post-drive surveys. Eight-eight percent readily interpreted the seat vibration alerts, 80 percent readily interpreted the LDW audible alerts, and 86 percent readily interpreted the visual alerts. Participants rated the following favorably: LDW and CSW alert timing, LDW and CSW missed-alert frequency, and LDW false-positive alert frequency. The participants' unfavorable responses to certain survey items indicated that they recognized the LDW limitations in poor lighting and road surface conditions, such as wet roads at night.

6.1.2. Driver Acceptance

Although FOT participants liked the RDCW and its subsystems, they were less enthusiastic about the CSW. They considered the LDW alerts to be more valuable than the CSW alerts, and many participants indicated they adjusted their driving because of it. They used turn signals more consistently, which contributed to a decrease in the LDW alert rate during the treatment period. In addition, participants said the LDW helped them monitor and learn about their driving and made them aware of vehicles in their blind spots. Participants did not find the CSW alerts particularly valuable and were less likely to change their driving because of the CSW.

Several focus group participants who returned to UMTRI some time after completing their FOT driving said that they missed the RDCW when they resumed driving their own vehicle. They recalled situations where they expected to receive one of the RDCW alerts, and had to remind themselves that their own vehicle did not issue alerts.

Participants were more reserved in their praise for the CSW. They viewed it as a good concept in theory, but one that, in practice, issued too many false alerts. Some participants could not provide reliable feedback about the CSW because they had insufficient experience using it and needed more exposure to the subsystem. The FOT constraints required participants to restrict their driving to geographic areas mapped in the RDCW system. This restriction may have limited both the variation in the roads and the participants' exposure to unfamiliar roads.

Several factors contributed to the CSW driver-acceptance results. Participants distinguished between curves on familiar and unfamiliar roads. They did not feel the need for CSW alerts for familiar curves because they knew how to approach and negotiate these curves. When they received an alert on a familiar curve at a (for them) typical speed, they found it unnecessary and annoying. In simple terms, the system seemed to be telling them that something they had always done was now incorrect, even though they had no trouble maintaining control on these curves. Some participants said that had they driven more on unfamiliar roads, CSW alerts might have been more valuable to them. On the positive side, participants appreciated CSW alerts when driving in bad weather and at night.

Participants approved of the RDCW implementation and found it easy to use. They liked the haptic "modality" of the cautionary alerts, as opposed to audible modality of the imminent alerts, because they alerted only the driver and did not startle the passengers. Unlike the cautionary alerts' silent seat vibration, imminent alerts are issued over the vehicle's sound system. The LDW alert simulates a rumble strip sound, and the CSW alert is a male voice saying, "curve, curve." Participants accepted the rumble strip sound, but tended to dislike the CSW imminent alert.

Participants generally had positive experiences with the RDCW. They showed considerable interest in it, and are willing to spend approximately $750 to acquire one. When reviewing their alerts on video with an UMTRI researcher, they rated the majority of the alerts, 75 percent of the LDW and 50 percent of the CSW, as useful.

6.1.3. Safety Benefits

Conflict rates and conflict severity were analyzed in two pre-crash scenarios:

1. Going straight or negotiating a curve and departed road edge
2. Negotiating a curve and lost control.

Changes in conflict rates and severity from the baseline period to the treatment period result from the RDCW providing alerts; these changes determine the safety benefits. Because of their different alert functions, the LDW is relevant to conflicts in the first category and the CSW to conflicts in the second. In the departed-road-edge category, the conflict rate decreased (from baseline to treatment period) at speeds greater than 55 mph. Conflict severity decreased over the 35 to 45 mph speed range. The FOT data, however, did not support a credible estimate of the condition crash probability (which is used to estimate crash reduction) over this speed range. Thus, no change in crash counts due to a reduction in conflict severity is forecast. The FOT data did not show any statistically significant changes in conflict rate or severity in the second pre-crash scenario, negotiating a curve and lost control. Extrapolating changes in conflict frequency to all domestic drivers, we can predict a net annual crash reduction. If the RDCW were deployed in all light vehicles and if the device were always available, an annual reduction of 9,400 to 74,800 crashes would result. If the device were fully deployed and available for 55 percent of the VDT—the availability observed in the FOT data—a reduction of 5,200 to 41,200 crashes would result.

Driver performance analyses examined changes in driving in the following categories: curves, in the lane, lane changes, and turns. An analysis of FOT data revealed neutral to positive driver performance associated in each of these categories. FOT participants did not take curves any slower (or faster) when the device was enabled. They did, however, tend to drive closer to the lane center and meander less. For lane changes, we analyzed turn-signal usage for both the baseline and treatment periods, treating the percent of lane changes accompanied by a turn signal as the performance measure. The FOT data show a significant improvement in turn-signal use when the RDCW was enabled, a positive outcome. FOT participants appeared to take turns slightly faster, but the magnitude of the change in lateral acceleration change is miniscule.

6.1.4. Summary

Analysis of FOT, system characterization, and survey data indicates that:

- The RDCW performed reasonably well
- Participants generally liked the RDCW and are willing to pay for it
- Driver appreciated the LDW alerts and responded to them
- At speeds above 55 mph participants crossed solid lane boundaries less often with the RDCW
- When participants did cross solid lane boundaries, they came slightly closer to departing the road at lower speeds with the RDCW and stayed further from the road edge at higher speeds with the RDCW
- Subject to certain assumptions, RDCW deployment will result in an annual reduction of 5,200 to 41,200 crashes.

These encouraging results associate a safety benefit with the RDCW and a willingness of drivers to pay for it.

6.2 RECOMMENDATIONS

During the independent evaluation, we have become very familiar with the RDCW and the FOT. We analyzed many data samples, collected performance data, examined subjective responses, and listened to focus groups. Our recommendations are divided into three areas: future RDCW development, future FOTs, and future data analysis.

6.2.1. Future RDCW

While we recognize that some of these recommendations for improving the RDCW are likely to be well known to system designers, we also recognize that some may be difficult or impossible to achieve. Recommendations are based on comments from FOT participants and our own observations.

- *Make the LDW available on a greater range of road types and conditions.* Improve performance on non-freeways, where at speeds greater than 25 mph the system was only available 36 percent of the distance traveled.
- *Improve the AMR estimate.* During the characterization testing the RDCW frequently chose a default AMR based on road class, rather than attempt to measure the actual AMR. Improvements in the AMR estimate would decrease false-positive and missed alert rates and improve alert timing.
- *Improve the MLP accuracy.* This recommendation is particularly relevant near ramps and Michigan left U-turns.
- *Increase the alert thresholds for repeat LDW and CSW alert locations, or perhaps disable the alerting in certain areas.* When traveling through a construction zone, a driver may receive false-positive or nuisance alerts. If the system–perhaps with driver-supplied cues–could recognize this area as a source of frequent or probable errors in issuing

alerts, the system could be disabled locally. Given that the current system has a dedicated database for previously passed objects, a future system could have a dedicated no-alert-zone database.

- *Selectively disable CSW alerting to reduce nuisance alerts.* Passed exit ramps and map errors produced numerous false positives in the FOT and characterization test data. An NAZD could eliminate repeated alerts at the same location. Furthermore, drivers who take familiar curves at a speed the system believes is excessive could add these locations to the NAZD. In rain or snow the system could override a driver's preference and issue alerts for high-speed familiar curves, but not for exit ramps or map errors.
- *Disable the LDW at night in the rain.* The RDCW issued many false-positive LDW alerts in these conditions, particularly where there was overhead lighting or oncoming traffic.
- *Eliminate mapping errors or allow drivers (or driving) to correct the errors.* Mapping errors near overpasses created a false curvature in the road and produced false-positive CSW alerts. Drivers could add these locations to the NAZD.

6.2.2. Experimental Design and FOT

We do not view any of these recommendations as essential, but do believe that they merit consideration in the next FOT. Recommendations include:

- *Direct calibrated side cameras at the lane markers.* The main limitation in the FOT data was an inaccurate estimate of the AMR. Calibrated side cameras directed at the lane markers could provide researchers with accurate lane-position and AMR estimation, while calibrated left and right side-forward cameras could provide accurate adjacent vehicle or object detection and measurement.
- *Increase exposure time and diversity:*
    - Recruit participants who have high annual mileage, or perhaps include a subgroup with high annual mileage (another potential explanatory variable). Validate prospective participants' annual mileage claims.
    - Consider including participants who frequently vary their routes
    - Increase the FOT area and include areas with many curves
    - Increase the overall duration of the FOT experience: the FOT 6-day baseline period and 19-day treatment period did not provide sufficient conflicts for many participants.
- *Include participants older than 70.* Driving improvement depends on a driver's perception of sensory inputs; therefore, it is important to include older drivers to determine if they can perceive the warning modes.

6.2.3. Analysis

Suggestions for analyzing future FOTs include:

- *Detect repeated routes and determine how many alerts were issued at the same location.* Drivers who receive repeated alerts may like the system less and be less inclined to heed its alerts.
- *Determine if a combination of exposure (in VDT) and availability influence driver acceptance and changes in driving.* Drivers who travel a lot and have high LDW availability may like the system more and respond better to alerts. If we can determine the factors that influence both drivers accepting the device and heeding its warnings, we may help accelerate deployment of the device
- *Determine if there is an association between LDW or CSW alert rates, driver acceptance and changes in driving.*
- *Determine the optimal alert rate versus driver acceptance and improvements in driver performance.*

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APPENDIX A Road-Departure Crash Warning System

This appendix describes the RDCW, including its LDW and CSW subsystems and the RDCW driver-vehicle interface. The appendix also includes a brief description of the data acquisition system used in the FOT.

A-1. System Architecture

The RDCW provides lateral-drift and curve-speed warnings through its LDW and CSW subsystems, which sense their surroundings and provide information to the RDCW Situational Awareness Module. The SAM integrates information from a variety of sensors and issues an alert if required. Figure A-1 illustrates the RDCW architecture and the central role of the SAM.

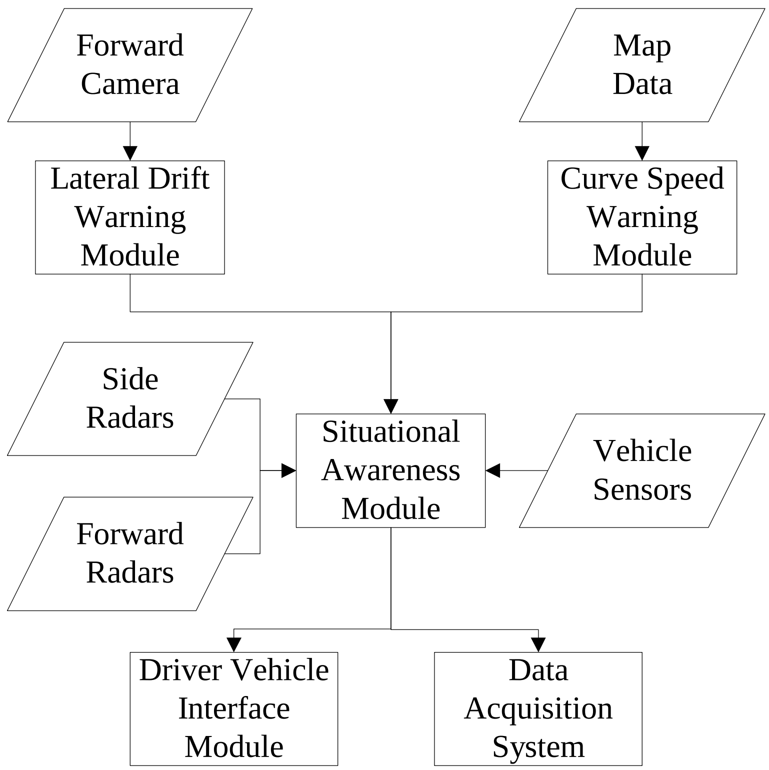


Figure A-1. RDCW Architecture

The LDW and CSW subsystems operate cooperatively, issuing alerts to the driver as one combined collision avoidance system. A suite of sensors provide information to the LDW, CSW, and SAM, including a:

- Forward camera;
- Digital map database;
- Look-aside database;
- GPS;

- Side radar (left and right);
- Forward radar (left and right);
- Yaw rate gyro;
- Speedometer;
- Turn signal;
- Brake switch;
- Wiper switch; and
- Thermometer.

A-2. Lateral-Drift-Warning Subsystem

The RDCW LDW subsystem issues a lateral-drift warning when sensors and processors indicate the vehicle is drifting toward a lane boundary or adjacent vehicle. The LDW analyzes up to 30 m of upcoming road with its forward camera and determines if the current lateral drift and lane position are causing the vehicle to depart the road or collide with a solid object such as an adjacent vehicle. The SafeTRAC technology (Assistware, 2006) functions as the LDW foundation. RDCW developers added additional sensors to SafeTRAC so the system would have more situational information.

The LDW requires two conditions to issue alerts: speeds greater than 11.2 m/s (25 mph) and detectable boundaries. At slower speeds or when the system cannot determine either the left or right lane boundary, the LDW cannot issue an alert. Figure A-2 illustrates the system display when the LDW cannot issue right-side alerts. The red circle highlights the lack of right-side (alert) availability; it is not part of the actual display.

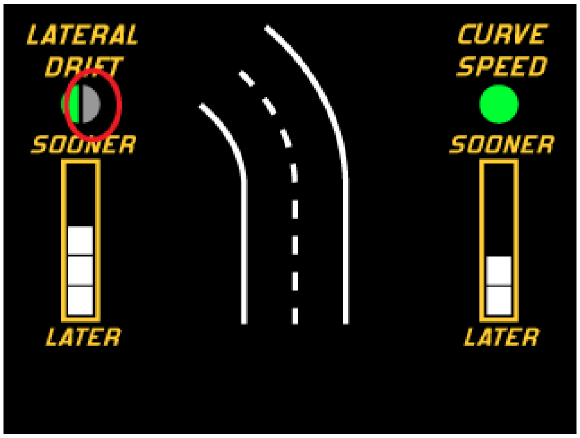


Figure A-2. Dashboard Display Indicating No Right Side LDW Availability

The RDCW issues both cautionary and imminent LDW alerts, but tries to avoid issuing nuisance alerts. If a vehicle drifts across a dashed line and does not detect a vehicle in the adjacent lane, the system issues a cautionary alert. If the vehicle drifts across a solid or a dashed boundary and detects a vehicle in the adjacent lane, the driver receives an imminent alert. If a driver activates the turn signal or brake pedal, the system will not issue an alert, regardless of the lane's boundary type and adjacent objects. In these situations the system assumes the driver intends to change lanes and is aware of the surroundings, so it does not issue what would likely be perceived as a nuisance alert.

The SafeTRAC unit includes a monochrome charge-coupled device camera and combined processor-driver-vehicle-interface. RCDW developers added two side and two forward radars to thoroughly assess the lateral drift threat. The RDCW has side radars mounted in the front corners of the vehicle; these 24-GHz radars have a 120° field of view. A limited range of 10 m enables them to sense only nearby adjacent objects alongside and slightly ahead of the vehicle. Left and right forward radars supplement the side radars and sense more distant objects. These 77-GHz forward-facing radars are also mounted on the front corners of the vehicle where they have a narrower 8° FOV and a range of 60 and 120 m for stationary and moving objects, respectively. The forward radars detect upcoming adjacent objects, which may affect the Available Maneuvering Room. The AMR is the RDCW estimate of the distance beyond the lane marker at which a road departure or collision will occur. A digital-map database containing information about previously passed objects may modulate the AMR. This *Look-Aside Database* stores the location of stationary objects sensed by the side radars. If these objects are detected after multiple passes, the LADB registers them as a “fixed” object that locally reduces the AMR. If a fixed object is no longer sensed after multiple passes, e.g., a parked vehicle is moved, the LADB no longer retains it.

The RDCW integrates sensor and LADB information and a sensitivity setting to determine if an LDW alert is required. The sensor data and processing provides estimates for vehicle position in relation to the lane markings, predicted vehicle position, and current and upcoming AMR. The RDCW uses this information and the driver-selected LDW sensitivity setting to gauge alert need. Using a dashboard-mounted rocker switch, drivers can select one of five sensitivity settings. The nominal setting is 3: a low sensitivity setting of 1 instructs the RDCW to issue alerts later than it would issue them at the nominal setting; a high setting of 5 instructs the RDCW to issue LDW alerts earlier than the nominal setting.

A-3. Curve-Speed-Warning Subsystem

The RDCW CSW subsystem issues a curve-speed warning when its sensors and processing indicate the vehicle is approaching a curve at an unsafe speed. The CSW is active (available) only when vehicle speed exceeds 8.0 m/s (18 mph), the GPS is functioning, and the digital map recognizes the road associated with the GPS location. Figure A-3 shows the system display with full LDW availability but not CSW availability (the red circle is not part of the actual display).

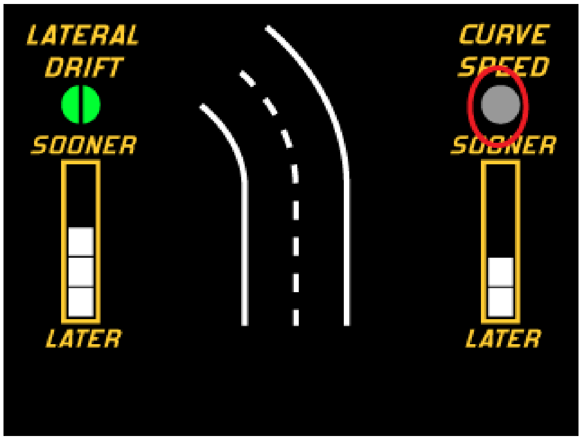


Figure A-3. Dashboard Display Indicating No CSW Availability

To determine alert need the CSW integrates digital maps, GPS position, vehicle speed and lateral acceleration sensors, and environmental conditions. An advanced digital map from NAVTEQ provides additional road detail and attributes such as number of lanes for the area where the FOT was conducted. A GPS receiver provides location information, and the RDCW supplements this with an inertial navigation system, which enables the system to estimate vehicle location during brief GPS signal outages while passing under overpasses or trees. The speed sensor and lateral accelerometer enable the RDCW to determine its location relative to a nearby curve during GPS outages. As wet or icy roads can sharply decrease the adhesion between tires and the road, the RDCW attempts to infer road conditions from vehicle sensors. The RDCW measures outside temperature and road moisture, using windshield wiper activation to estimate the latter. The RDCW uses a combination of temperature and wiper settings to modulate alert need and timing. For example, a certain speed may elicit an alert on a wet road, but not on a dry road. Similarly, cold and wet conditions will result in more alerts and earlier alerts than warm and dry conditions.

At a basic level the CSW subsystem uses vehicle speed and the upcoming road to check alert need. As the upcoming road may have multiple paths, e.g., an upcoming exit ramp, the CSW determines the vehicle's Most Likely Path by first combining GPS location and digital map information to determine the upcoming road geometry. It then integrates this geometry, turn-signal activation (or lack of), lane boundary type(s), and the road class, and determines the MLP. For example, the system will choose an exit ramp as the MLP when the system identifies the vehicle is in the right lane and the turn signal is active. Once the MLP is selected the CSW determines the distance to the next curve (if any) and the maximum safe speed for the curve. A preset maximum lateral acceleration and estimated road curvature determine the maximum safe speed. Environmental conditions—low temperatures and windshield wiper use—decrease the maximum lateral acceleration.

The RDCW issues both cautionary and imminent CSW alerts. The CSW subsystem integrates upcoming curve information (i.e., estimated radius), environmental conditions, vehicle location, vehicle speed, an assumed driver reaction time, maximum lateral acceleration, and the distance to the curves, and determines if a cautionary or imminent alert is required. The subsystem issues a cautionary alert when either only a moderate speed reduction is required to traverse the curve safely or the distance and time to the curve is relatively large. The subsystem issues an imminent alert, which can follow cautionary alerts for the same upcoming curve, when a significant speed reduction is required to negotiate a curve safely. Similar to the LDW subsystem, a sensitivity setting alters the CSW alert type and timing. A low sensitivity setting results in later alerts, and a high sensitivity setting results in earlier alerts. Unlike the LDW subsystem, neither braking nor turn-signal application suppresses CSW alerts. RDCW designers want to warn drivers that their approach to a curve (or exit ramp) is too fast, and even if they are already braking, it is not sufficient.

A-4. DVI

Once the RDCW determines an alert is needed, it must communicate this to the driver across visual, auditory, and haptic modes using visual icons in the instrument cluster, simulated rumble strips through vehicle speakers, and seat vibration. Figure A-4 illustrates the visual icons associated with LDW left cautionary and imminent alerts. Right alerts are identical, except for arrow direction. A color screen on the left side of the instrument cluster replacing a tachometer, displays these alerts to the driver. For cautionary alerts to replicate a rumble strip, small motors embedded in the driver's seat vibrate the side of the seat corresponding to the alert side. LDW imminent alerts generate the visual alert icon and three pairs of tones from vehicle speakers corresponding to the alert side. Again, the intent is to replicate a rumble strip from the side of the vehicle causing the alert. To make audio alerts easy to discern, the RDCW temporarily mutes the vehicle sound system when it issues an audio alert.

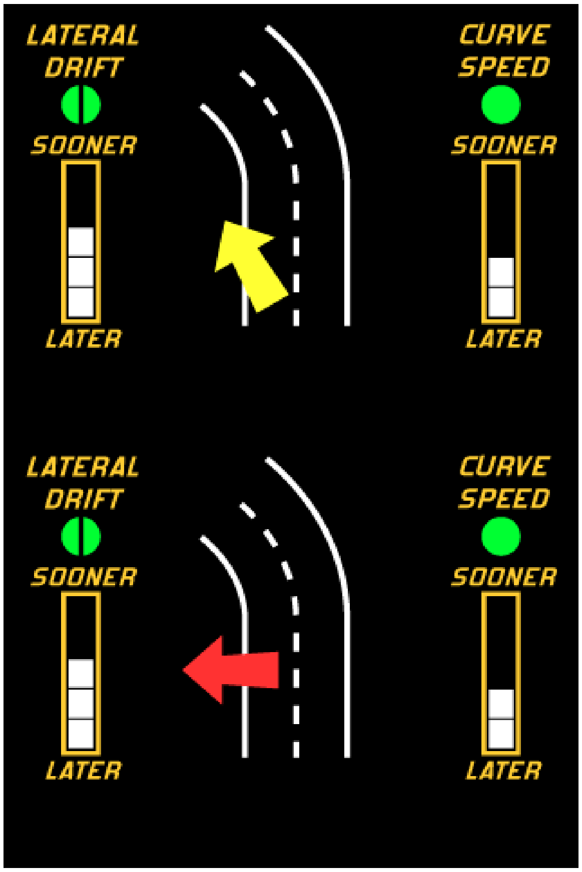


Figure A-4. LDW Left Cautionary and Left Imminent Alert Display Examples

Figure A-5 illustrates the visual icons associated with CSW cautionary and imminent alerts. CSW alert modalities are similar to LDW modalities, with one minor difference. Unlike the LDW, which indicates if the alert is from the left or the right side, CSW alerts indicate only the presence of an upcoming curve, not its direction, communicating only the need to decelerate. For cautionary alerts, the front of the seat vibrates, not to simulate a rumble strip, but to warn the driver. CSW imminent alerts generate the visual alert icon and an auditory warning of a voice saying, “Curve! Curve!” CSW auditory alerts also temporarily mute the audio system.

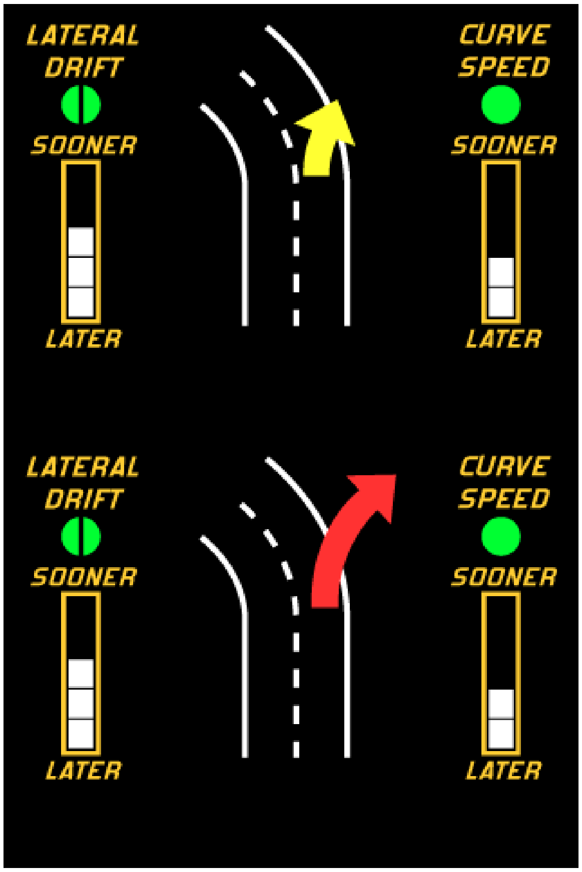


Figure A-5. CSW Cautionary and Imminent Alert Display Examples

A-5. DAS

A data acquisition system is essential to the FOT and the RDCW evaluation and collects data from all the RDCW components and additional on-board cameras and sensors. The DAS samples RDCW channels and many relevant vehicle system channels and records most variables at a 10 Hz sampling rate, although some channels are only recorded when they change or at the beginning and end of an ignition cycle.

In addition to numeric data, the DAS records video from a forward-facing camera and a second camera in the vehicle cabin aimed at the driver’s face. The FOT conductor had to strike a balance between recording essential FOT video information and not generating excessive data storage requirements. The solution is to buffer forward and face video continuously and store an 8-second block around alerts, from 5 seconds before to 3 seconds after, and to sample forward video once every second and store these images.

APPENDIX B Overview of On-Road System Characterization Testing

An on-road system characterization test was conducted to measure RDCW performance under a wide variety of atmosphere and real world road conditions. Testing took place on public roads in the Ann Arbor, MI area, with an additional Independent Measurement System to provide ground truth.

We collected similar data during FOT subject driving but this data did not include detailed measurements analysis from the IMS. Appendix B describes test scenarios and guidelines to test each function of the LDW and CSW subsystems. Some tests were not conducted due to lack of exposure or applicable conditions.
Overall Exposure

Figure B-1 illustrates the Detroit and Ann Arbor Michigan metropolitan area. The red dots indicate the locations of the characterization testing. Testing focused on a diverse route in the Ann Arbor area created by UMTRI for pilot vehicle testing. Participants traveled the route several times under all lighting conditions to examine system performance under repeatable road conditions. Additional driving focused on exposing the RDCW system to specific test scenarios not available on the test route, such as Michigan lefts, construction, or urban freeway geometry.

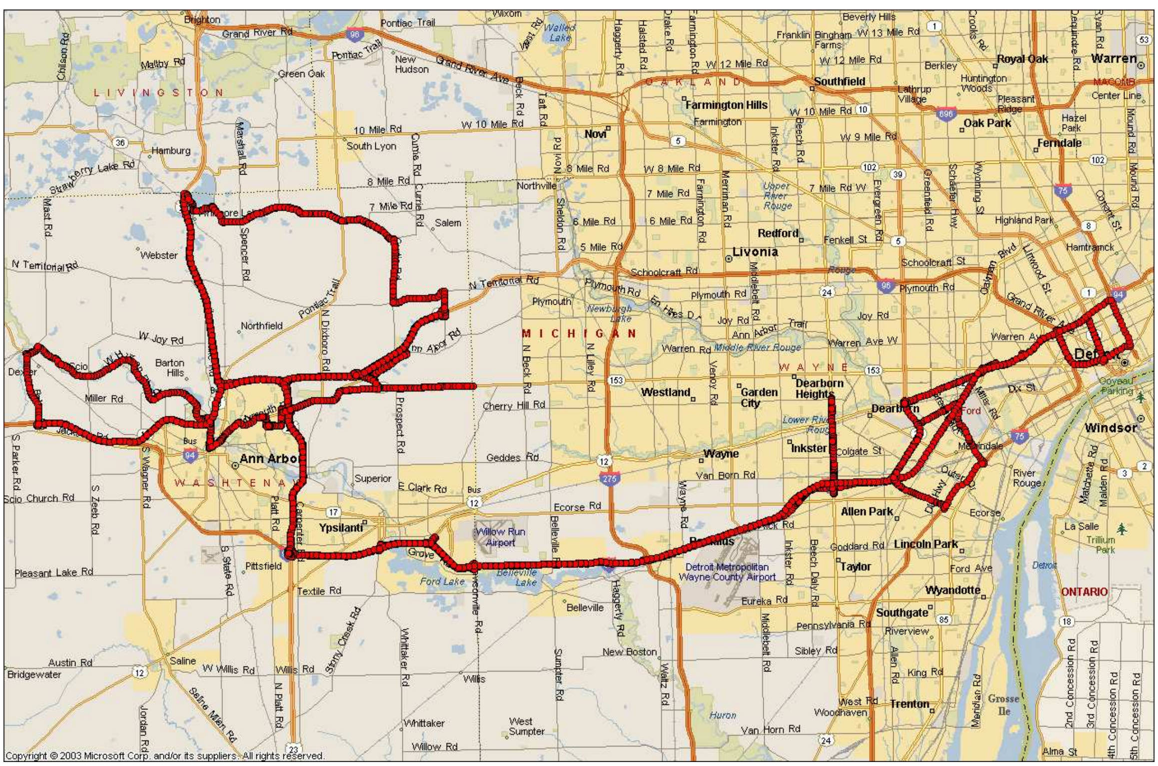


Figure B-1: Characterization Test Driving Locations

Table B-1 shows percentage and actual distance traveled by road class out of 1,278 km total driven during the characterization test. Road class categories are derived from the Navtech functional class variable (http://www.navteq.com/) which defines the road based on general characteristics, such as volume, travel speed, and throughput. Approximately 62 percent of the distance driven during testing was on Class 1 or 2 roads that are considered freeways. Although the goal of the test was to focus on *non-freeways*, only approximately 37 percent of the test took place on these roads, according to the functional class definition of non-freeway. The likely explanation for this was the long distances between diverse non-freeway roads of interest and potential differences in the classification of road type between Navtech functional class and the more strict definition of freeways as divided roads with a posted speed limit of 55 mph or greater used for crash data analysis. Road Class 0 indicates that the RDCW could not identify which road the vehicle was traveling on, so this distance was not counted in either road type.

Table B-1: Distance Traveled by Road Class for On-Road System Characterization Test

Road Class		
0	VDT (km)	20
	Row Percent	2%
1	VDT (km)	353
	Row Percent	28%
2	VDT (km)	438
	Row Percent	34%
3	VDT (km)	171
	Row Percent	13%
4	VDT (km)	239
	Row Percent	19%
5	VDT (km)	58
	Row Percent	5%
Total	VDT (km)	1,278

As shown in Figure B-2, we divided the lighting conditions into day and night and further divided day conditions into cloudy, low angle sunlight, and other sun, and included distances for each condition included. The purpose was to observe the possible effect of difficult lighting situations on the LDW subsystem performance. We also included rain conditions for night and day, although no rain occurred during testing. For additional details on atmosphere conditions refer to Table B-2.

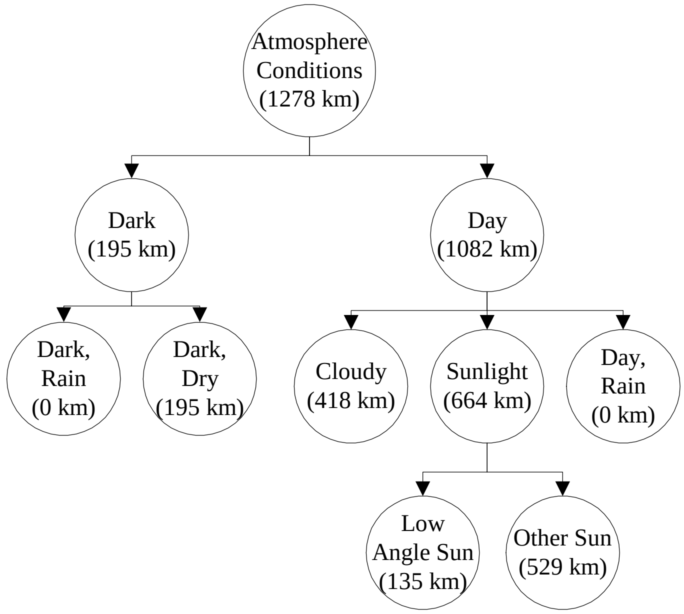


Figure B-2: On-Road System Characterization Test Atmosphere Conditions Breakdown

Table B-2: Distance Traveled by Atmosphere Condition for On-Road System Characterization Test

Atmospheric Conditions		
Low Angle Sun	VDT (km)	135
	Row Percent	11%
Other Sun	VDT (km)	529
	Row Percent	41%
Day, Cloudy	VDT (km)	418
	Row Percent	33%
Night, Dry	VDT (km)	195
	Row Percent	15%
Total	VDT (km)	1278

We determined atmosphere conditions using both time of day and video from the test vehicle's cameras. For the test location and date, we used civil twilight time to find the beginning and end of daylight. We defined low angle sunlight as the time two hours after sunlight began and two hours before sunlight ended, when conditions were not cloudy. Other sun conditions consisted of any daylight time not during low angle sun periods when no clouds were present. To determine cloudy conditions we examined forward and side video images for shadow lines beside the vehicle or nearby objects every two minutes. When we saw a shadow line we marked that part of the test as sun. If no shadow was seen we marked the video as cloudy.

We monitored outside temperature. We selected 2 degrees Celsius as a cutoff point for not conducting testing, since below this temperature the CSW subsystem uses different alert timing to compensate for the possibility of ice. Approximately 20 percent of the test-driving occurred at or below 2 degrees, while 64 percent of the driving took place in conditions above 2 degrees. The remaining 14 percent of driving was not known due to unknown values from the temperature sensor.

We also evaluated wiper use as a percentage of total driving. In all categories wiper use was 0 percent, except for when the temperature was greater than 2 degrees where it was 2 percent. Even though there was no rain during testing, during some CSW subsystem tests drivers turned on windshield wipers temporarily to affect alert timing by artificially simulating wet conditions.

APPENDIX C RDCW Data Analysis Tool and Logger Instruction Manual

Driver	Trip	Time	Speed	AccelPedal	Steer	Ax	LateralSpe	Ay
10	27	18130	18.13888	19	2.119825	-0.3008898	0.7199999	0.3
10	27	18140	18.19444	16	1.760685	-0.2471185	0.8	0.2
10	27	18150	18.13888	11	1.545258	-0.2471185	0.8599999	0.2
10	27	18160	18.19444	11	1.545258	-0.1993218	0.8799999	0.2
10	27	18170	18.22222	11	1.11454	-0.2232202	0.8799999	0.2
10	27	18180	18.22222	10	0.8274975	-0.3367373	0.8799999	0.1
10	27	18190	18.19444	10	0.6122707	-0.3427119	0.8799999	0.1
10	27	18200	18.13888	4	0.8274975	-0.3008898	0.8799999	0.1

Figure C-1: RDCW Multimedia Analysis Tool

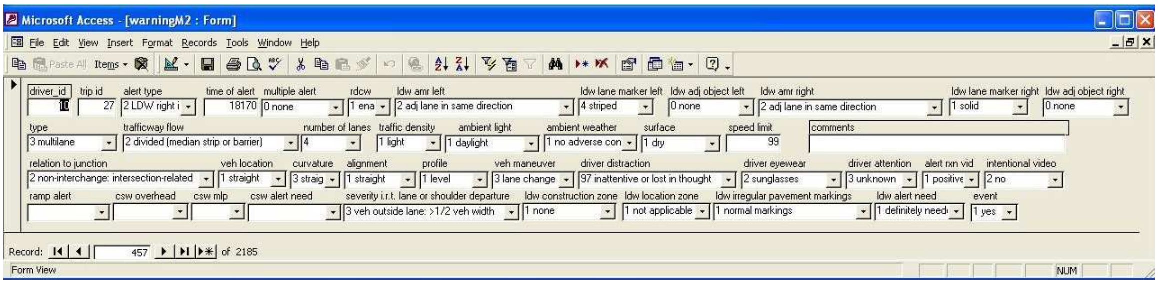


Figure C-2: RDCW Logger Form

Logger Variables

Event Information

Driver ID

Trip ID

RDCW enabled or disabled

- 0 = Disabled
- 1 = Enabled

Alert type

- 1 = LDW left imminent
- 2 = LDW right imminent
- 3 = CSW imminent

Alert time

- Integer input

Multiple Alerts

- 0 = none
- 1 = LDW alert preceded this alert
- 2 = CSW cautionary alert preceded this alert
- 3 = CSW imminent alert preceded this alert

Ambient Conditions

Light Condition

- 1 = Daylight
- 2 = Dark
- 3 = Dark but artificially illuminated
- 4 = Dawn or dusk
- 9 = Unknown

Weather

- 1 = No adverse conditions
- 2 = Rain
- 3 = Sleet
- 4 = Snow
- 5 = Fog
- 6 = Rain & fog

7 = Sleet & fog
8 = Other (smog, smoke, sand/dust, crosswind, hail)
9 = Unknown

Driver Characteristics

Alert Reaction Video
1 = Positive
2 = Negative
3 = No obvious reaction
4 = Unknown

Driver Attention
1 = On road
2 = Off road
3 = Unknown

Driver Distracted By
0 = Not distracted
1 = Looked but did not see
3 = By other occupants
4 = By moving object in vehicle
5 = While talking or listening to phone
6 = While dialing phone
10 = While using or reaching for other devices
11 = Sleepy or fell asleep
12 = Outside person or object
13 = Eating or drinking
14 = Smoking related
15 = While reaching to/adjusting center console
16 = RDCW
17 = Reading
18 = Grooming
19 = Checking mirrors/blind spot
97 = Inattentive or lost in thought
98 = Other distraction or inattention
99 = Unable to determine

Eyewear
1 = Prescription glasses
2 = Sunglasses
3 = None

Intentional Video
1 = Yes
2 = No
3 = Uncertain

Road and Lane Characteristics

Curvature
1 = Left turn

2 = Left curve
3 = Straight
4 = Right curve
5 = Right turn

Relation to junction

Non-interchange area

0 = Non-Junction
1 = Intersection
2 = Intersection-related
3 = Driveway, alley access, etc.
4 = Entrance/exit ramp
5 = Rail grade crossing
6 = On a bridge
7 = Crossover related
8 = Other, non-interchange
9 = Unknown, non-interchange

Interchange area

10 = Non-Junction
11 = Intersection
12 = Intersection-related
13 = Driveway, alley access, etc.
14 = Entrance/exit ramp
16 = On a bridge
17 = Crossover related
18 = Other location in interchange
19 = Unknown, Interchange area
99 = Unknown if Interchange

Trafficway Flow

0 = Not physically divided with center two-way left-turn lane (TWLTL)
1 = Not physically divided (2-way trafficway)
2 = Divided (median strip[3] or barrier)
3 = One-way trafficway
9 = Unknown

Number of travel lanes

1 = 1
2 = 2
3 = 3
4 = 4
5 = 5
6 = 6
7 = 7+
9 = unknown

Road alignment

1 = Straight
2a = Curve right
2b = Curve left

9 = Unknown

Road profile

1 = Level
2a = Grade up
2b = Grade down
3 = Hillcrest
8 = Sag
9 = Unknown

Road surface condition

1 = Dry
2 = Wet
3 = Snow or slush
4 = Ice
5 = Sand, oil, dirt
8 = Other
9 = Unknown

Posted speed limit

Integer input
99 = Unknown

Level of service

1 = Light
2 = Medium
3 = Heavy

Road type

1 = Freeway or expressway
2 = Ramp
3 = Multilane
4 = Single-lane
5 = Other

Vehicle conditions

Location

1 = Straight
2 = In curve
3 = Curve entry
4 = Curve exit
5 = Unknown

Maneuver

1 = Curve
2 = Going straight
3 = Lane change
4 = Merge
5 = Passing
6 = Turn
7 = Turn onto exit ramp
8 = unknown

Curve-Speed-Warning Video Information

CSW Road Characteristics

MLP versus true path

1 = Same
2 = Different

CSW Alert need

1 = Definitely needed
2 = Probably needed
3 = Not sure
4 = Probably not needed
5 = Definitely not needed

Ramp alert

0 = Not applicable
1 = On an exit ramp
2 = On an on ramp

Overhead structure present

0 = No
1 = Yes

Lateral-Drift-Warning Video Information

LDW Road and Lane Characteristics

AMR left

1 = Adjacent lane is in opposite direction
2 = Adjacent lane is in same direction
3 = No adjacent lane, available shoulder or mean: narrow (0–1 m)
4 = No adjacent lane, available shoulder or mean: medium (1–2 m)
5 = No adjacent lane, available shoulder or mean: wide (> 2 m)

Adjacent object left

0 = None
1 = Stationary vehicle
2 = Moving vehicle
3 = Jersey barrier
4 = Traffic barrel(s)
5 = Guardrail
6 = Sign or telephone pole
7 = Other
8 = Unknown

AMR right: see AMR left

Adjacent object: right see adjacent object left

Lane marker left

1 = Single solid
2 = Double solid
3 = Solid striped

4 = Striped
5 = Double striped
6 = Striped solid
7 = None

*Lane marker right***:** same as Lane marker left.

Severity in relation to lane or shoulder departure

1 = Vehicle remained in lane
2 = Vehicle departed lane by less than 1/2 vehicle width
3 = Vehicle departed lane by more than 1/2 vehicle width
4 = Vehicle changed lanes

Construction zone

1 = None
2 = Approaching
3 = In

Location of construction zone

1 = Not applicable
2 = Left
3 = Right
4 = Left and right

Irregular pavement markings

1 = Normal markings
2 = Divergent markings for lane split
3 = Convergent markings for lane merge
4 = Other peculiar lane marking

LDW Alert need

1 = Definitely needed
2 = Probably needed
3 = Not sure
4 = Probably not needed
5 = Definitely not needed

Event

0 = No
1 = Yes

Comment

Logger Instructions

Driver ID
Located in multiple locations including: left panel of "Now Playing" window, bottom of MDAT (last line with data source), and within the MDAT data table. The driver ID can also be found in the XML file name itself. Each video is labeled FOT.*driver#.trip#.episode#*.RDCW

Trip ID
Found in the same locations as Driver ID.

RDCW
Indication of whether the RDCW system is enabled or disabled is found in the "Trip Summary" panel on the left of the MDAT.

Alert Type
Play the video and watch the DVI. When the alert is issued note whether the imminent alert was LDW left, LDW right, or CSW. In the case of multiple alerts log each alert separately according to the rules defined for the multiple alert variable.

Alert Time
After viewing the video and noting the alert type scroll to the frame where the imminent alert is issued. Looking at the data table in the viewer portion of the MDAT, note the timestamp when the alert is issued.

Multiple Alerts
For an alert to qualify as a multiple alert situation it must meet one of the two following criteria:

1. LDW alerts occur within 2 seconds of each other **and** have the same source **and** involve the same maneuver.
2. CSW alerts occur within 10 seconds of each other **and** have the same source

Multiple alerts can occur in the same episode or in adjacent episodes.

Light Conditions
While viewing the video note the amount of ambient outside light. Headlight and tail light use by other cars can help determine the amount of light available if necessary. Tunnels or long underpasses should be marked with the lighting at the time of alert. Artificial illumination includes any man made lighting. Dawn or dusk should be marked for cases where it is clear lighting is transitioning between daylight and dark or vise versa.

Weather
Record atmospheric weather based on video observation and other cues such as wiper use.

Alert Reaction Video
Note driver reaction to the alert when the system was enabled. Silent alerts issued during the baseline period will not have a reaction. Identify basic cues for a negative reaction, such as lowered eyebrows, a frown, squinted eyes, or other indication of frustration or annoyance. Positive reactions tend to elicit a smile, a surprised facial expression, or a sigh of relief. If a driver reacts pleasantly after purposely eliciting an alert, this is a positive reaction. If the reaction is unclear for any reason, choose unknown.

Driver Attention

Note location of the drivers' eyes for the 5 seconds prior to and during the alert. If the driver appeared to be looking at locations other than the forward view for a particular instance for 1.5 seconds or more choose "off road", otherwise "on road". "unknown" includes situations where it is unclear if the driver was looking at the forward scene or elsewhere or where the drivers eyes are hidden by sunglasses or otherwise obscured.

Driver Distracted by

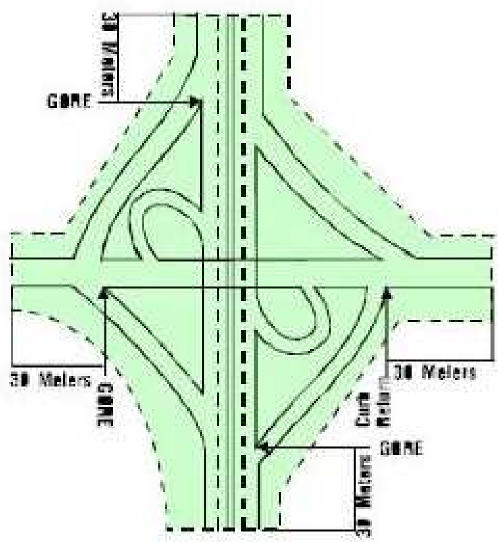
Watch the driver's actions, eyes, and face during the episode and note any distractions that occurred from the list. If more than one distraction exists, choose the distraction with the greatest collision potential and list the other distractions in the comment field.

> *0 = Not Distracted* - No obvious distraction
> *1 = Looked but did not see* – The driver is paying attention to the driving scene but does not appear to see the relevant vehicle or object
> *3 = By other occupants* – Attention directed toward other passengers, recognized by glances or talking when other passengers are visible
> *4 = By moving object in vehicle* – Subject moves unknown object, the object is not visible
> *5 = While talking/listening to phone* – Phone or earpiece visible
> *6 = While dialing phone* – Phone dialed and visible during episode
> *10 = While using/reaching for other devices* – Driver visibly using unknown object
> *11= Sleepy or fell asleep* – Obvious signs of fatigue (yawn, long blinking, droopy eyelids)
> *12 = Outside person or object* – Attention directed at other areas other than pertinent road information (forward scene, mirrors, blind spot)
> *13 = Eating or drinking* – Visible food, drink, or chewing
> *14 = Smoking related* – Any visible smoking activity
> *15 = While reaching to adjust center console* – Driver reaching toward center console
> *16 = RDCW* – Obviously viewing DVI or distracted by previous alert
> *17 = Reading* – Attention focused on reading material in view
> *18 = Grooming* – Any act of personal maintenance (itching, brushing, rubbing, etc.)
> *19 = Checking mirrors/blind spot* – Glancing at mirrors or blind spots, if not obvious, choose "98 – Other distraction or inattention" for inside object or "12- Outside person/object" for outside objects
> *97 = Inattentive or lost in thought* - A blank stare or obvious lack of focus on the driving situation
> *98 = Other distraction or inattention* – Any visible distraction which does not fit previous categories
> *99 = Unable to determine* – Video not available

Eyewear

During the video, note if the driver was wearing glasses or sunglasses.

Intentional Video
Note any indications that the driver purposely triggered an alert. Indications of intentionally provoked alerts include a smile of satisfaction after the alert or unexplained swerving accompanied by explanation to passenger.
Curvature
Record road curvature of the road the vehicle is traveling. A turn indicates a true turn (changed to new road) at an intersection or junction.
Relation to Junction
An interchange is the area around a grade separation, which involves at least two traffic ways as shown below. Included within its boundaries are all ramps which connect the roads and each road entering or leaving the interchange to a point 30 m beyond the gore or curb return at the outermost ramp connection for the road. An interchange differs from an overpass/underpass because an option to change roads has to be presented. An interchange allows the driver to choose between the two levels of grade separation. Intersection related pertains to the road approaching or exiting the intersection. After determining whether the alert occurred during an interchange or non-interchange area, identify any other characteristics of the road. Use unknown if unable to tell whether the alert occurred in an interchange or non-interchange.



Traffic Flow
At the moment of the alert, note the flow of traffic. A two-way-left-turn lane (TWLTL) is used in both directions for left turns only, usually bounded by a solid-striped line. A median is the area between two roads and excludes turn lanes.
Number of Travel Lanes
Count the number of lanes in the direction of travel at the instant of the alert. Count only full lanes, where a lane split occurs, if the lane is not useable at the moment of alert do not count it.
Road Alignment
At the moment of the alert, note the curvature of the road the car is traveling on. Even slight curves should be coded as curves.

Road Profile
At the moment of alert, note the pitch of the road. A hillcrest is the area at the peak of a hill, whereas sag is the opposite, the lowest point, the transition from grade down to grade up.

Road Surface Conditions
During the episode, note the conditions of the road.

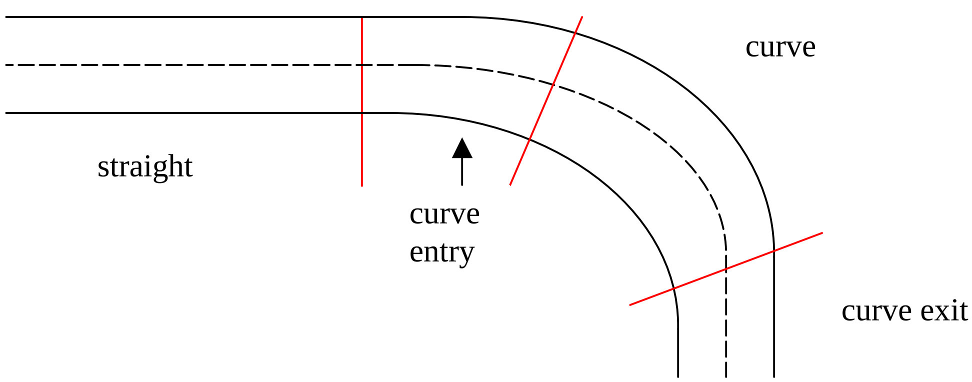
Posted Speed Limit
While watching the video, look for road signs indicating a speed limit, if no road sign is available, enter 99 for unknown.

Level of Service
This measure is based on a combination of vehicle speed for the road type and how crowded the road is with other vehicles. The traffic density corresponds to what the driver experiences.

Road Type
Observe number of lanes, lane markers, and if there is a median.

> *1 = Freeway or expressway* – 2 or more lanes in the direction of travel, divided, limited access
> *2 = Ramp* - On-ramp or off-ramp
> *3 = Multilane* – 2 or more lanes in each direction, open access
> *4 = Single lane* – Single lane in each direction
> *5 = Other* – Roads not meeting any of the above categories, explain in comments

Location
Vehicle location in relation to road curvature at the time of alert. Curve entry/exit are transitions of road curvature.



Maneuver

The vehicle maneuver at the time of alert. Describe the maneuver that occurred in the video, if more than one maneuver occurred choose the maneuver with the biggest impact on the alert. Certain actions take precedence, for example, “Lane Change” will take precedent over “going straight” or “curve.”

CSW Alert (only code for CSW alerts)

MLP
Compare the actual vehicle path with the Most Likely Path shown in the planar view of the MDAT, labeled 'MLP'. If vehicle goes straight while the MLP predicts a curve choose "different," otherwise if the values are in general agreement choose "same."
Alert Need
Alert need considers whether the alert was required given the situation at the time of alert. Situational measures include vehicle speed, lateral acceleration, road geometry, vehicle location, and the true path versus system MLP. For an alert to be judged as needed the driver must be approaching a curve and require deceleration to prevent a moderate level of lateral acceleration during the curve. To a much lesser extent driver attention can contribute to greater alert need if the driver was clearly not focused to the road as an alert was issued. On the other hand, alert need is not influenced for alerts when the driver appeared to be paying attention.
Ramp Alert
Indicate if the vehicle was traversing an on ramp or off ramp when the alert was issued. If the entire video episode takes place while negotiating a ramp but the type is not discernable choose "on a on-ramp."
Overhead
Indicate if the vehicle is under or approaching a significant overhead structure when the alert is issued. A bridge, overpass, or tunnel constitutes a significant structure.

LDW Alert (only code for LDW alerts)

AMR Left\Right
For the alert direction and time determine if an adjacent lane exists and what type. If no adjacent lane exists determine the amount of available shoulder present.
Adjacent Object Left\Right
Mark this category when objects occur in the direction of alert directly adjacent to the vehicle travel lane. If more than one object exists choose the object that poses the greatest threat.
Lane Maker Left\Right
Note the lane marker type for the alert direction that bounds the vehicle travel lane. Lane markers are labeled with respect to the host vehicle. For example, a solid striped line would indicate that there is no passing for the host vehicle.
Severity in Relation to Lane or Shoulder Departure
Determine if the vehicle departed the lane, partially, fully, or did not depart. Using the forward video if the lane marker goes beyond half the screen for the forward video, than it suggests the more than half the vehicle departed the lane.
Construction Zone
Indicate if the vehicle was in or approaching a construction zone when the alert was issued. Traffic barrels, construction signs, or other irregularities help indicate a construction zone.
Location of Construction Zone
If a construction zone was present, indicate the side(s) of the construction zone(s).

Irregular Pavement Markings
Choose the appropriate category of lane marking at the time of alert. An example of a peculiar lane marking would include no lane markers or temporary construction lane markings.

Alert Need
Alert need considers whether the alert was required given the situation at the time of alert. Situational measures include vehicle speed, position in relation to the road, road geometry, pavement markings, drift direction, and potential presence of an object in the drift direction. To a much lesser extent driver attention can contribute to greater alert need if the driver was clearly not focused to the road as an alert was issued. On the other hand, alert need is not influenced for alerts when the driver appeared to be paying attention.

All Alerts

Event
If alert was highly useful to the driver and enabled them to avoid a severe situation put a yes in the event field. Also indicate alerts where the system issued an alert due to highly unusual circumstances. Normal system errors should not be noted here but only cases where an alert was caused by conditions or a situation not seen previously. Also note if the driver performed any highly unusual maneuvers or actions or had a particularly strong positive or negative reaction to the alert or situation.

Comments
Here list any comments that will indicate anything odd or anything that could not be captured by the basic logger.

APPENDIX D Driver Acceptance Goals and Objectives

A 1997 NHTSA Report to Congress (NHTSA, 1997) stated that driver acceptance should be understood in terms of ease of use, ease of learning, adaptation, and perception. Building on NHTSA's definition of driver acceptance, the RDCW Independent Evaluation team created a framework to express the breadth and complexity of driver acceptance, identifying key aspects of driver acceptance. Collectively, these aspects of driver acceptance should answer whether the RDCW satisfies drivers' needs, requirements, and expectations.

In the present context, driver acceptance refers to the compatibility between drivers' understanding and expectations of RDCW operation, the degree to which drivers use RDCW output to improve their vehicle handling and driving safety, the comfort and safety drivers experience using RDCW, interest in acquiring RDCW, and perceptions of system setup and adjustments as easy and intuitive. Formed from these elements, the heuristic framework guided data collection and analysis.

The final driver acceptance framework modifies the preliminary driver acceptance framework proposed (Wilson et al., February 2002) and was revised as a result of meetings with, and input from, Volpe Center and NHTSA staff. The framework has five objectives. Each objective has several subobjectives, together forming a comprehensive picture of drivers' FOT experience using RDCW.

The Technology Acceptance Model developed by Davis and Bagozzi (Davis & Bagozzi, 1989; Davis, 1985) is widely used to understand user acceptance of computer technology and is applied to driver acceptance. The TAM explains how users come to accept and use a new technology. The TAM identified "perceived ease of use" and "perceived usefulness" as the important influences on technology acceptance. These categories were derived from the technology acceptance model described in the work done by Davis (1993, 1989). The TAM is developed from the field of information systems and describes the "relationships between system design features, perceived usefulness, perceived ease of use, attitude toward using, and actual usage behavior" (Davis, 1993). The Driver Acceptance Scale, a scaling technique developed and tested in Europe to assess acceptance of transportation (van der Laan, Heino, & de Waard, 1997) gives independent and convergent support for the TAM concepts.

Using the TAM and the Driver Acceptance Scale as precursors, two objectives in the RDCW Driver Acceptance Framework are designated "ease of use" and "perceived value." Ease of use focuses on drivers' encounters with RDCW expressed as the usability of its interface, individual variability in use patterns, and how understandable and intuitive drivers find the implementation. The perceived-value objective refers to whether drivers think that using RDCW improved their safety, comfort and driving skill and their tolerance of RDCW alarm issuance algorithms and the incidence of valid versus false alarms.

Because drivers need to learn as well as retain RDCW operational requirements, there needs to be an assessment of how easy it is to learn to use. The ease-of-learning objective documents how long it takes drivers to become competent RDCW users and whether drivers consider it easy to recall how the RDCW operates. Research has shown that simplified learning processes result in quicker acceptance of new technologies.(Kantowitz et al., 1996)

The driving performance objective assesses whether RDCW use had an effect on driving behavior, trip making, and vehicle use. It is intended to capture alterations in driving behavior, including risk compensation coincident with RDCW use. Driving performance also incorporates behavioral adaptation, i.e., “those behaviors, which may occur following the introduction of changes…which are not consistent with the initial purpose of the change” (Organisation for Economic Cooperation and Development, 1990).

The fifth objective, advocacy, examines whether sustained exposure to, and use of, the RDCW caused drivers to become interested in acquiring it. Advocacy is measured in several ways including willingness to accept RDCW in a rental vehicle, interest in purchasing the RDCW, level of trust felt for the RDCW capability, amount of money they would spend to acquire the RDCW, and interest in endorsing the RDCW. As part of the advocacy objective, analyses use the FOT data to estimate drivers’ interest in purchasing the RDCW.

Van der Laan and colleagues (van der Laan et al., 1997) developed a procedure to assess driver acceptance using subjective scales. After collecting scaled responses to advanced telematics using data from both simulation and on the road studies, factor analyses showed that the scaled responses formed two clusters described as usefulness and satisfaction. Scale scores on these two factors provide a summary measure of driver acceptance. The van der Laan scale scores provide face validity for the other driver acceptance measures.

Figure D-1 presents the five objectives used to examine driver acceptance of the RDCW.

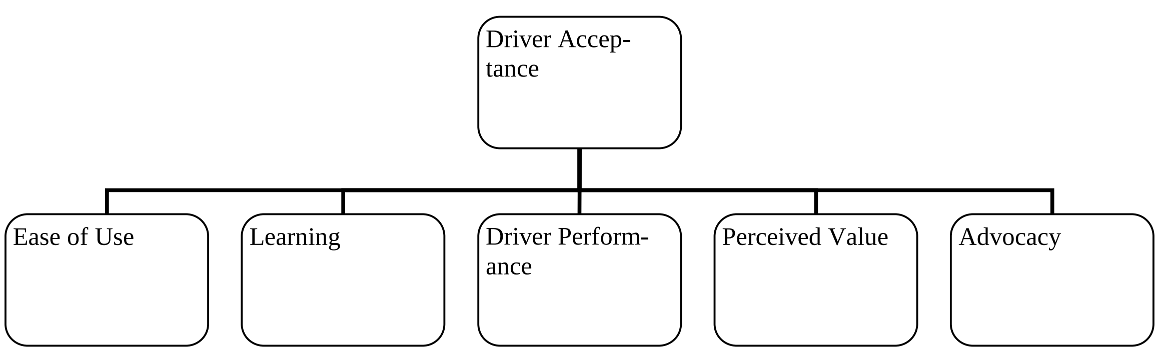


Figure D-1. Primary Driver Acceptance Objectives for RDCW Evaluation

The RDCW driver acceptance framework is similar to that of the Automotive Collision Avoidance System. The ACAS driver acceptance framework also has five objectives: ease of use, ease of learning, perceived value, advocacy, and driving performance. Four of the five objectives in the RDCW driver acceptance framework are identical to the ACAS framework; the ease-of-learning objective in the ACAS framework became one of the two subobjectives (see Subsection 5.2.3) under the learning objective for the RDCW framework. In addition, the ordering of the five objectives for the RDCW framework, from left to right, represent a temporal effect of driver acceptance where the advocacy objective is the final driver acceptance objective.

Ease of Use

There are four subobjectives for the ease-of-use objective:

- Demands on driver;
- Understanding of warning;
- Usability; and
- Use patterns.

Demands on Driver. Drivers must be able to parse the information provided by the RDCW to permit appropriate vehicle handling and maintain a reasonable workload. Ambiguous information or information that does not match drivers' processing speed will impede this process. Questions to be explored in this subobjective include:

- How is driver workload and stress level affected by responding to RDCW?
- Do LDW and CSW warnings provide enough "environmental affordance" (i.e., the format of the input provides all the information users need to understand what it is and how to use it) to be understood quickly?
-

Understanding Warnings. Drivers vary in cognitive processing and reaction to events. RDCW gives drivers additional multi-sensory information that they must detect, validate, process, and use to initiate a course of action. This subobjective examines whether drivers can process and respond to the RDCW warnings quickly. Drivers improve their chances to avoid potential conflicts when they can quickly interpret the meaning of the warnings.

Usability. The RDCW should provide drivers with useful information to which drivers are able to respond. This subobjective addresses issues related to the RDCW design, including the information display panel and the sensitivity adjustment switches. Questions from the post-drive survey that cover this subobjective include:

- Was the RDCW display panel located at a suitable location?
- What was driver feedback regarding the sensitive adjustment switches?

- Did FOT participants made any suggestions on the design of the RDCW?

<u>Use Pattern.</u> This subobjective examines how drivers use the two RDCW subsystems: LDW and CSW. Do drivers change the sensitivity setting for the LDW and CSW subsystems? How often do drivers change the sensitivity setting and for what reasons?
<u>Learning</u>. Two subobjectives are under the learning objective: ease of learning and time to learn.

Ease of Learning. Since the RDCW only issues warnings and does not control any portion of the vehicle, one needs to understand how well drivers learn to integrate the RDCW with vehicle handling. This subobjective examines how well drivers learn to use the RDCW the way it is intended and if they reported any difficulty learning to operate the RDCW.

Time to Learn. Drivers must learn the capabilities and limitations of the RDCW and how to interpret and apply its warnings. How long does it take for a driver to feel comfortable with the operations of the RDCW? Driving has its own requirements and, with the introduction of the RDCW, additional demands are placed on the drivers.

Driver Performance

<u>Subobjectives</u> Use of the RDCW can lead to changes in driving behavior as drivers come to rely on it. Some drivers may become too accustomed to it and use it in unforeseen ways. For example, if drivers become overly reliant on the RDCW, the driver could assume riskier driving behavior such as driving at a higher speed on curving roads. Driving changes are more likely to occur after a period of time. The introduction of a new device can have a novelty effect during initial usage. With continuing use, the driver behavior should stabilize. It is important to observe changes in driving behavior as consequences of RDCW use.

There are three listed under the driver performance objective:

a. Awareness;
b. Driving style adjustments; and
c. Trip patterns.

Awareness. This refers to drivers' ability to maintain the vigilance necessary to operate the vehicle in a safe and efficient manner. It is important to know if the inclusion of the RDCW changes drivers' awareness while operating vehicles.

Driving Style Adjustments. This subobjective refers to changes in driving behavior following the introduction and exposure to the RDCW. There could be a range of responses to the alerts provided by the RDCW. Some of the questions related to this subobjective include:

- How do drivers integrate the RDCW usage into their everyday driving?

- Do drivers use the RDCW in unintended ways?

Trip Patterns. This subobjective examines the trips taken by participants during the FOT and how their travel may influence their perception of the RDCW. Data used to examine the *trip patterns* subobjective come from DAS.

Perceived Value. There are three subobjectives listed under the perceived value objective:

a. Safety;
b. Driving skill; and
c. Tolerance of warnings.

Safety. This subobjective measures whether drivers think the RDCW helps them to become safer drivers and, if so, the areas of safety improvement. It is important to distinguish the safety benefit of a new vehicle technology from the perspective of drivers versus system developers.

Driving Skill. This subobjective investigates the influence of RDCW use on driver activities. RDCW has the capability to make driving performance more consistent by reducing variance in lane position and speed and may also enhance drivers' attentiveness while operating their vehicles. Some of the questions that are answered by this subobjective include:

- Did drivers use turn signals more frequently as a result of the LDW subsystem?
- Did drivers tend to slow down more when approaching curves as a result of the CSW subsystem?

Did the RDCW improve study participants' driving experience during various environmental and traffic conditions?

Tolerance of Warnings. This subobjective looks at whether drivers perceived RDCW warnings to be valuable. The probability of a driver observing the warnings and modifying driving increases if the driver sees the warnings as valuable information sources. Responses to several post-FOT survey questions capture participants' views about the warnings:

- Whether they were annoyed with the frequency of the LDW/CSW subsystem warnings.
- Whether they received any unnecessary or false warnings.

Advocacy. To be accepted, drivers need to think that the benefits of the RDCW outweigh the costs. Advocacy examines whether sustained exposure to, and use of, the RDCW resulted in drivers expressing an interest in acquiring, or endorsing the use of, the RDCW. The subobjectives for advocacy are: interest in purchasing, amount willing to pay, and willingness to endorse.

Interest in Purchasing. Does sustained use of the RDCW result in drivers expressing an interest in buying an RDCW-equipped vehicle? Drivers' interest in buying the system is a proxy for their valuation of the device. The post-FOT survey asked participants whether they would purchase the RDCW device as an option.

Amount Willing to Pay. This subobjective further explores advocacy by asking participants how much they would be willing to pay to acquire the RDCW. This subobjective provides an indication of the "value" of the RDCW from the driver's perspective.

Willingness to Endorse. A driver may view the RDCW as beneficial, but may not be willing to endorse its use to others. This subobjective examines the RDCW features that influence drivers' decisions to endorse the system.

APPENDIX E Driver Acceptance Methodology

This section describes the methods implemented to gather the RDCW FOT data related to driver acceptance, from recruiting FOT participants and data collection procedures to types of data collected and data analysis techniques.

Sampling and Recruitment

UMTRI implemented the RDCW FOT and recruited suitable study participants, using the following procedures:

- Obtained names and addresses of licensed drivers from the Michigan Department of State, the driving license bureau. The request for names was limited to drivers who resided in the adjacent counties in the southeastern part of Michigan. These counties represent major metropolitan and rural areas.
- UMTRI mails postcards emblazoned with the University of Michigan logo to potential participants announcing the RDCW FOT and asking for participation. UMTRI estimates a 10- to 15-percent response rate to the postcards.
- When a potential participant calls the toll-free number on the postcard, an UMTRI research staffer conducts a telephone interview with the potential participant to ask a number of questions including annual vehicle mileage traveled and health status. At the end of the telephone interview, the UMTRI staffer informs the potential participant whether they have been selected for the RDCW FOT.

Based on prior experience in FOTs, UMTRI researchers estimated that the yield is approximately 10 responses from every 100 postcards mailed. Usually, 1 out of the 10 people who responded to the FOT postcard is a good match with the selection criteria of VMT per year, age, gender, and health condition. The experimental design for the RDCW FOT requires 78 study participants balanced by age and gender and equal cell size. The participants are sorted into 6 cells, 13 per cell, with equal representation of age and gender. There are 13 younger males and females (20 to 30 years old), 13 middle-aged males and females (40 to 50 years old), and 13 older males females (60 to 70 years old).

When selected, if a potential participant agrees to participate in the FOT after the telephone interview, UMTRI staff schedules a date and time for the participant to come to the UMTRI facility, attend a pre-FOT orientation and pick up the FOT vehicle. Approximately one week before the pre-FOT orientation, UMTRI mails a project information package to participants. The package contains a project information letter, consent form, pre-FOT questionnaire asking for demographic and driving pattern data, and directions to UMTRI. Participants are expected to review the information package and complete all required forms before they arrive for the orientation.

Data Collection and Process

Data for the driver acceptance analyses is gathered from the stages of the FOT: pre-FOT orientation, during the FOT (26 days), post-FOT debriefing session, and focus group meeting (if participants elected to attend one of the four meetings held at UMTRI during FOT).

Pre-FOT Orientation. When a participant arrives at UMTRI to pick up the FOT vehicle, project staff escort the participant to a meeting room equipped with computer, VCR players, and television monitor. The key activities during the pre-FOT orientation include:

- UMTRI research staff member checks the driver's license of the each participant to verify the driver's identity and provide contact information with UMTRI during the FOT.
- The participant returns the completed background, driving habit questionnaires, and consent form. UMTRI staff review the consent form with the participant and ask for a signature.
- The participant watches a 20-minute training video describing the RDCW and the FOT vehicle.
- The participant takes the 20-minute Useful Field of View test, a computer-administered and scored test of visual attention. This test is used to help predict the degree to which the participant can perform everyday activities safely, such as driving a vehicle.
- The UMTRI staff review with participant the FOT guidelines and answer questions related to the FOT, such as how the driver should contact UMTRI in case of a traffic accident, and the requirement that the vehicle cannot be taken outside of the United States. .
- The UMTRI staff member walks participants to the UMTRI facility parking lot and assign RDCW test vehicles. UMTRI staff review the vehicle with the participant to point out control buttons and equipment related to the RDCW; explain that the RDCW may not be available at all times depending on road conditions, driving speeds, and GPS coverage; demonstrate the graphic displays of the RDCW; and point out the locations of paperwork and cell phone in the vehicle. UMTRI staff point out that the LDW and CSW subsystems will not activate until the driving speed exceeds 25 and 18 mph, respectively.
- A UMTRI staff person accompanies the participant on a 30-minute demo drive using a pre-defined route, so the driver can become familiar with vehicle operation and the RDCW. The participant gets to see, hear, and feel the LDW and CSW warnings during the demo drive.
- The UMTRI staff and participants return to the UMTRI facility after the demo drive and the FOT vehicle is released to the participant for the next 26 days.

Data gathered from the background and driving habit questionnaires, including age, gender, employment status, occupation, education level, years of driving, and annual miles driven, is used in the driver acceptance analysis.

FOT. During the 26-day period when participants have the FOT vehicle, the data acquisition system in the vehicle records information on the RDCW, vehicle operation and performance, driver activity, and driving environment. Although the RDCW operation is disabled during the first 6 days, the RDCW operates in the background. The DAS records the same type and amount of information as during the 20 days when the RDCW is enabled.

At the completion of the FOT, when participants return the FOT vehicles to the UMTRI facility, the RDCW project personnel checks the quality of the DAS data and transfers the data to UMTRI's mainframe computer dedicated to the RDCW project.

A portion of DAS information is used for the driver acceptance analysis, including variables such as trips taken, distance driven by participants during the FOT, and LDW and CSW warnings issued.

Post-FOT Debriefing Session. Upon completion of the FOT, participants return the FOT vehicles to UMTRI and spend approximately 2 hours at the facility to provide their views of the RDCW.

One of the primary activities participants do during the post-FOT debriefing session is complete the post-drive survey, which consists of three major and two minor sections with a total of 146 questions:

- Manual Driving, 5 questions;
- Overall RDCW (LDW & CSW) Questionnaire and Evaluation, 37 questions;
- Lateral-Drift Warning Questionnaire and Evaluation, 50 questions;
- Curve-Speed Warning Questionnaire and Evaluation, 50 questions; and
- Participant Handling, 4 questions.

The post-drive survey is designed to capture participants' perceptions of RDCW and their experience with the system. Most survey questions ask participants to provide responses in the form of the Likert scale with "1" usually representing "strongly disagree" and "7," "strongly agree." There are also open-ended questions where participants provide written comments. A few survey questions ask participants to make one or more choices from a list of alternatives.

After participants complete the post-drive survey, an UMTRI project staff conducts a quality check of their responses and reviews the responses to selected questions to ensure that questions were interpreted accurately. At this time, participants are encouraged to provide additional verbal comments describing their experiences with the RDCW.

Participants are also asked to review approximately 12 video clips selected from the RDCW warnings they received. When the video clips are played for the participants, the monitor shows a screen split simultaneously showing the road situation, driver's face when imminent alerts were received, a map with the vehicle's location at the time of the issuance of the warning, and a chronological list of the RDCW warnings issued.
After reviewing a video clip, the UMTRI staff ask the participant to rate each warning played retrospectively as either "useful" or 'not useful," rate the value of the warning ("1" to "5", "1" = Not at all useful, "5" = Quite useful), and to describe why they thought they received each alert. Of the 12 video clips reviewed by the FOT participants, 6 are LDW warnings and 6 are CSW warnings.

Upon completion of the video clip review, UMTRI project staff thank participants and pays them $250 for their participation of the RDCW FOT.

Focus Group Meeting. After taking part in the FOT, participants are invited to take part in one of four focus groups to discuss their experiences with the RDCW. During each focus group meeting, a predetermined set of questions is used for discussion among the attendees, with a researcher from UMTRI facilitating the discussion. All focus group meetings are videotaped and participants' comments are transcribed. Focus groups are held at intervals throughout the FOT to minimize the time between participating in the field test and taking part in a focus group. Not all FOT subjects participated in the focus group meetings; however, those who did attend the focus group meetings were paid an additional fee. Questions used to facilitate discussion in the focus group meetings are provided in Appendix F.

Analyses of Data From Surveys, Debrief Sessions, and Focus Groups

The driver acceptance analyses are based on subjective data gathered via surveys, debriefing sessions, and focus groups. This part of Section 5 describes the data analysis methods for the subjective data.

Descriptive Statistics and Graphs. Descriptive statistics provide summary information about the survey responses of FOT participants. One or more of the following descriptive statistics are calculated for the survey responses:

- Mean;
- Standard deviation;
- Median;
- Mode; and
- Range.

In addition, bar charts and line graphs are also generated to illustrate trends in survey responses.

Pre-FOT Questionnaire. Descriptive statistics for the following pre-questionnaire variables are calculated:

- Times at work – a.m. versus p.m.;
- Occupation – employed versus home/retired;
- Highest education level completed – high school, college, or graduate school;
- Age – younger, middle-aged, and older;
- Years of driving experience;
- Miles driven in the past year – below median versus equal to and above median; and
- Glasses/contacts – yes or no

Post-Drive Survey. Descriptive statistics are calculated for most of the post-FOT survey questions that asked for quantitative responses, for example, responses given in the 7-point Likert scale. Bar charts/line graphs are also plotted for some questions.

Descriptive statistics and plots of the responses to the post-FOT survey questions are presented in Sections 5.5, 5.6, and 5.7 of this chapter for the RDCW, LDW, and CSW, respectively.

Analysis of Variance. ANOVA is used to assess how nominal independent variables affect a dependent variable. ANOVA is also used to compare population means, with the simplest comparing population means between two groups. For the RDCW FOT data, ANOVA is applied to compare mean responses to survey questions by groups, for example, younger drivers, middle-aged drivers, and older drivers. In Section 5.5, 5.6, and 5.7, RDCW, LDW, and CSW are examined, respectively, in terms of ease of use, learning, driver performance, perceived value, and advocacy.

Qualitative Analysis. Several post-drive survey questions asked participants to provide written responses. Besides qualitative data from the post-drive survey and debriefing session, the RDCW project team at UMTRI held four focus group meetings. Qualitative information from the post-FOT survey, post-drive debriefing sessions, and focus group meetings provide supplemental information and help to interpret participants' perception of the RDCW.

Objective Data from the Data Acquisition System

Objective data for the RDCW FOT is gathered by the on-board data acquisition system. Information gathered by DAS includes operational and performance data for the vehicle as well as the RDCW.

For the purpose of driver acceptance analysis, a portion of objective data from DAS is used to validate and supplement the subjective data. Information captured by DAS useful for the driver acceptance analyses includes:

- Trips made by participant (total, RDCW baseline, and RDCW treatment);

- Distance (in kilometers) driven by participant (total, RDCW baseline, and RDCW treatment);
- Hours driven by participant (total, RDCW baseline, and RDCW treatment);
- Mean trips taken by participant per day;
- Mean distance (in kilometers) driven by participant per day;
- Mean hours driven by participant per day;
- Mean distance (in kilometers) driven by participant per trip;
- Mean hours driven by participant per trip;
- Number of LDW warnings by FOT participant when RDCW was disabled versus enabled;
- Number of CSW warnings by FOT participant when RDCW was disabled versus enabled; and
- LDW and CSW warnings per 100 kms when RDCW was disabled versus enabled.

Summary statistics and plots of the DAS data are presented in Section 5.4. The DAS data statistics and plots reveal driver activity and RDCW warnings issued during the FOT.

Setup for the Subjective and Objective Database

Upon completion of the RDCW FOT, the UMTRI research team made available the subjective and objective data to the Volpe Center independent evaluation team. The Volpe team consolidated information into the driver acceptance database. The following is a list of data integrated into Volpe Center's RDCW project database for the driver acceptance analyses:

- *Pre-FOT Survey Data.* The UMTRI project team entered the pre-FOT survey data into an Excel file. Before the pre-FOT survey data was delivered to the Volpe Center, UMTRI team members performed quality checks on the information. The pre-FOT data was integrated into the Volpe Center RDCW driver acceptance database.
- *Post-FOT Survey Data.* UMTRI provided hard copies of all post-FOT surveys to the Volpe Center independent evaluation team. Following the data-coding scheme established by the Volpe Center researchers, members of the independent evaluation team entered the post-FOT survey data in an Excel file. Volpe Center staff performed quality checks to correct data entry errors. Finally, the Volpe Center database was sent to UMTRI to compare against its data before being used in the driver acceptance analyses.
- *Post-FOT Debriefing Notes*. Members of the Volpe Center independent evaluation team participated in all post-FOT debriefing sessions, mostly via telephone. The Volpe Center independent evaluation team

reviewed the debriefing session notes, including ratings of the 12 video clips.

- *Focus Group Meeting Notes.* UMTRI provided transcripts from the four RDCW focus group meetings. The Volpe Center research team reviewed the focus group transcripts and notes, selected participants' comments that are pertinent to the driver acceptance analysis, and organized the comments per five driver acceptance objectives.
- *DAS Data*. The objective data collected by DAS was delivered to the Volpe Center in batches, due to the size of the data, using external hard drives. After the DAS data arrived, Volpe Center team members transferred this objective data to the RDCW project storage drives, using a predefined data storage structure. Criteria were applied to filter out any "invalid" objective data. Computer programs were written to extract information needed for the driver acceptance analysis. DAS data for the driver acceptance analysis was imported into an Excel file.

Driving Behavior of FOT Participants versus National Data

This section compares FOT participants' travel to national estimates in terms of trips per day, distance driven per year, and minutes driven per day. The national travel behavior data is extracted from the 2001 National Household Travel Survey because the age and gender categories from the survey matched well with the RDCW FOT. The 2001 NHTS data is available online at **http://nhts.ornl.gov/2001/index.shtml**.

NHTS provides an inventory of the nation's daily and long-distance travel. The survey includes demographic characteristics of households, people, vehicles, and detailed information on daily and longer-distance travel for all purposes by all modes. The data links the characteristics of personal travel to the demographics of the traveler and these relationships provide a foundation to better understand how the transportation systems serve the public. NHTS survey data is collected from a sample of U.S. households and expanded to provide national estimates of trips and miles by travel mode, trip purpose, and a host of household attributes. The 2001 NHTS dataset has responses from approximately 66,000 households.

Figure E-1 compares mean trips per day by RDCW FOT participants to the 2001 NHTS. For comparable age-gender groups, the results shown in Figure E-1 suggest that UMTRI successfully recruited participants who made more trips per day than the national mean for all age and gender groups. Most notable are the differences in the younger age groups; younger drivers in the FOT drove approximately 30 percent more than younger drivers in the NHTS. Results shown in Figure E-1 imply that the data collected from the 78 RDCW FOT participants represent and over-represent the national travel behavior in term of trips per day.

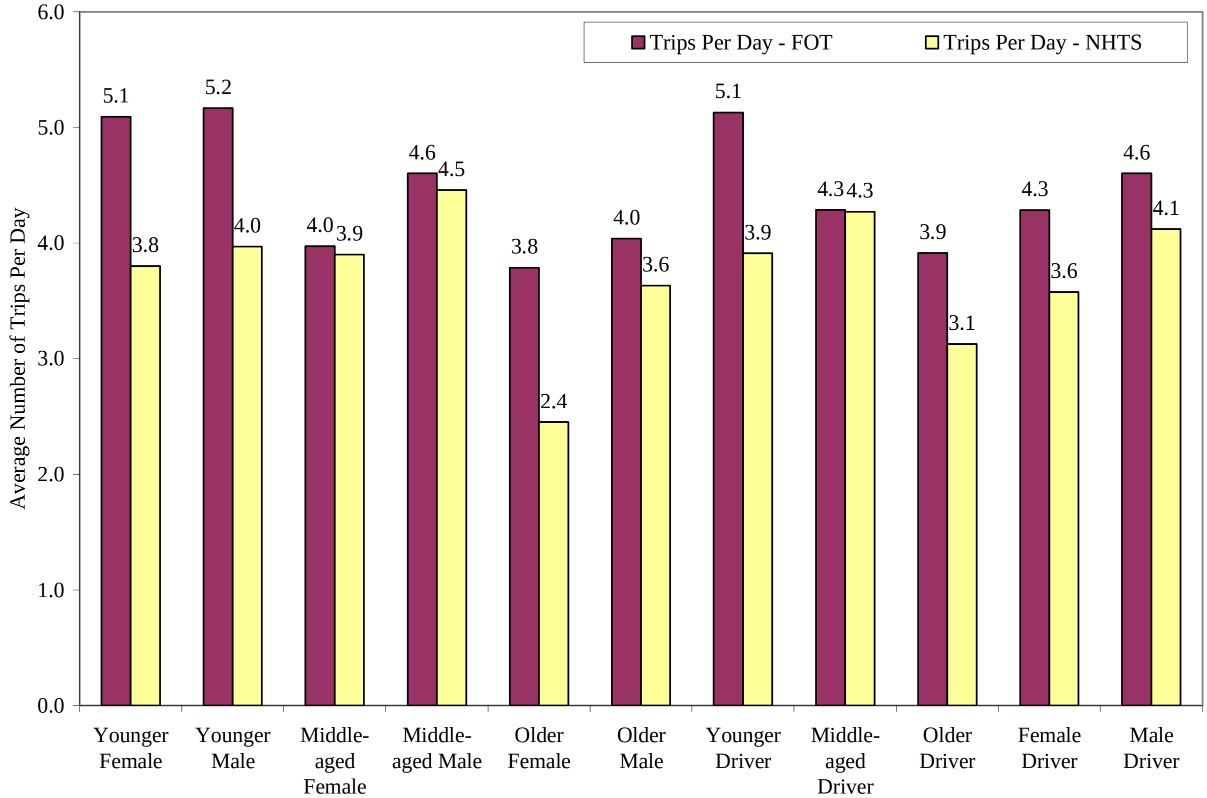


Figure E-1. Comparison of Trips per Day Between RDCW FOT Participants and NHTS

Figure E-2 shows the VMT estimated for the RDCW FOT participants, extrapolated to annual values, compared to the estimates calculated from the 2001 NHTS. Male participants in the RDCW FOT drove fewer vehicle miles compared to the national average. The difference is especially obvious for the FOT middle-aged male driver category, with estimated 16,857 annual vehicle miles traveled compared to NHTS average of 19,429 miles. The female drivers in the FOT drove more than the national estimates in all age categories.

Figure E-3 compares driving-minutes per day, by age-gender categories for the FOT participants and NHTS. Middle-aged and older driver groups in the RDCW FOT spent less time driving their vehicles compared to their NHTS counterparts. On average, for those who drove on their travel day:

- The NHTS middle-aged driver group drove 85 minutes per day compared to 75 minutes per day for the FOT participants;
- Older drivers in the NHTS drove 81 minutes per day compared to 60 minutes per day for the FOT participants.

Other than older males, the driving of the FOT participant groups tracks that of the national population. The VMT data in Figure E-2 and the minutes per day data in Figure E-3 shows a close correspondence between the FOT participant groups and the NHTS data. As for older males, the minutes per day discrepancy shown in Figure E-3 may be due to the geographical restriction imposed on the participants.[13] The FOT data do not suggest any limitations in extrapolating participant driving changes to the national population.

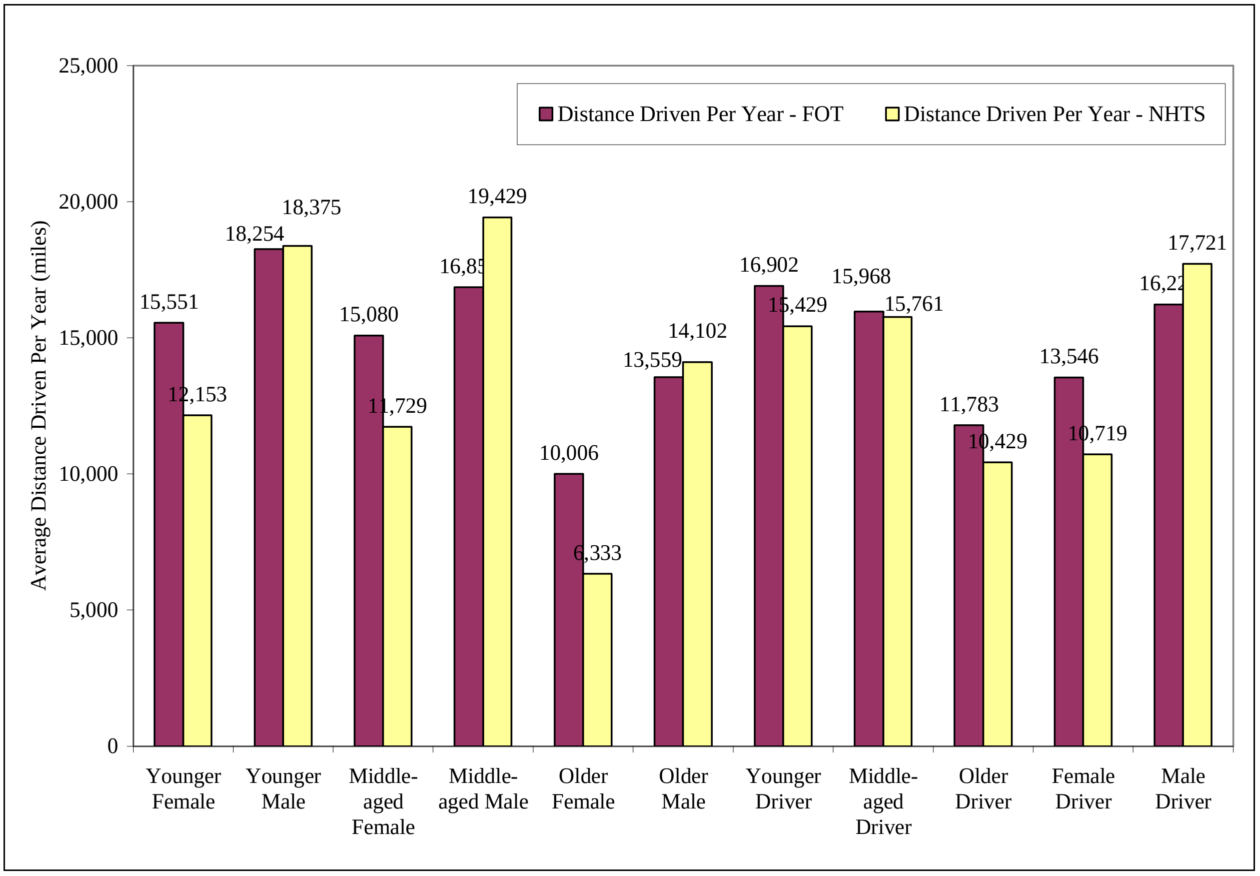


Figure E-2. Comparison of VMT (Estimated) per Year Between RDCW FOT Participants and NHTS

[13] RDCW FOT participants were instructed not to drive outside the geographic area that was not covered by the on-board GPS system. Consequently, this restriction may have eliminated some long-distance trips that participants could have taken during the FOT.

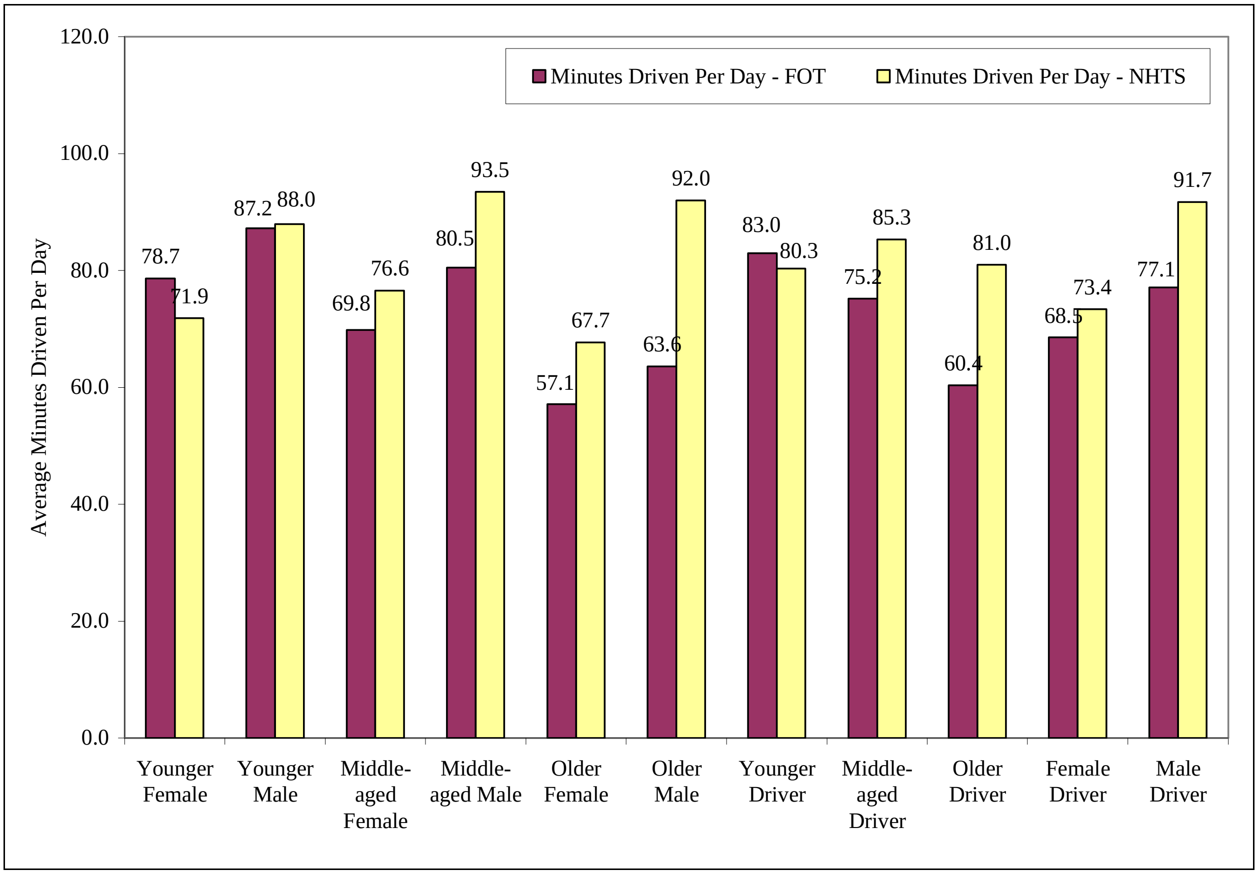


Figure E-3. Comparison of Minutes Driven per Day Between RDCW FOT Participants and NHTS

APPENDIX F Questions Used for Focus Group Discussion

1. Overall, did you feel more or less comfortable in a vehicle with the RDCW system?
2. Overall, did you feel more or less safe using the RDCW system?
3. Was the system intuitive to use?
4. Overall, what do you think about how the information was conveyed?
5. How easy was it for you to remember what each warning meant?
6. How many times a month do you come close to leaving your lane unintentionally?
7. How often did you encounter situations where you felt the LDW was useful?
8. Were there situations when you got an alert when you were not paying enough attention?
9. Were there any situations when the LDW may have prevented an accident?
10. 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?
11. Were there situations when you did not get an alert when you felt one was required?
12. (Added question) Did you experiment with LDW?
13. Overall, did you think LDW alerts were useful?
14. Would you have turned LDW off if you could have? If so, when and why?
15. When you got an imminent LDW alert, what did you typically do? Apply the brakes, check the traffic, or simply ignore the alert?
16. Did the way you responded to the alerts change with more LDW experience?
17. Do you think the LDW cautionary alert (when the seat vibrated) affected how you stayed in your lane? If so, how?
18. 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?

19. Do you think that LDW will prevent drivers from leaving their lanes?

20. Do you think LDW made you a safer driver? Did you drive more or less aggressively?

21. Are there other ways you think LDW may have changed the way you drove?

22. Did LDW perform in the way you expect it would if you bought this feature? If not, how should LDW perform differently?

23. What needs to be different before LDW becomes a product?

24. Would you buy the LDW? If not, why not? If so, why? (Money is not a concern.) Now, considering the cost of LDW.

25. How would you suggest improving the LDW?

26. How many times a month did you approach a curve too fast?

27. How often do you encounter situations where you felt that the CSW was useful?

28. Were there situations when you got an alert because you were not paying enough attention?

29. Were there any situations when the CSW may have prevented an accident?

30. 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?

31. Were there situations when you did not get an alert but felt one was required?

32. Overall, did you think CSW alerts were useful? When (if ever) were the CSW alerts useful?

33. Would you have turned CSW off if you could have? If so, when and why?

34. When you got an imminent CSW alert, what did you typically do? Apply the brakes, check the road geometry, or simply ignore the alert?

35. Did the way you responded to the alerts change with more CSW experience? If so, how?

36. Do you think the CSW cautionary alert (when the seat vibrated) affected your speed as you approached a curve? If so, how?

37. What did you think of the timing of the CSW imminent alert (when you heard "Curve, Curve")? Was it too early, too late?

38. Do you think that CSW will prevent drivers from approaching curves too fast?

39. Do you think that CSW made you a safe driver? Did you drive more or less aggressively?

40. Are there other ways you think that CSW may have changed the way you drove?

41. Did CSW perform in the way you expect it would if you bought this feature? If not, how should CSW perform differently?

42. Would you buy the CSW? If not, why not? If so, why? (Money is not a concern.) Now, considering the cost of CSW.

43. How would you suggest improving the CSW?

Mapping of Focus Group Topics to Driver Acceptance Framework	RDCW	LDW	CSW
Ease of Use	1.Overall, did you feel more or less comfortable in a vehicle with the RDCW system?		
Perceived Value: Safety	2.Overall, did you feel more or less safe using the RDCW system?		
Learning	3.Was the system intuitive to use?		
Ease of Use: Usability	4.Overall, what did you think about how the information was conveyed?		
Learning: Ease of Learning	5.How easy was it to remember what each warning meant?		
Driver Performance		6. How many times a month do you come close to leaving your lane unintentionally?	25.How many times a month do you approach a curve too fast?
Perceived Value:Safety		7.How often did you encounter situations where you felt the LDW system was useful?	26.How often did you encounter situations where you felt the CSW system was useful?
Perceived Value: Driving Skill Enhancement		8.Were there situations when you got an alert when you were not paying enough attention?	27. Were there situations when you got an alert when you were not paying enough attention?
Perceived Value: Safety		9.Were there any situations when the LDW system may have prevented an accident?	28. Were there any situations when the CSW system may have prevented an accident?
Perceived Value:Tolerance of Warnings		10. When (if ever) did you find false alarms annoying?	29. When (if ever) did you find false alarms annoying?
Ease of Use		11. Were there situations when you did not get an alert when you felt one was required?	30. Were there situations when you did not get an alert when you felt one was required?
Advocacy: Advocacy Overall		12. Overall, did you think LDW warnings were useful?	31. Overall, did you think CSW warnings were useful?
Advocacy: Advocacy Overall		13. Would you have turned LDW off if you could have?	32. Would you have turned CSW off if you could have?
Driver Performance: Driving Style Adjustments		14.When you got an imminent LDW alert, what did you typically do?	33.When you got an imminent CSW alert, what did you typically do?
Learning: Time to Learn		15. Did the way you responded to the alerts change with more LDW experience?	34. Did the way you responded to the alerts change with more CSW experience?
Driver Performance		16. Do you think the LDW cautionary alert (when the seat vibrated) affected how you stayed in your lane?	35.Do you think the CSW cautionary alert (when the seat vibrated) affected your speed as you approached a curve
Ease of Use: Usability		17. What did you think of the timing of the LDW imminent alert (when you heard the rumbling sound)?	36.What did you think of the timing of the CSW imminent alert (when you heard “Curve, Curve”)?
Driver Performance: Trip Pattern		18. Do you think that LDW will prevent drivers from leaving their lane?	37. Do you think that CSW will prevent drivers from approaching curves too fast?
Perceived Value: Safety		19.Do you think LDW made you a safer driver?	38.Do you think CSW made you a safer driver?
Driver Performance		20.Are there other ways you think LDW may have changed the way you drove?	39.Are there other ways you think CSW may have changed the way you drove?
Advocacy: Willingness to Endorse		21.Did LDW perform in the way you would expect it to if you bought this feature?	40. Did CSW perform in the way you would expect it to if you bought this feature?

APPENDIX G Driving Statistics of the 78 FOT Participants – Recorded by DAS

Subject No.	Gender	Age Group	FOT Days	Trips – RDCW Disabled	Trips – RDCW Enabled	Total Trips	Distance Driven – RDCW Disabled	Distance Driven – RDCW Enabled	Total Distance (km)	Total Hours	Trips/ Day	Km/Day	Hours/ Day	Km/Trip	Hours/ Trip
1	F	M	26	11	50	61	293.60	907.36	1,200.96	23.05	2.35	46.19	0.89	19.69	0.38
2	F	M	26	13	66	79	434.30	1,851.29	2,285.59	33.95	3.04	87.91	1.31	28.93	0.43
3	F	M	26	38	121	159	365.20	1,980.79	2,345.99	39.37	6.12	90.23	1.51	14.75	0.25
4	M	O	26	28	65	93	267.03	436.18	703.22	16.55	3.58	27.05	0.64	7.56	0.18
5	M	M	26	40	124	164	645.03	1,976.42	2,621.45	48.38	6.31	100.83	1.86	15.98	0.30
6	F	O	26	36	88	124	641.83	1,102.58	1,744.41	40.12	4.77	67.09	1.54	14.07	0.32
7	F	M	26	8	68	76	181.57	961.10	1,142.67	24.83	2.92	43.95	0.96	15.04	0.33
8	M	M	26	33	165	198	251.17	1,662.53	1,913.70	34.95	7.62	73.60	1.34	9.67	0.18
9	F	O	26	23	42	65	172.72	282.46	455.18	9.48	2.50	17.51	0.36	7.00	0.15
10	M	O	26	11	43	54	177.82	450.62	628.44	15.23	2.08	24.17	0.59	11.64	0.28
11	F	Y	26	50	132	182	706.90	1,539.26	2,246.16	50.02	7.00	86.39	1.92	12.34	0.27
12	M	O	26	28	123	151	669.27	2,167.08	2,836.35	38.87	5.81	109.09	1.49	18.78	0.26
13	F	M	26	66	109	175	623.79	1,479.74	2,103.53	39.78	6.73	80.90	1.53	12.02	0.23
14	F	M	26	24	57	81	354.68	1,461.91	1,816.59	29.92	3.12	69.87	1.15	22.43	0.37
16	M	O	26	21	47	68	381.70	1,509.58	1,891.29	27.77	2.62	72.74	1.07	27.81	0.41
17	F	M	26	37	130	167	816.03	2,114.87	2,930.91	46.25	6.42	112.73	1.78	17.55	0.28
19	F	M	26	7	42	49	122.44	421.72	544.16	12.57	1.88	20.93	0.48	11.11	0.26
20	F	Y	26	61	164	225	618.71	787.80	1,406.51	42.40	8.65	54.10	1.63	6.25	0.19
21	M	M	26	26	23	49	538.30	979.57	1,517.88	27.83	1.88	58.38	1.07	30.98	0.57
22	F	Y	26	26	79	105	1,471.60	1,265.14	2,736.74	41.47	4.04	105.26	1.59	26.06	0.39
23	F	M	26	29	96	125	382.45	1,096.39	1,478.85	31.68	4.81	56.88	1.22	11.83	0.25
24	M	Y	26	34	171	205	270.66	664.72	935.38	22.72	7.88	35.98	0.87	4.56	0.11
25	F	O	26	16	41	57	274.56	1,167.39	1,441.96	23.23	2.19	55.46	0.89	25.30	0.41
26	F	Y	26	25	47	72	407.44	419.13	826.57	21.30	2.77	31.79	0.82	11.48	0.30
27	M	Y	26	39	99	138	663.21	2,089.12	2,752.33	38.18	5.31	105.86	1.47	19.94	0.28
28	M	M	27	27	80	107	870.47	1,108.76	1,979.23	32.67	3.96	73.30	1.21	18.50	0.31

Subject No.	Gender	Age Group	FOT Days	Trips – RDCW Disabled	Trips – RDCW Enabled	Total Trips	Distance Driven – RDCW Disabled	Distance Driven – RDCW Enabled	Total Distance (km)	Total Hours	Trips/ Day	Km/Day	Hours/ Day	Km/Trip	Hours/ Trip
29	F	Y	27	40	126	166	713.15	1,207.91	1,921.06	29.85	6.15	71.15	1.11	11.57	0.18
30	F	M	26	40	96	136	935.07	1,596.82	2,531.89	41.17	5.23	97.38	1.58	18.62	0.30
31	M	O	26	39	128	167	699.21	1,671.84	2,371.06	44.05	6.42	91.19	1.69	14.20	0.26
32	M	Y	26	48	84	132	889.55	1,199.54	2,089.09	44.05	5.08	80.35	1.69	15.83	0.33
33	F	Y	26	9	27	36	163.24	425.34	588.57	12.15	1.38	22.64	0.47	16.35	0.34
34	F	Y	27	54	204	258	436.07	1,465.07	1,901.15	44.23	9.56	70.41	1.64	7.37	0.17
35	M	M	26	42	100	142	524.39	1,673.95	2,198.34	39.80	5.46	84.55	1.53	15.48	0.28
36	F	O	26	34	145	179	206.60	876.49	1,083.09	36.72	6.88	41.66	1.41	6.05	0.21
37	M	O	26	29	72	101	327.08	2,146.34	2,473.42	35.32	3.88	95.13	1.36	24.49	0.35
38	F	O	26	36	102	138	353.57	845.05	1,198.63	28.55	5.31	46.10	1.10	8.69	0.21
39	M	Y	26	30	109	139	699.38	1,679.01	2,378.39	41.20	5.35	91.48	1.58	17.11	0.30
40	F	O	26	30	58	88	243.46	728.35	971.81	22.02	3.38	37.38	0.85	11.04	0.25
41	M	M	26	26	71	97	514.75	1,510.07	2,024.81	33.75	3.73	77.88	1.30	20.87	0.35
42	M	Y	26	26	101	127	1,216.54	2,090.71	3,307.25	50.40	4.88	127.20	1.94	26.04	0.40
43	M	M	26	36	68	104	653.25	1,681.58	2,334.83	36.60	4.00	89.80	1.41	22.45	0.35
44	F	Y	26	30	101	131	373.49	1,050.46	1,423.95	27.80	5.04	54.77	1.07	10.87	0.21
46	M	M	26	19	78	97	221.98	1,449.43	1,671.40	26.18	3.73	64.28	1.01	17.23	0.27
47	F	Y	26	52	80	132	1,083.44	1,617.82	2,701.26	42.93	5.08	103.89	1.65	20.46	0.33
48	M	O	26	27	53	80	388.82	1,675.65	2,064.46	29.97	3.08	79.40	1.15	25.81	0.37
49	M	O	26	12	34	46	271.12	634.07	905.19	20.33	1.77	34.82	0.78	19.68	0.44
50	F	O	26	24	72	96	331.61	873.36	1,204.96	23.38	3.69	46.34	0.90	12.55	0.24
53	M	O	26	34	114	148	215.57	1,076.78	1,292.36	23.62	5.69	49.71	0.91	8.73	0.16
54	F	O	26	11	41	52	134.78	476.61	611.38	11.85	2.00	23.51	0.46	11.76	0.23
55	M	Y	26	21	81	102	488.12	1,748.26	2,236.38	34.85	3.92	86.01	1.34	21.93	0.34
56	F	O	26	1	40	41	10.43	658.58	669.01	12.07	1.58	25.73	0.46	16.32	0.29
58	M	Y	26	22	103	125	816.68	1,721.79	2,538.48	40.93	4.81	97.63	1.57	20.31	0.33
59	F	M	26	30	114	144	863.23	2,059.53	2,922.77	42.67	5.54	112.41	1.64	20.30	0.30
60	F	Y	26	15	34	49	468.33	500.55	968.88	14.98	1.88	37.26	0.58	19.77	0.31
61	F	O	26	41	80	121	705.41	1,306.43	2,011.83	37.55	4.65	77.38	1.44	16.63	0.31
62	F	O	27	16	77	93	184.75	882.38	1,067.13	24.15	3.44	39.52	0.89	11.47	0.26
63	M	O	27	27	117	144	411.97	1,032.01	1,443.98	23.20	5.33	53.48	0.86	10.03	0.16

Subject No.	Gender	Age Group	FOT Days	Trips – RDCW Disabled	Trips – RDCW Enabled	Total Trips	Distance Driven – RDCW Disabled	Distance Driven – RDCW Enabled	Total Distance (km)	Total Hours	Trips/ Day	Km/Day	Hours/ Day	Km/Trip	Hours/ Trip
64	F	Y	27	40	124	164	786.81	1,941.63	2,728.43	45.55	6.07	101.05	1.69	16.64	0.28
66	F	Y	26	35	62	97	545.24	761.59	1,306.83	27.78	3.73	50.26	1.07	13.47	0.29
67	F	O	26	39	100	139	478.14	640.88	1,119.02	27.97	5.35	43.04	1.08	8.05	0.20
68	M	Y	26	42	117	159	612.93	1,816.85	2,429.78	41.27	6.12	93.45	1.59	15.28	0.26
70	M	Y	26	30	54	84	517.28	1,033.18	1,550.46	26.80	3.23	59.63	1.03	18.46	0.32
71	F	M	26	12	38	50	88.16	405.88	494.04	14.47	1.92	19.00	0.56	9.88	0.29
72	M	M	25	24	84	108	246.78	1,411.90	1,658.68	33.48	4.32	66.35	1.34	15.36	0.31
73	M	O	25	30	54	84	330.69	590.07	920.76	20.63	3.36	36.83	0.83	10.96	0.25
74	M	Y	26	47	81	128	510.95	1,069.42	1,580.38	33.18	4.92	60.78	1.28	12.35	0.26
75	M	O	25	25	70	95	280.89	980.57	1,261.46	31.30	3.80	50.46	1.25	13.28	0.33
76	M	M	26	35	95	130	451.69	1,749.51	2,201.20	41.58	5.00	84.66	1.60	16.93	0.32
77	M	Y	26	37	123	160	724.09	1,854.42	2,578.51	46.05	6.15	99.17	1.77	16.12	0.29
78	F	M	25	16	23	39	268.83	380.77	649.60	13.13	1.56	25.98	0.53	16.66	0.34
79	F	Y	26	34	92	126	707.84	1,954.42	2,662.26	47.17	4.85	102.39	1.81	21.13	0.37
80	F	O	26	17	73	90	336.77	1,036.57	1,373.34	25.72	3.46	52.82	0.99	15.26	0.29
81	M	Y	26	33	105	138	585.83	1,054.46	1,640.29	44.75	5.31	63.09	1.72	11.89	0.32
82	M	O	25	32	95	127	299.72	1,028.74	1,328.47	29.10	5.08	53.14	1.16	10.46	0.23
83	M	M	27	50	99	149	361.76	557.86	919.62	26.95	5.52	34.06	1.00	6.17	0.18
84	M	Y	26	49	60	109	496.82	689.84	1,186.67	27.08	4.19	45.64	1.04	10.89	0.25
85	M	M	26	31	78	109	370.33	1,362.84	1,733.17	30.32	4.19	66.66	1.17	15.90	0.28
87	M	M	25	26	77	103	480.97	1,815.22	2,296.20	40.28	4.12	91.85	1.61	22.29	0.39
Total	***	***	***	2,342	6,686	9,028	37,630.05	95,581.93	133,211.98	2,463.45	***	***	***	***	***
Mean	***	***	26.013	30.03	85.72	115.74	482.44	1,225.41	1,707.85	31.58	4.44	65.63	1.21	15.62	0.29
Median	***	***	26	30	80.5	115	435.19	1,138.08	1,665.04	31.49	4.49	65.32	1.21	15.42	0.29

APPENDIX H Summary of RDCW Alerts Issued to the 78 FOT Participants Recorded by DAS

Subject No.	Age-Gender Group	Baseline										Treatment									
		RDCW		CSW				LDW				RDCW		CSW				LDW			
				Cautionary		Imminent		Cautionary		Imminent				Cautionary		Imminent		Cautionary		Imminent	
		Trips	Distance (Km)	Alert Count	Alerts/100 Km	Alert Count	Alerts/100 Km	Alert Count	Alerts/100 Km	Alert Count	Alerts/100 Km	Trips	Distance (Km)	Alert Count	Alerts/100 Km	Alert Count	Alerts/100 Km	Alert Count	Alerts/100 Km	Alert Count	Alerts/100 Km
11	Y-F	50	706.9	53	7.5	24	3.4	33	4.7	19	2.7	132	1,539.3	119	7.7	28	1.8	45	2.9	78	5.1
20	Y-F	61	618.7	56	9.1	7	1.1	10	1.6	5	0.8	164	787.8	68	8.6	15	1.9	2	0.3	7	0.9
22	Y-F	26	1,471.6	43	2.9	12	0.8	54	3.7	26	1.8	79	1,265.1	36	2.8	5	0.4	14	1.1	22	1.7
26	Y-F	25	407.4	4	1.0	1	0.2	12	2.9	17	4.2	47	419.1	8	1.9	1	0.2	1	0.2	15	3.6
29	Y-F	40	713.2	23	3.2	11	1.5	25	3.5	17	2.4	126	1,207.9	62	5.1	17	1.4	41	3.4	20	1.7
33	Y-F	9	163.2	0	0.0	0	0.0	5	3.1	4	2.5	27	425.3	9	2.1	5	1.2	10	2.4	22	5.2
34	Y-F	54	436.1	30	6.9	5	1.1	36	8.3	19	4.4	204	1,465.1	190	13.0	63	4.3	117	8.0	156	10.6
44	Y-F	30	373.5	4	1.1	1	0.3	2	0.5	4	1.1	101	1,050.5	16	1.5	5	0.5	4	0.4	35	3.3
47	Y-F	52	1,083.4	70	6.5	23	2.1	114	10.5	57	5.3	80	1,617.8	122	7.5	29	1.8	68	4.2	87	5.4
60	Y-F	15	468.3	11	2.3	2	0.4	27	5.8	22	4.7	34	500.5	27	5.4	8	1.6	4	0.8	27	5.4
64	Y-F	40	786.8	57	7.2	25	3.2	52	6.6	52	6.6	124	1,941.6	125	6.4	48	2.5	21	1.1	52	2.7
66	Y-F	35	545.2	34	6.2	14	2.6	23	4.2	47	8.6	62	761.6	46	6.0	11	1.4	0	0.0	23	3.0
79	Y-F	34	707.8	33	4.7	8	1.1	68	9.6	29	4.1	92	1,954.4	119	6.1	41	2.1	64	3.3	68	3.5
AVG	*******	**36.2**	**652.5**	**32.2**	**4.9**	**10.2**	**1.6**	**35.5**	**5.4**	**24.5**	**3.7**	**97.8**	**1,148.9**	**72.8**	**6.3**	**21.2**	**1.8**	**30.1**	**2.6**	**47.1**	**4.1**
24	Y-M	34	270.7	22	8.1	8	3.0	3	1.1	11	4.1	171	664.7	39	5.9	15	2.3	3	0.5	11	1.7
27	Y-M	39	663.2	38	5.7	10	1.5	13	2.0	27	4.1	99	2,089.1	83	4.0	9	0.4	12	0.6	47	2.2
32	Y-M	48	889.5	36	4.0	22	2.5	11	1.2	86	9.7	84	1,199.5	91	7.6	24	2.0	5	0.4	57	4.8
39	Y-M	30	699.4	5	0.7	1	0.1	7	1.0	36	5.1	109	1,679.0	27	1.6	11	0.7	38	2.3	68	4.1
42	Y-M	26	1,216.5	32	2.6	5	0.4	4	0.3	23	1.9	101	2,090.7	78	3.7	14	0.7	1	0.0	34	1.6
55	Y-M	21	488.1	48	9.8	15	3.1	98	20.1	47	9.6	81	1,748.3	131	7.5	34	1.9	28	1.6	98	5.6
58	Y-M	22	816.7	34	4.2	14	1.7	43	5.3	23	2.8	103	1,721.8	54	3.1	17	1.0	10	0.6	43	2.5
68	Y-M	42	612.9	27	4.4	6	1.0	63	10.3	33	5.4	117	1,816.9	84	4.6	32	1.8	18	1.0	63	3.5

70	Y-M	30	517.3	22	4.3	4	0.8	53	10.2	58	11.2	54	1,033.2	38	3.7	9	0.9	62	6.0	53	5.1
74	Y-M	47	511.0	18	3.5	6	1.2	14	2.7	13	2.5	81	1,069.4	30	2.8	7	0.7	6	0.6	14	1.3
77	Y-M	37	724.1	61	8.4	26	3.6	155	21.4	64	8.8	123	1,854.4	208	11.2	72	3.9	77	4.2	155	8.4
81	Y-M	33	585.8	16	2.7	7	1.2	39	6.7	6	1.0	105	1,054.5	46	4.4	3	0.3	12	1.1	39	3.7
84	Y-M	49	496.8	20	4.0	6	1.2	32	6.4	26	5.2	60	689.8	29	4.2	13	1.9	3	0.4	32	4.6
AVG	*******	**35.2**	**653.2**	**29.2**	**4.5**	**10.0**	**1.5**	**41.2**	**6.3**	**34.8**	**5.3**	**99.1**	**1,439.3**	**72.2**	**5.0**	**20.0**	**1.4**	**21.2**	**1.5**	**54.9**	**3.8**

Subject No.	Age-Gender Group	Baseline										Treatment									
		RDCW		CSW				LDW				RDCW		CSW				LDW			
				Cautionary		Imminent		Cautionary		Imminent				Cautionary		Imminent		Cautionary		Imminent	
		Trips	Distance (Km)	Alert Count	Alerts/100 Km	Alert Count	Alerts/100 Km	Alert Count	Alerts/100 Km	Alert Count	Alerts/100 Km	Trips	Distance (Km)	Alert Count	Alerts/100 Km	Alert Count	Alerts/100 Km	Alert Count	Alerts/100 Km	Alert Count	Alerts/100 Km
1	M-F	11	293.6	17	5.8	0	0.0	3	1.0	3	1.0	50	907.4	36	4.0	5	0.6	4	0.4	2	0.2
2	M-F	13	434.3	10	2.3	4	0.9	2	0.5	14	3.2	66	1,851.3	79	4.3	24	1.3	7	0.4	55	3.0
3	M-F	38	365.2	9	2.5	2	0.5	2	0.5	11	3.0	121	1,980.8	33	1.7	13	0.7	13	0.7	52	2.6
7	M-F	8	181.6	0	0.0	0	0.0	1	0.6	2	1.1	68	961.1	15	1.6	4	0.4	2	0.2	11	1.1
13	M-F	66	623.8	9	1.4	1	0.2	30	4.8	19	3.0	109	1,479.7	44	3.0	11	0.7	20	1.4	72	4.9
14	M-F	24	354.7	6	1.7	3	0.8	19	5.4	4	1.1	57	1,461.9	29	2.0	6	0.4	40	2.7	35	2.4
17	M-F	37	816.0	12	1.5	6	0.7	2	0.2	17	2.1	130	2,114.9	56	2.6	25	1.2	7	0.3	22	1.0
19	M-F	7	122.4	11	9.0	1	0.8	0	0.0	2	1.6	42	421.7	14	3.3	5	1.2	2	0.5	12	2.8
23	M-F	29	382.5	8	2.1	5	1.3	5	1.3	23	6.0	96	1,096.4	40	3.6	14	1.3	17	1.6	64	5.8
30	M-F	40	935.1	45	4.8	18	1.9	10	1.1	55	5.9	96	1,596.8	82	5.1	27	1.7	13	0.8	75	4.7
59	M-F	30	863.2	14	1.6	5	0.6	62	7.2	88	10.2	114	2,059.5	28	1.4	13	0.6	77	3.7	62	3.0
71	M-F	12	88.2	0	0.0	0	0.0	0	0.0	4	4.5	38	405.9	7	1.7	1	0.2	6	1.5	0	0.0
78	M-F	16	268.8	0	0.0	0	0.0	15	5.6	2	0.7	23	380.8	9	2.4	2	0.5	7	1.8	15	3.9
AVG	*******	**25.5**	**440.7**	**10.8**	**2.5**	**3.5**	**0.8**	**11.6**	**2.6**	**18.8**	**4.3**	**77.7**	**1,286.0**	**36.3**	**2.8**	**11.5**	**0.9**	**16.5**	**1.3**	**36.7**	**2.9**
5	M-M	40	645.0	27	4.2	11	1.7	22	3.4	17	2.6	124	1,976.4	102	5.2	45	2.3	16	0.8	45	2.3
8	M-M	33	251.2	4	1.6	0	0.0	5	2.0	4	1.6	165	1,662.5	60	3.6	25	1.5	27	1.6	82	4.9
21	M-M	26	538.3	17	3.2	2	0.4	60	11.1	96	17.8	23	979.6	54	5.5	21	2.1	181	18.5	155	15.8
28	M-M	27	870.5	27	3.1	13	1.5	68	7.8	32	3.7	80	1,108.8	30	2.7	8	0.7	7	0.6	13	1.2
35	M-M	42	524.4	18	3.4	6	1.1	6	1.1	31	5.9	100	1,674.0	56	3.3	33	2.0	19	1.1	135	8.1
41	M-M	26	514.7	17	3.3	8	1.6	6	1.2	31	6.0	71	1,510.1	89	5.9	14	0.9	33	2.2	85	5.6

43	M-M	36	653.2	38	5.8	9	1.4	2	0.3	23	3.5	68	1,681.6	113	6.7	31	1.8	20	1.2	59	3.5
46	M-M	19	222.0	7	3.2	4	1.8	11	5.0	13	5.9	78	1,449.4	34	2.3	12	0.8	127	8.8	54	3.7
72	M-M	24	246.8	4	1.6	0	0.0	57	23.1	3	1.2	84	1,411.9	56	4.0	18	1.3	16	1.1	57	4.0
76	M-M	35	451.7	13	2.9	2	0.4	15	3.3	8	1.8	95	1,749.5	32	1.8	2	0.1	9	0.5	15	0.9
83	M-M	50	361.8	12	3.3	5	1.4	26	7.2	10	2.8	99	557.9	33	5.9	6	1.1	24	4.3	26	4.7
85	M-M	31	370.3	29	7.8	12	3.2	54	14.6	19	5.1	78	1,362.8	48	3.5	14	1.0	11	0.8	54	4.0
87	M-M	26	481.0	22	4.6	9	1.9	142	29.5	29	6.0	77	1,815.2	93	5.1	21	1.2	222	12.2	142	7.8
AVG	*******	**31.9**	**471.6**	**18.1**	**3.8**	**6.2**	**1.3**	**36.5**	**7.7**	**24.3**	**5.2**	**87.8**	**1,456.9**	**61.5**	**4.2**	**19.2**	**1.3**	**54.8**	**3.8**	**70.9**	**4.9**

Subject No.	Age-Gender Group	Baseline										Treatment									
		RDCW		CSW				LDW				RDCW		CSW				LDW			
				Cautionary		Imminent		Cautionary		Imminent				Cautionary		Imminent		Cautionary		Imminent	
		Trips	Distance (Km)	Alert Count	Alerts/100 Km	Alert Count	Alerts/100 Km	Alert Count	Alerts/100 Km	Alert Count	Alerts/100 Km	Trips	Distance (Km)	Alert Count	Alerts/100 Km	Alert Count	Alerts/100 Km	Alert Count	Alerts/100 Km	Alert Count	Alerts/100 Km
6	O-F	36	641.8	3	0.5	0	0.0	7	1.1	16	2.5	88	1,102.6	19	1.7	8	0.7	7	0.6	33	3.0
9	O-F	23	172.7	1	0.6	0	0.0	4	2.3	1	0.6	42	282.5	9	3.2	0	0.0	12	4.2	3	1.1
25	O-F	16	274.6	4	1.5	0	0.0	1	0.4	1	0.4	41	1,167.4	16	1.4	3	0.3	17	1.5	17	1.5
36	O-F	34	206.6	3	1.5	1	0.5	2	1.0	8	3.9	145	876.5	9	1.0	4	0.5	9	1.0	11	1.3
38	O-F	36	353.6	19	5.4	6	1.7	26	7.4	18	5.1	102	845.1	52	6.2	18	2.1	23	2.7	24	2.8
40	O-F	30	243.5	6	2.5	4	1.6	5	2.1	7	2.9	58	728.4	27	3.7	13	1.8	18	2.5	53	7.3
50	O-F	24	331.6	18	5.4	3	0.9	11	3.3	6	1.8	72	873.4	40	4.6	12	1.4	4	0.5	18	2.1
54	O-F	11	134.8	1	0.7	0	0.0	7	5.2	1	0.7	41	476.6	6	1.3	1	0.2	1	0.2	7	1.5
56	O-F	1	10.4	0	0.0	0	0.0	14	134.2	0	0.0	40	658.6	10	1.5	3	0.5	3	0.5	14	2.1
61	O-F	41	705.4	13	1.8	0	0.0	118	16.7	40	5.7	80	1,306.4	28	2.1	8	0.6	55	4.2	118	9.0
62	O-F	16	184.8	5	2.7	0	0.0	18	9.7	5	2.7	77	882.4	40	4.5	5	0.6	57	6.5	18	2.0
67	O-F	39	478.1	14	2.9	7	1.5	52	10.9	15	3.1	100	640.9	52	8.1	16	2.5	34	5.3	52	8.1
80	O-F	17	336.8	9	2.7	2	0.6	41	12.2	18	5.3	73	1,036.6	47	4.5	4	0.4	25	2.4	41	4.0
AVG	*******	**24.9**	**313.4**	**7.4**	**2.4**	**1.8**	**0.6**	**23.5**	**7.5**	**10.5**	**3.3**	**73.8**	**836.7**	**27.3**	**3.3**	**7.3**	**0.9**	**20.4**	**2.4**	**31.5**	**3.8**
4	O-M	28	267.0	0	0.0	0	0.0	12	4.5	9	3.4	65	436.2	5	1.1	2	0.5	10	2.3	11	2.5
10	O-M	11	177.8	1	0.6	1	0.6	6	3.4	6	3.4	43	450.6	1	0.2	0	0.0	6	1.3	5	1.1
12	O-M	28	669.3	7	1.0	3	0.4	60	9.0	34	5.1	123	2,167.1	50	2.3	19	0.9	17	0.8	30	1.4
16	O-M	21	381.7	14	3.7	1	0.3	1	0.3	1	0.3	47	1,509.6	25	1.7	8	0.5	5	0.3	20	1.3
31	O-M	39	699.2	19	2.7	1	0.1	38	5.4	35	5.0	128	1,671.8	46	2.8	10	0.6	19	1.1	82	4.9

37	O-M	29	327.1	9	2.8	3	0.9	2	0.6	3	0.9	72	2,146.3	48	2.2	8	0.4	11	0.5	40	1.9
48	O-M	27	388.8	6	1.5	1	0.3	3	0.8	12	3.1	53	1,675.6	41	2.4	10	0.6	21	1.3	49	2.9
49	O-M	12	271.1	6	2.2	1	0.4	4	1.5	4	1.5	34	634.1	13	2.1	3	0.5	9	1.4	44	6.9
53	O-M	34	215.6	18	8.3	1	0.5	50	23.2	6	2.8	114	1,076.8	59	5.5	25	2.3	115	10.7	50	4.6
63	O-M	27	412.0	16	3.9	5	1.2	10	2.4	39	9.5	117	1,032.0	36	3.5	15	1.5	9	0.9	10	1.0
73	O-M	30	330.7	7	2.1	3	0.9	47	14.2	7	2.1	54	590.1	21	3.6	8	1.4	21	3.6	47	8.0
75	O-M	25	280.9	2	0.7	1	0.4	17	6.1	9	3.2	70	980.6	7	0.7	6	0.6	16	1.6	17	1.7
82	O-M	32	299.7	3	1.0	1	0.3	37	12.3	9	3.0	95	1,028.7	37	3.6	15	1.5	45	4.4	37	3.6
AVG	*******	**26.4**	**363.1**	**8.3**	**2.3**	**1.7**	**0.5**	**22.1**	**6.1**	**13.4**	**3.7**	**78.1**	**1,184.6**	**29.9**	**2.5**	**9.9**	**0.8**	**23.4**	**2.0**	**34.0**	**2.9**

APPENDIX I Simulator Testing

Crash statistics and driver exposure surveys indicate that actual road-departure crashes are very infrequent and highly unlikely to occur during the RDCW FOT. This infrequency works against the need to understand driver behavior in road-departure crash or near crash situations. To obtain crash and near crash data, we ran a series of RDCW-equipped driving simulator experiments at the Virtual Environment for Surface Transportation Research at the University of Minnesota's HumanFIRST Program (Human Factors Interdisciplinary Research in Simulation and Transportation) in the Intelligent Transportation Systems Institute. Simulator experiments took place in the spring of 2005.

I-1. Method

The University of Minnesota recruited simulator-experiment participants through Masterson Personnel (a Minneapolis temporary agency). Under our guidance they recruited males and females in the same age ranges as the FOT participants. Three drivers were scheduled during each two-hour period on a first-come, first-serve basis. Other scheduled participants waited in a separate waiting room until the simulator was ready. The University of Minnesota closely controlled gender, age group, and condition assignments in a 2 x 3 x 2 experiment (gender, age group, condition). Table 4-16 lists the simulator experiment participant pool. Of the 122 licensed participants there were 59 in the control group and 63 in the treatment group, 64 females and 58 males. There were 44 younger participants, 39 middle-aged, and 39 older. Each cell in Table 1 contains an average of 10 participants.

Table I-1. Simulator Experiment Participant Pool

	Condition	Age	Female	Male	Row Totals
Count	Control	Younger	10	10	**20**
Percent			8.20%	8.20%	**16.39%**
Count	Control	Middle	10	9	**19**
Percent			8.20%	7.38%	**15.57%**
Count	Control	Old	10	10	**20**
Percent			8.20%	8.20%	**16.39%**
Count	Total		**30**	**29**	**59**
Percent			24.59%	23.77%	**48.36%**
Count	Treatment	Young	13	11	**24**
Percent			10.66%	9.02%	**19.67%**
Count	Treatment	Middle	11	9	**20**
Percent			9.02%	7.38%	**16.39%**

	Condition	Age	Female	Male	Row Totals
Count	Treatment	Old	10	9	**19**
Percent			8.20%	7.38%	**15.57%**
Count	Total		34	29	**63**
Percent			27.87%	23.77%	**51.64%**
Count	Column Total		**64**	**58**	**122**
Percent			**52.46%**	**47.54%**	

The University assigned participants in either the RDCW treatment or control (normal driving without assistance) condition based on their gender and age, to balance each condition. Once in the simulator lab, participants signed a consent form after they were told that it listed any benefits or potential risks of participating and that they could discontinue participation at any time. Participants were then taken to the simulator and told to make themselves comfortable behind the wheel.

Once inside the vehicle, participants read the instructions specific to their system condition, treatment or control. Unlike the FOT, which involved RDCW-baseline and treatment periods, the short simulator exposure precluded any such division of driving time. Participants were assigned to either the treatment group or the control group. After they read the instructions, the experimenter explained how to drive the vehicle, that the simulator had a motion base, and what participants should do if they began to feel simulator-induced discomfort (i.e., simulator sickness). The experimenter explained the secondary distraction task to the participants and allowed them to practice the task at least two times. The experimenter also explained to treatment-group participants how the LDW and CSW subsystems functioned, including what they would hear, see, and feel and what would trigger warnings.

After ensuring that the participants understood the instructions and were ready to begin, the experimenter initiated the simulated drive and told the driver to start the vehicle and proceed at the posted speed limit. The driver practiced going around two curves and a straight section where they tested the brakes and practiced a secondary task. Experimenters also instructed RDCW system participants to test the LDW warnings.
Once the driver completed the experimental drive, an audio file instructed them to stop the car and await further instruction from the experimenter. The experimenter then led the driver out of the simulator lab and instructed them to fill out a questionnaire on demographic information and simulator sickness. Treatment-group participants also answered a questionnaire about the RDCW. Once they completed the questionnaire participants were thanked for their participation.

Simulator

The study used the VESTR in the University of Minnesota’s HumanFIRST Program. This immersive, motion-base driving simulator, illustrated in Figure 1, is linked to a full-sized Saturn vehicle with realistic operational controls and instrumentation. The visual scene is projected with a high-resolution (2.5 arc-minutes per pixel), five-channel, 210-degree forward field of view (FOV) with 50-degree rear projected FOV and side mirrors comprised of color LCD panels. A 3-D surround audio system, subwoofer, car body vibration, force feedback steering, and a three-axis electric motion system (roll, pitch, z-axis) provided auditory and haptic feedback. A 5-inch LCD screen mounted to the center panel, just below the dashboard, serves as the RDCW display. An additional 7-inch LCD touch-screen, mounted to the passenger seat at dashboard height about 80 degrees from the driver's forward view, displays the secondary task.

Figure I-2. University of Minnesota Motion-Based Driving Simulator

Driving Database

The simulated drive, illustrated in Figure I-3, consists of nine curves of 1,000, 800, and 250 feet radii connected by straight sections. The rural two-lane road takes about 25 minutes to drive around. The land next to the road is populated with trees and shrubs so that optic flow is maximized. The speed limit for the drive is 55 mph, with selected curves marked as 45 mph. The final 250-foot curve has a posted 45 mph speed limit, approximately 20 mph over the recommend speed. This condition allows the curve-speed warning to be exercised (activated and tested) across all participants. Figure I-4 illustrates a representative straight section from the simulator's forward channel, while Figure I-5 shows a representative curved section from the same channel.

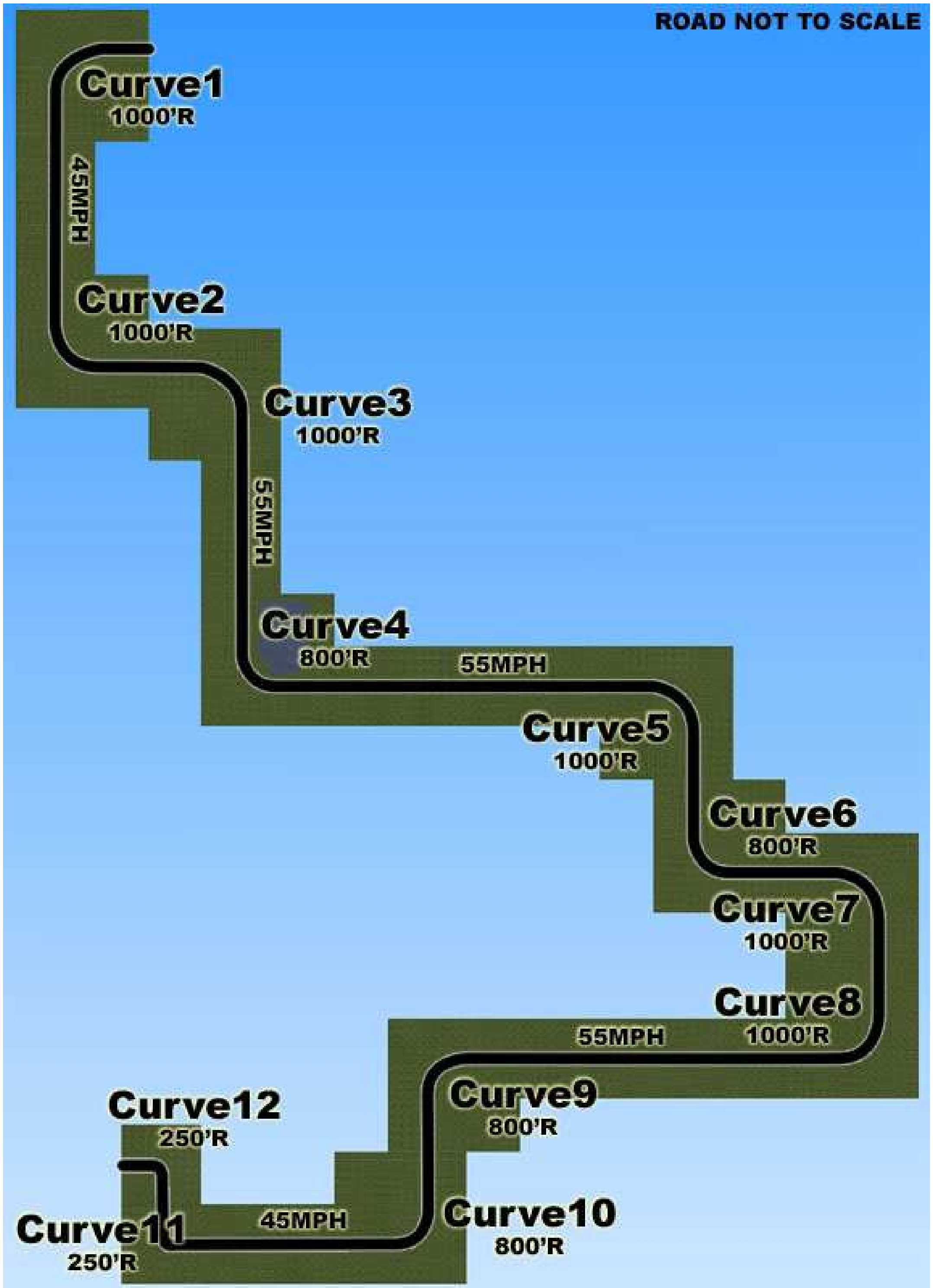


Figure I-3. Simulator Database

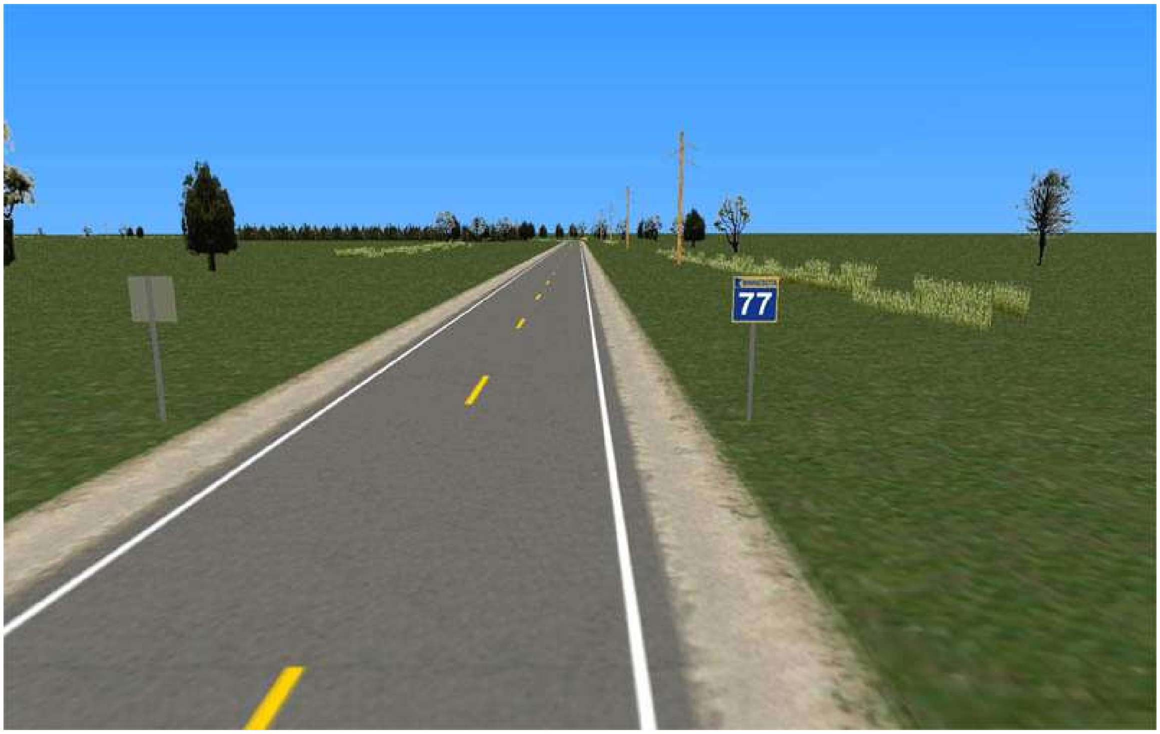


Figure I-4. Forward-Channel Simulator Straight Section

Figure I-5. Forward-Channel Simulator Curve

Secondary Task and Wind Gust

Undisturbed, simulator drivers are unlikely to depart the lane or the road during the 30-minute simulated drive. As the purpose of the experiment was to obtain driving performance under crash-like conditions, we needed to push drivers toward these conditions. We generated a simulated leftward wind gust several times during the simulated drive, selecting a leftward—as opposed to rightward—gust so that drivers, while likely to experience a large lane excursion and trigger an alert, were unlikely to depart the road. Our rationale was that a road departure early in the experiment would likely bias drivers' responses in the remainder of the experiment and would reduce the credibility of their data.

We also included a secondary task during some of the gusts to increase the likelihood that a driver would drift off the road or into the oncoming traffic lane and trigger a lateral-drift warning. The task involved determining the direction of the center arrow in a three-by-three grid of arrows and then selecting from the other eight arrows the one whose direction matched that of the center arrow. Driver preparation in the simulator included one wind gust during the practice session, so that drivers would not be completely surprised by this during the simulated drive.

The simulator experiment collected data from many variables. The most relevant for safety benefits in potential road-departure scenarios is the distance of the *front-left* tire from the lane center because the leftward gust pushes drivers toward the left and the distance from the lane center (particularly when it was negative, indicating the vehicle was in oncoming-traffic lane) is a sensitive proxy for safety.

I-2. Results

Three ANOVA studies yielded no dominant safety-significant results. The explanatory variables for these studies included gender, age, and *condition*, where the latter indicates if the drivers were in the control or treatment group. Unlike the FOT, where participants, by driving in baseline and treatment periods, served as their own controls, the simulator experiment placed drivers in a control or treatment group. Their short exposure to the RDCW (30 minutes of driving) precluded separate collection of control and treatment data for the same driver. The dependent variables included the peak leftward excursions associated with the first wind gust and the second wind gust, where the latter also had a distraction task. The first study approached the two dependent variables as a repeated measure, recognizing both their link to the same driver and a likely difference between them. The second study used the non-distracted leftward excursion as a single dependent variable, and the last study used the distracted leftward excursion as a single dependent variable.

Repeated-Measures ANOVA Study

The first study, the repeated-measures ANOVA, yields two statistically significant effects, neither of which has particular safety relevance. The left-front-tire distance from the road centerline for the two wind-gust events, one without a distraction task and the other with the task, had a smaller mean deviation without the distraction task (-30 versus -73 inches), $F(1,110) = 82.4$, $p < 0.001$. The smaller deviation without the distraction tasks is expected.

The first study also reveals an interaction between the distraction task, gender, and condition. The distance from centerline data, plotted in Figure 5, shows a modest improvement in the distance from the centerline (i.e., less incursion into the opposite lane) for males and females from the control (no alert) to the treatment (alert) group when there is not distraction task, the left side of the figure. Conversely, when there is a distraction task, the distance from the centerline improves by approximately 20 inches for males in the treatment group, but increases (i.e., is more negative) by approximately 14 inches for females in this group.

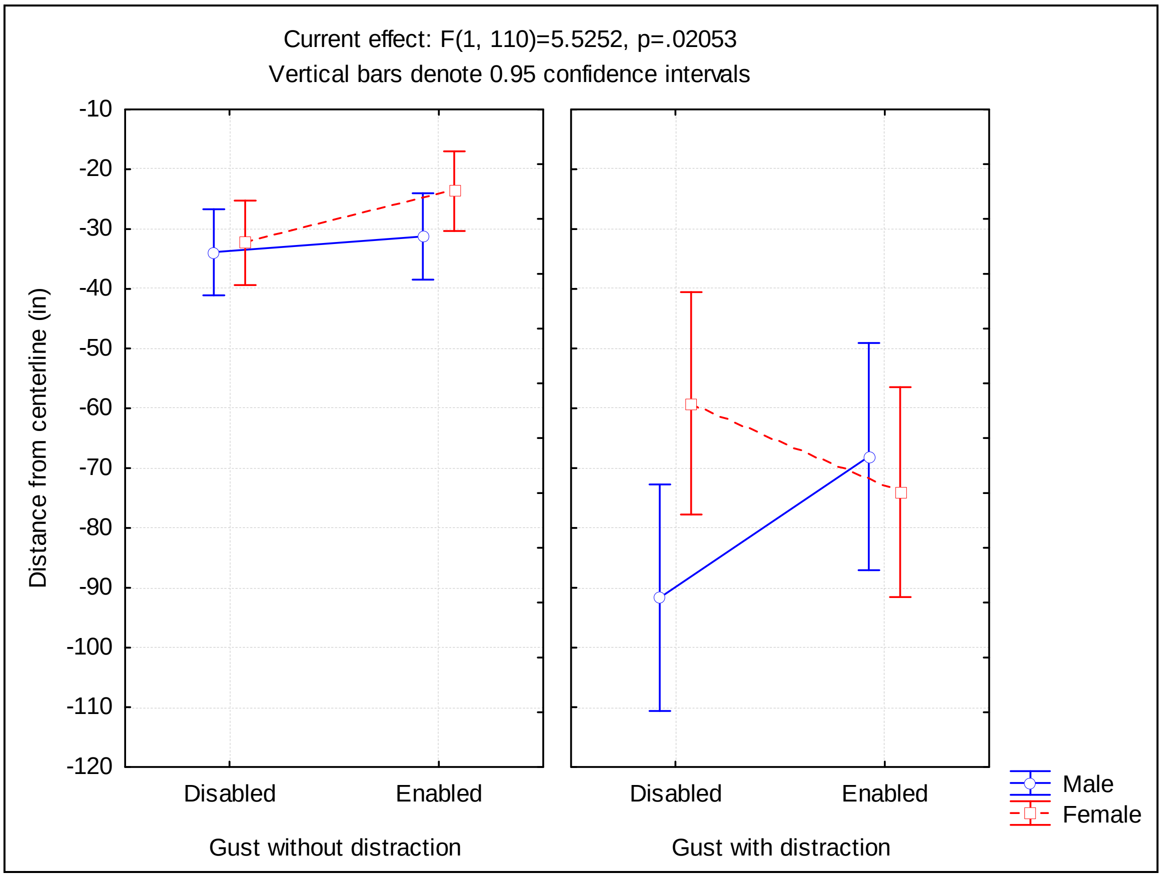


Figure I-6. Interaction Among Distraction Task, Condition, and Gender

Single Variable (First Wind Gust) ANOVA Study

The second ANOVA study is a simpler version of the first study, which uses both dependent variables: the peak leftward excursions associated with the first wind gust and with the second wind gust that also had a distraction task. The second study uses only the peak leftward excursion associated with the first wind gust. We performed this study to determine if the improved performance with condition observed in the left side of Figure

5 was statistically significant. It was not. Nor is there any statistically significant effect of gender or age group on the leftward excursion.

Single Variable (Second Wind Gust) ANOVA Study

The third study, also a simpler version of the first, uses the peak leftward excursion associated with the second wind gust, which had a distraction task, as the sole dependent variable. The ANOVA study shows a statistically significant interaction between gender and condition, plotted on the right side of Figure 5.

APPENDIX J Survey Question Responses

Table J-1. Descriptive Statistics for the RDCW Ease-of-Use Survey Questions

Sub-Objective	Survey Question	Mean	Std. Dev.	Mode	Max. Value	Min. Value
Demand on Driver						
Question 27, I was not distracted by RDCW system components (e.g., alerts, displays or controls).						
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.6	1.5	7	7	1
Understanding of Warning						
Question 9, It was easy to determine how changes to the LDW sensitivity setting affected LDW warnings.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.0	1.3	7	7	2
Question 12, It was easy to determine how changes to the CSW sensitivity setting affected CSW warnings.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.5	1.8	7	7	1
Question 16, I could easily distinguish between RDCW auditory warnings (i.e., as being an LDW or a CSW warning).						
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.3	1.1	7	7	3
Question 17, I understood the meaning and required response of each auditory warning when they occurred.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.9	1.4	7	7	2
Question 18, I could easily distinguish between the RDCW seat vibration warnings (i.e., as being an LDW or a CSW warning).						
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.7	1.6	7	7	1
Question 19, I understood the meaning and required response of each seat vibration warning when they occurred.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.6	1.6	7	7	1
Question 20a, It was easy for me to recognize what warning condition the RDCW was attempting to convey (e.g., LDW Left Cautionary, CSW Imminent, etc.) from the visual warnings.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.1	1.9	6	7	1
Question 20b, It was easy for me to recognize what warning condition the RDCW was attempting to convey (e.g., LDW Left Cautionary, CSW Imminent, etc.) from the auditory warnings.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.3	1.2	7	7	1
Question 20c, It was easy for me to recognize what warning condition the RDCW was attempting to convey (e.g., LDW Left Cautionary, CSW Imminent, etc.) from the seat vibration warnings.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.8	1.2	7	7	2
Question 21, Overall, I could easily identify the urgency of the RDCW warnings.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.9	1.3	7	7	1

Sub-Objective	Survey Question	Mean	Std. Dev.	Mode	Max. Value	Min. Value
Usability						
Question 1, The RDCW display was in a convenient location on the instrument panel (i.e., I did not have to change my posture to see it).						
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.9	1.4	7	7	1
Question 2, It was easy to understand the RDCW system operation from the information displayed in the instrument cluster.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.3	0.9	7	7	3
Question 4, I was not confused by the fact that the curve on the RDCW display always pointed to the left, regardless of the direction of the curve ahead in the road.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.9	1.4	7	7	1
Question 5, It was easy to use the RDCW (LDW & CSW) sensitivity adjustment switches.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.8	0.4	7	7	5
Question 6, It was easy for me to locate the sensitivity switches when I needed them.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.6	0.4	7	7	4
Question 7, It was easy was to understand which switch controlled the LDW sensitivity and which controlled the CSW sensitivity.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.8	0.5	7	7	4
Question 8It was easy to determine the existing sensitivity settings for both LDW and CSW by looking at the display.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.8	0.4	7	7	5
Question 15, It was easy to become familiar with the layout of the RDCW display (distinguishing between where the LDW and CSW system information was presented).						
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.4	1.0	7	7	1
Use Patterns						
Question 10, I frequently adjusted the LDW sensitivity setting during my drive.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	3.3	1.8	1	7	1
Question 11, If you did change the LDW sensitivity, which of the following factors caused you to change the setting. Please check all that apply.						
	The traffic conditions	24 out of 78 = 30.8%				
	The weather conditions	16 out of 78 = 20.5%				
	Whether I was in a rush	9 out of 78 = 11.5%				
	Whether I was tired	17 out of 78 = 21.8%				
	Whether I felt alert	18 out of 78 = 23.1%				
Question 13, I frequently adjusted the CSW sensitivity setting during my drive.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	3.0	1.8	1	7	1

Sub-Objective		Survey Question	Mean	Std. Dev.	Mode	Max. Value	Min. Value
Question 14, If you did change the CSW sensitivity, which of the following factors caused you to change the setting. <u>Please check all that apply.</u>							
		The traffic conditions	24 out of 78 = 30.8%				
		The weather conditions	11 out of 78 = 14.1%				
		Whether I was in a rush	11 out of 78 = 14.1%				
		Whether I was tired	12 out of 78 = 15.4%				
		Whether I felt alert	15 out of 78 = 19.2%				

Table J-2. Descriptive Statistics for the RDCW Learning Survey Questions

Sub-Objective	Survey Question	Mean	Std. Dev.	Mode	Max. Value	Min. Value
Ease of Learning						
Question 25, Overall, it was easy to become familiar with the RDCW system.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.4	0.9	7	7	2
Question 26, I developed a good understanding of how the RDCW system worked after hearing a brief description, and after I had the chance to drive with the system.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.5	0.8	7	7	3

Table J-3. Descriptive Statistics for the RDCW Driver Performance Survey Questions

Sub-Objective	Survey Question	Mean	Std. Dev.	Mode	Max. Value	Min. Value
Awareness						
Question 28, Driving with the RDCW system made me more aware of the position of my car on the road and of upcoming curves.						
1 (Strongly Disagree) – 7 (Strongly Agree)		5.9	1.5	7	7	1
Driving Style Adjustments						
Question 29, I relied on the RDCW system.						
1 (Strongly Disagree) – 7 (Strongly Agree)		3.1	1.8	1	7	1

Table J-4. Descriptive Statistics for the RDCW Perceived Value Survey Question

Sub-Objective	Survey Question	Mean	Std. Dev.	Mode	Max. Value	Min. Value
Safety						
Question 30, I think RDCW is going to increase driving safety.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.6	1.4	7	7	1

Table J-5. Descriptive Statistics for the RDCW Advocacy Survey Questions

Sub-Objective	Survey Question	Mean	Std. Dev.	Mode	Max. Value	Min. Value
Interest in Purchasing						
Question 33, Approximately how soon might you consider purchasing a new vehicle?						
	Within the next month	5 out of 77 = 6.5%				
	Within the next six months	12 out of 77 = 15.6%				
	Within the next two years	39 out of 77 = 50.6%				
	Within the next five years	14 out of 77 = 18.2%				
	Over five years	7 out of 77 = 9.1%				
Question 34, Cost aside, if you were purchasing a new vehicle, how likely would you be to consider purchasing the RDCW (LDW & CSW) system?						
1 (Definitely Would Not Consider) – 7 (Definitely Would Consider)		5.0	1.8	7	7	1
Amount Willing to Pay						
Question 36, What is the maximum amount you would pay for the RDCW (LDW & CSW) system?						
	Write-In Response	$729	$782	$500	$4K	$0
Question 37, At the actual price of $800, how likely would you be to consider purchasing RDCW (LDW & CSW) if you were purchasing a new vehicle?						
	1 (Definitely Would Not Consider) – 7 (Definitely Would Consider)	4.3	2.1	4	7	1

Table J-6. Descriptive Statistics for RDCW Usefulness and Satisfaction

Sub-Objective	Survey Question	Mean	Std. Dev.	Mode	Max. Value	Min. Value
Driver Acceptance Scale						
Usefulness Scale Score		1.2	0.8	2	2	-2
Satisfaction Scale Score		0.6	0.9	1	2	-2

Table J-7. Descriptive Statistics -- LDW Ease-of-Use Post-Drive Survey Questions

Sub-Objective	Survey Question	Mean	Std. Dev.	Mode	Max. Value	Min. Value
Demand on Driver						
Question 6, The visual LDW warnings were not distracting.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.9	1.5	7	7	1
Question 7, The LDW Availability icons were not distracting.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.1	1.2	7	7	1
Question 13, The auditory LDW warnings were not distracting.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.6	1.6	7	7	1
Question 20, The LDW seat vibration warnings were not distracting.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.0	1.4	7	7	1
Understanding of Warning						
Question 5, I knew what to do when I saw the LDW visual warnings.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.3	1.9	7	7	1
Question 8, The LDW Availability icons helped me to understand and to use the LDW system.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.9	1.4	7	7	1
Question 10, I knew what to do when I heard the LDW auditory warnings.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.4	1.2	7	7	1
Question 18, I knew what to do when I felt the LDW seat vibration warnings.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.3	1.1	7	7	1
Question 23, Overall, I could easily identify the urgency of the LDW warnings.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.0	1.4	7	7	1
Usability						
Question 15, How often did passengers in the car comment on the auditory LDW warnings when they occurred?						
	1 (Not at All) – 7 (Very Often)	5.0	2.0	7	7	1
Question 22, Passengers in the car did not notice the LDW seat vibration warnings when they occurred.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.0	1.4	7	7	1

Table J-8. Descriptive Statistics for the LDW Learning Survey Questions

Sub-Objective	Survey Question	Mean	Std. Dev.	Mode	Max. Value	Min. Value
Ease of Learning						
Question 32, Overall, it was easy to become familiar with the LDW system.						

Sub-Objective	Survey Question	Mean	Std. Dev.	Mode	Max. Value	Min. Value
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.4	1.0	7	7	1
Question 33, I developed a good understanding of how the LDW system worked after hearing a brief description, and after I had the chance to drive with the system.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.4	1.0	7	7	2
Time to Learn						
Question 31,How long did it take before you became comfortable driving the car with LDW? Check one.						
	I became comfortable with the operations of LDW within the first day	31 out of 78 = 39.7%				
	I became comfortable with the operations of LDW within 2 to 3 days	35 out of 78 = 44.9%				
	I became comfortable with the operations of LDW within the first week	10 out of 78 = 12.8%				
	I became comfortable with the operations of LDW within 2 to 3 weeks	1 out of 78 = 1.3%				
	I never became comfortable with the operations of LDW	1 out of 78 = 1.3%				

Table J-9. Descriptive Statistics for the LDW Driver Performance Survey Questions

Sub-Objective	Survey Question	Mean	Std. Dev.	Mode	Max. Value	Min. Value
Awareness						
LDW Question 34, Driving with the LDW system made me more aware of the position of my car on the road.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.2	1.2	7	7	1
Driving Style Adjustments						
LDW Question 36, I relied on the LDW system.						
1 (Strongly Disagree) – 7 (Strongly Agree)		3.6	1.8	4	7	1
LDW Question 42, I felt more comfortable performing additional tasks, (e.g., adjusting the heater, operating the radio, talking on a cellular telephone, etc.) while using LDW as compared to manual driving.						
1 (Strongly Disagree) – 7 (Strongly Agree)		4.3	2.0	6	7	2

Table J-10. Descriptive Statistics for the LDW Perceived Value Survey Questions

Sub-Objective	Survey Question	Mean	Std. Dev.	Mode	Max. Value	Min. Value
Safety						
Question 37, I found the LDW system useful in providing warnings about situations that might have resulted in collisions.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	4.6	1.9	4	7	1

Sub-Objective	Survey Question	Mean	Std. Dev.	Mode	Max. Value	Min. Value
Question 38, LDW is going to increase driving safety.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.6	1.3	7	7	1
Driving Skill						
Question 35, The LDW system made me more attentive to using my turn signals when changing lanes.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.9	1.9	7	7	1
Question 39, I found the LDW system useful in adverse weather conditions.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	3.9	1.9	4	7	1
Question 40, I found the LDW system useful in light traffic.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	4.8	1.8	7	7	1
Question 41, I found the LDW system useful in heavy traffic.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.2	1.8	7	7	1
Tolerance of Warnings						
Question 14, The frequency with which I received auditory LDW warnings was not annoying.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.5	1.6	7	7	1
Question 21, The frequency with which I received LDW seat vibration warnings was not annoying.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.0	1.3	7	7	1
Question 28, I did not receive any unnecessary LDW warnings.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	4.1	2.0	7	7	1
Question 29, I did not receive any false LDW warnings.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	4.5	2.1	7	7	1
Question 30, Overall, I received LDW warnings						
	1 (Too Frequently) – 7 (Too Infrequently)	4.0	0.9	4	6	1

Table J-11. Descriptive Statistics for the LDW Advocacy Survey Questions

Sub-Objective	Survey Question	Mean	Std. Dev.	Mode	Max. Value	Min. Value
Interest in Purchasing						
Question 47, Cost aside, if you were purchasing a new vehicle, how likely would you be to consider purchasing the LDW system?						
1 (Definitely Would Not Consider) – 7 (Definitely Would Consider)		5.2	1.8	7	7	1
Amount Willing to Pay						
Question 49, What is the maximum amount you would pay for the LDW system?						

Sub-Objective	Survey Question	Mean	Std. Dev.	Mode	Max. Value	Min. Value
	Write-In Response	$500	$513	$500	$2,500	$0
Question 50, At the actual price of $300, how likely would you be to consider purchasing LDW if you were purchasing a new vehicle?						
	1 (Definitely Would Not Consider) – 7 (Definitely Would Consider)	5.2	1.9	7	7	1
Willingness to Endorse						
Question 43, I would have used an on/off switch at some point, had it been provided, to turn off the LDW for the rest of my experience.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	2.6	2.0	1	7	1

Table J-12. Descriptive Statistics for the CSW Ease-of-Use Survey Questions

Sub-Objective	Survey Question	Mean	Std. Dev.	Mode
Demand on Driver				
Question 6, The visual CSW warnings were not distracting.				
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.7	1.6	7
Question 7, The CSW Availability icons were not distracting.				
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.3	1.2	7
Question 13, The auditory CSW warnings were not distracting.				
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.6	1.7	7
Question 20, The CSW seat vibration warnings were not distracting.				
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.0	1.5	7
Understanding of Warning				
Question 5, I knew what to do when I saw the CSW visual warnings.				
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.1	1.9	7
Question 8, The CSW Availability icons helped me to understand and to use the CSW system.				
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.8	1.7	7
Question 10, I knew what to do when I heard the CSW auditory warnings.				
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.2	1.4	7
Question 18, I knew what to do when I felt the CSW seat vibration warnings.				
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.0	1.5	7
Question 23, Overall, I could easily identify the urgency of the CSW warnings.				
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.8	1.7	7
Usability				

Sub-Objective	Survey Question	Mean	Std. Dev.	Mode
Question 15, How often did passengers in the car comment on the auditory CSW warnings when they occurred?				
	1 (Not at All) – 7 (Very Often)	4.4	2.3	7
Question 22, Passengers in the car did not notice the CSW seat vibration warnings when they occurred.				
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.0	1.4	7

Table J-13. Descriptive Statistics for the CSW Learning Survey Questions

Sub-Objective	Survey Question	Mean	Std. Dev.	Mode	Max. Value	Min. Value
Ease of Learning						
Question 32, Overall, it was easy to become familiar with the CSW system.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.2	1.3	7	7	1
Question 33, I developed a good understanding of how the CSW system worked after hearing a brief description, and after I had the chance to drive with the system.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	6.4	1.1	7	7	1
Time to Learn						
Question 31, How long did it take before you became comfortable driving the car with CSW? <u>Check one.</u>						
	I became comfortable with the operations of CSW within the first day	36 out of 78 = 46.2%				
	I became comfortable with the operations of CSW within 2 to 3 days	28 out of 78 = 35.9%				
	I became comfortable with the operations of CSW within the first week	7 out of 78 = 9.0%				
	I became comfortable with the operations of CSW within 2 to 3 weeks	3 out of 78 = 3.8%				
	I never became comfortable with the operations of CSW	4 out of 78 = 5.1%				

Table J-14. Descriptive Statistics for the CSW Driver Performance Survey Questions

Sub-Objective	Survey Question	Mean	Std. Dev.	Mode	Max. Value	Min. Value
Awareness						
Question 34, Driving with the CSW system made me more aware of upcoming curves.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.3	1.9	7	7	1
Driving Style Adjustments						
Question 36, I relied on the CSW system.						

Sub-Objective	Survey Question	Mean	Std. Dev.	Mode	Max. Value	Min. Value
	1 (Strongly Disagree) – 7 (Strongly Agree)	3.2	1.8	1	7	1
Question 42, I felt more comfortable performing additional tasks, (e.g., adjusting the heater, operating the radio, talking on a cellular telephone, etc.) while using CSW as compared to manual driving.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	3.9	2.0	4	7	1

Table J-15. Descriptive Statistics for the CSW Perceived Value Survey Questions

Sub-Objective	Survey Question	Mean	Std. Dev.	Mode	Max. Value	Min. Value
Safety						
Question 37, I found the CSW system useful in providing warnings about situations that might have resulted in collisions.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	3.9	2.1	2	7	1
Question 38, CSW is going to increase driving safety.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.2	1.8	7	7	1
Driving Skill						
Question 35, The CSW system made me more attentive to slowing down for curves.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.5	1.8	7	7	1
Question 39, I found the CSW system useful in adverse weather conditions.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	4.4	1.9	4	7	1
Question 40, I found the CSW system useful in light traffic.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	4.3	2.0	4	7	1
Question 41, I found the CSW system useful in heavy traffic.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	4.1	2.0	4	7	1
Tolerance of Warnings						
Question 14, The frequency with which I received auditory CSW warnings was not annoying.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.4	1.9	7	7	1
Question 21, The frequency with which I received CSW seat vibration warnings was not annoying.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	5.4	1.9	7	7	1
Question 28, I did not receive any unnecessary CSW warnings.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	3.8	2.3	1	7	1
Question 29, I did not receive any false CSW warnings.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	3.7	2.4	1	7	1
Question 30, Overall, I received CSW warnings						
	1 (Too Frequently) – 7 (Too Infrequently)	3.9	1.5	4	7	1

Table J-16. Descriptive Statistics for the CSW Advocacy Survey Questions

Sub-Objective	Survey Question	Mean	Std. Dev.	Mode	Max. Value	Min. Value
Interest in Purchasing						
Question 47, Cost aside, if you were purchasing a new vehicle, how likely would you be to consider purchasing the CSW system?						
	1 (Definitely Would Not Consider) – 7 (Definitely Would Consider)	4.3	2.1	4	7	1
Amount Willing to Pay						
Question 49, What is the maximum amount you would pay for the CSW system?						
	Write-In Response	$402	$526	$0	$2,500	$0
Question 50, At the actual price of $500, how likely would you be to consider purchasing CSW if you were purchasing a new vehicle?						
	1 (Definitely Would Not Consider) – 7 (Definitely Would Consider)	3.8	2.2	1	7	1
Willingness to Endorse						
Question 43, I would have used an on/off switch at some point, had it been provided, to turn off the CSW for the rest of my experience.						
	1 (Strongly Disagree) – 7 (Strongly Agree)	2.9	2.2	1	7	1

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