STATUS REPORT ON USDOT PROJECT "AN INTELLIGENT VEHICLE INITIATIVE ROAD DEPARTURE CRASH WARNING FIELD OPERATIONAL TEST"

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ABSTRACT:

In support of the Intelligent Vehicle Initiative (IVI), the U. S. Department of Transportation (USDOT) initiated a field operational test (FOT) program of advanced technology in passenger cars designed to help drivers avoid road-departure crashes caused by drift off-road and/or by traveling too fast for an upcoming curve. A partnership between USDOT and the University of Michigan Transportation Institute (UMTRI), Visteon, and AssistWare Technology, was formed to conduct the "Road Departure Field Operational Test" program.

The goal of the program was to field test a technology designed to prevent or mitigate road-departure crashes and fatalities, which are defined as any single vehicle crash where the first harmful event occurs off the roadway. Statistical reviews of the General Estimates Systems (GES) and the Fatality Analysis Reporting System (FARS) databases, shows that road-departure crashes are the most serious of crash types within the US vehicle crash population. These crashes account for over 20% of all police-reported crashes (1.2 million/year), and over 41% of all in-vehicle fatalities, about (15,000/year).

The FOT vehicle fleet was constructed based on a Nissan Altima platform and consisted of 11 test vehicles, each equipped with the road-departure crash warning system designed and perfected during this program. There were 78 FOT drivers, each driving for a one (1) week baseline, with the system activated but unavailable to the driver, and three (3) weeks with the road-departure crash warning system activated, and available to the driver. During the above (1) week baseline period, all test data was being recorded by the crash warning system, but the system did not provide warnings to the driver. The system did provide warnings to the driver during the (3) week test period. The Field Test required a 10-month time period to conclude the required amount of vehicle driving by the 78 drivers.

The road-departure crash warning system FOT generated a large amount of test data representing the driver performance, driver reactions, and the FOT system performance, during the variety of driving environments encountered by the drivers during the FOT. In addition to the data analysis performed by the contractors, an independent evaluator was also used to study and analyze the resulting FOT test data to determine such things as driver acceptance and safety benefits of the FOT system. The following paper will present a discussion of the magnitude of the road departure safety problem, a brief outline of how the road departure FOT system works, and the FOT results and conclusions to date.

BACKGROUND:

The goal of this project was to field test a technology designed to prevent or mitigate road departure crashes, injuries, and fatalities by warning the driver of an impending road departure. This effort does not include any attempt to use driver active controls in the crash warning system. Road departure crashes are defined as any single vehicle crash where the first harmful event occurs off the roadway, except for backing and pedestrian related crashes. Road departure crashes may also be referred to as "run-off-road crashes", or "lane departure crashes"

The effort to define and quantify the safety benefits of run-off-road crash avoidance systems began over ten years ago and refinements continue to this day. A statistical review of the 1992 General Estimates System (GES) and the Fatality Analysis Reporting System (FARS) databases, as part of a previous NHTSA contract entitled "Run-Off-Road Collision Avoidance Using IVHS Countermeasures", (Report number DOT HS 809 170), indicated that run-off-road crashes are the most serious of the major crash types within the US vehicle crash population. The run-off-road crashes accounted for over 20% of all police-reported vehicle crashes (1.2million/year), and over 41% of all in-vehicle fatalities, about (15,000/year). A recent review of GES 2001 and FARS 2001 data for run-off-road crashes by the NHTSA authors, Figure 1, shows that out of 1,095,000 run-off-road crashes in 2001, the in-vehicle fatalities were 15,436. Thus a run-off-road crash avoidance system could potentially reduce the severity of, or eliminate, about 17.3% of the yearly crashes, and 41% of the yearly fatalities occurring on the nation's highways.

Some of the more important characteristics of road departure crashes found in the 1992 study are listed in Table 1.

Table 1: Important Sources of Road-Departure Crashes (GES 1992)

- Occur Often on Straight Roads (76%)
- Occur on Dry Roads (62%) in Good Weather (73%)
- Occur on Rural or Suburban Roads (75%)
- Occur Almost Evenly Split Between Day and Night

It was also found that run-off-road crashes are caused by a wide variety of factors. Detailed analysis of 200 National Automotive Sampling System (NASS) 1992 crash reports during the previous study, indicated that run-off-road crashes are primarily caused by the following six factors (in decreasing order of frequency) listed in Table 2.

Table 2: Major Causes of Road-Departure Crashes (CDS 1992)

- Excessive Speed (32.0%)
- Driver Incapacitation (20.1%)
- Lost Directional Control (16.0%)
- Evasive Maneuvers (15.7%)
- Driver Inattention (12.7%)
- Vehicle Failure (3.6%)

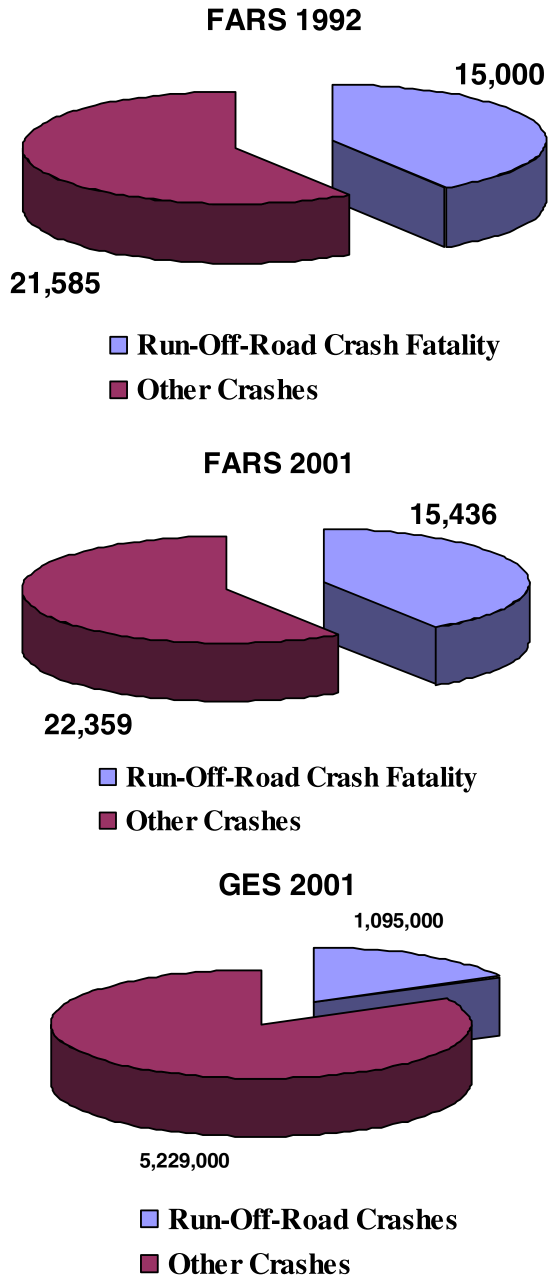

Figure 1: Run-Off-Road Crashes (FARS 1992 and 2001, GES 2001)

Vehicle rollover crashes are known to be particularly severe. The NHTSA 2001 Crashworthiness Data System (CDS) was examined by the NHTSA authors to determine the magnitude of the run-off-road vehicle rollover problem.

The results in Figure 2 show that, out of 217,879 rollover crashes occurring in 2001, 197,788 rollovers, about 91 %, occurred off the roadway. On-roadway rollover crashes accounted for a mere 19,039 rollovers. Thus a run-off-road crash avoidance system could potentially reduce the severity of, or eliminate, about 90% of the off-the-road rollover crashes.

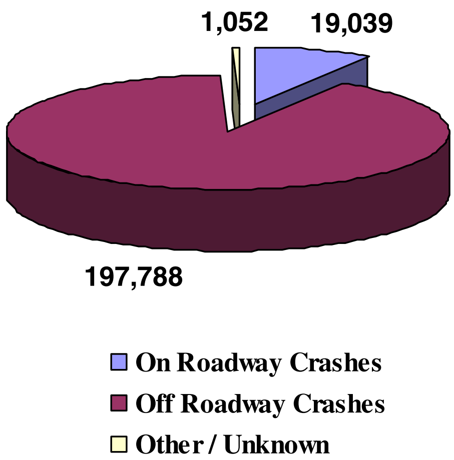

Figure 2: Vehicle Rollover Problem (CDS 2001)

Rollover crashes result in a high percentage of fatalities when compared with other types of crashes. The FARS 2001 database was searched, by the NHTSA authors, to determine the magnitude of the rollover fatality problem. The results are shown in Figure 3.

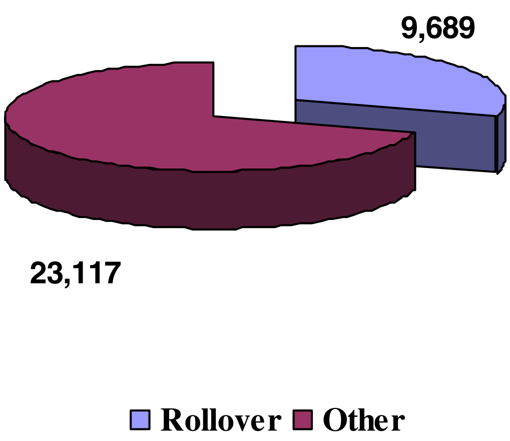

Figure 3: Fatality Problem (FARS 2001)

The results show that out of 32,806 in-vehicle fatalities occurring in 2001, 9,689 of these fatalities resulted from rollover crashes. In addition, the FARS 2001 data base system was examined by the NHTSA authors to determine the percentage of vehicle rollover fatalities resulting from single vehicle off-roadway crashes. The results are shown in Figure 4

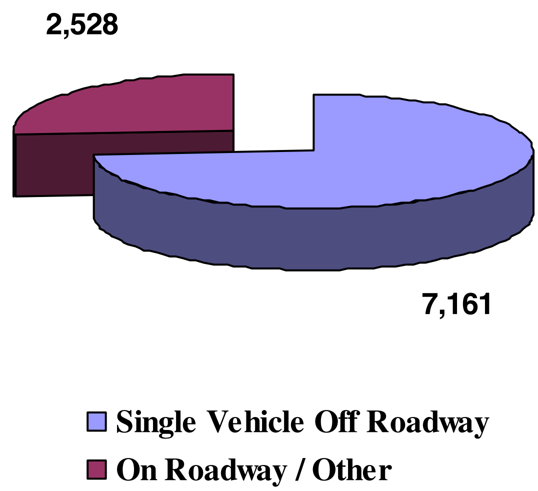

Figure 4: Rollover Fatalities (FARS 2001)

It was found that out of the 9,689 vehicle rollover fatalities occurring in 2001, 7,161 fatalities occurred in single vehicle off-roadway rollover crashes. Thus a run-off-road crash avoidance system has the potential to reduce the severity of, or eliminate, 7,161 single vehicle rollover fatalities or about 22% of the yearly in-vehicle fatalities.

Design Goals of the Run-Off-Road Crash Avoidance System FOT

The run-off-road crash avoidance system field operational test program is being conducted by a partnership between the Federal Highway Administration, the University of Michigan Transportation Institute (UMTRI), AssistWare Technology Corporation, and Visteon Corporation. The run-off-road crash avoidance system developed by the above partners for the field operational test effort is composed of two distinct functionalities, which are Lane Drift Warning (LDW) and Curve Speed Warning (CSW). The LDW function is designed to warn the driver when the vehicle begins to unintentionally drift from the roadway. It uses data about the dynamic state of the vehicle in combination with information about the geometry of the road ahead to determine if the vehicle's current position and orientation may lead to an unintentional road departure. If the likelihood of a roadway departure exceeds a predetermined threshold, vehicle-driver interface functions are triggered to alert the driver of the danger. It is believed that a countermeasure which implements the LDW function has the potential to prevent run-off-road crashes caused primarily by driver inattention, and incapacitation, which together account for approximately 33% (Table 2) of roadway departure crashes.

The second functional goal of the developed run-off-road crash warning system was to develop a curve speed warning capability. The CSW function is designed to warn the driver when the vehicle is traveling too fast for the upcoming curve. It utilizes vehicle dynamic state and performance data in combination with information about the current pavement conditions and upcoming road geometry, derived in real time from an electronic map and Global Positioning System signals, to determine the maximum safe speed for the vehicle through the upcoming curve. If the vehicle's current velocity exceeds the above safe speed for the curve, which is derived as explained above, a sequence of vehicle-driver interface functions is triggered to alert the driver of the danger and avoid a run-off-curve crash. A countermeasure algorithm, which implements the CSW function, has the potential to prevent those run-off-road crashes caused by loss of directional control, due to excessive speed, while negotiating a curve. It is believed that approximately 16% (Table 2) of road departure crashes result from directional control loss while negotiating a curve above a safe speed.

Together, it is estimated that the LDW and CSW functions of the FOT run-off-road crash avoidance warning system, have the potential to prevent or mitigate approximately 50% of all road departure crashes and fatalities.

Components of the Run-Off-Road Crash Avoidance System FOT

Situational Awareness Module

The heart of the system is the Situational Awareness Module, Figure 5, which serves as the information clearinghouse for the countermeasure. This module is where the diverse sensor data regarding the vehicle state and characteristics of the local road environment are merged into a unified representation for use by the other modules. A conceptual representation of the information that is encoded in the Situational Awareness Module is shown in Figure 5.

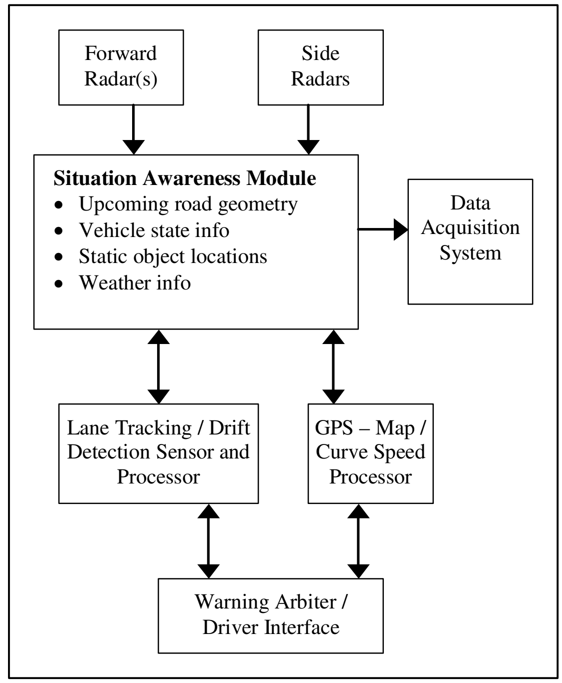

Figure 5: Conceptual Representation of Situational Awareness Module

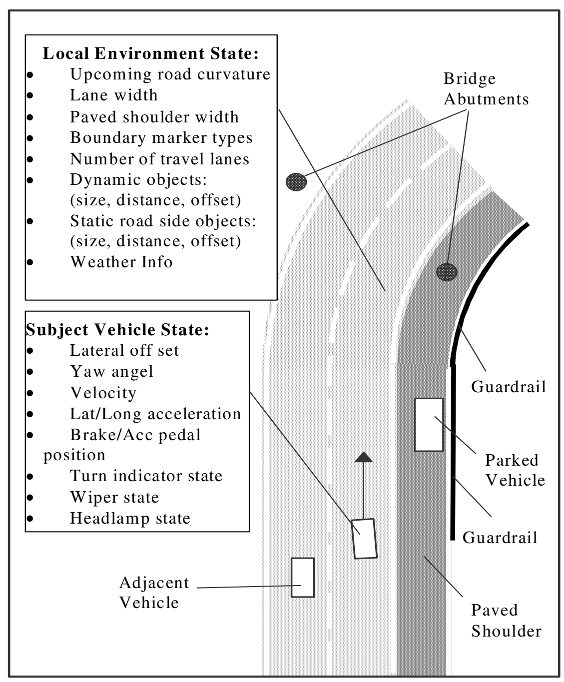

Figure 6: Examples of Situational Awareness Module Input Data

Examples of data merged by the Situational Awareness Module shown in Figure 6 are upcoming road curvature information from the GPS/map module, the Lane Tracking module, and potentially the Forward Radar Module (based on the lead vehicles and/or geometry of continuous roadside features like guard rails). A graphic depiction of the run-off-road crash avoidance system is shown in Figure 7.

"static" designation. Static objects refer to objects like guard rails, bridge abutments or road side trees, which have been observed repeatedly on previous traversals of this stretch of road, and have thus earned a permanent annotation in the map. The Situation Awareness Module maintains a "look-aside" file to the NAVTECH® digital map, to encode the, location and size of these static objects. Information encoded in the Situation Awareness Module, including available maneuvering room and upcoming road curvature, is used to modulate the behavior and decision thresholds of the lane drift and curve speed warning modules.

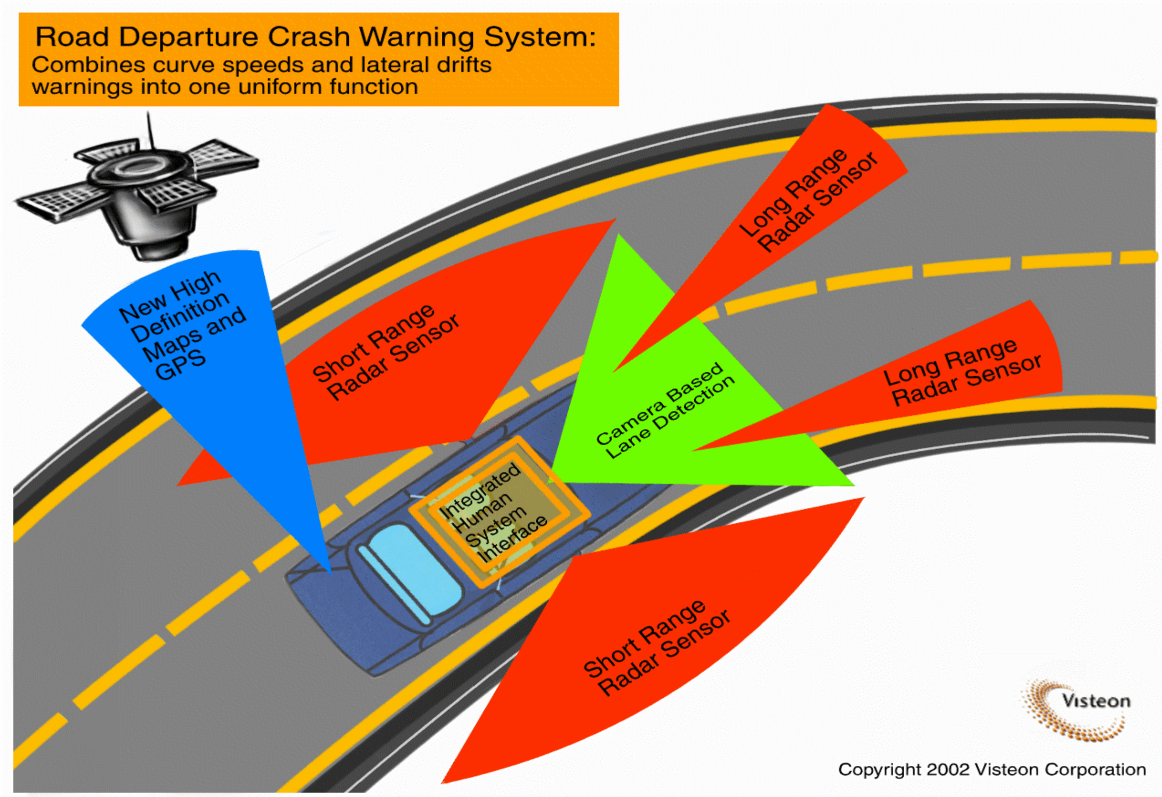

Figure 7: Graphic Depiction of FOT System

The Situational Awareness Module also estimates the maneuvering room available on each side of the travel lane based on estimates of paved shoulder width from the Lane Tracker Module, as well as the locations of objects on the roadside or in the adjacent lane from the forward and side radars.

A very important part of the Situation Awareness Module is the representation for "dynamic" and "static" objects ahead of, and adjacent to, the subject vehicle. In this case, dynamic objects refer to objects not detected on earlier traversals of this stretch of road. These may be temporary objects, like parked vehicles, or permanent objects like bridge abutments, which have not yet been observed enough times to warrant a

Forward Radar(s)

This module merges upcoming object information provided by one or more forward looking radars. These radars provide information to the Situation Awareness Module about the size, distance ahead, and offset from the lane, of forward objects like parked vehicles, roadside trees, and bridge abutments. It is expected that a detection range of 30m to approximately 60m will provide adequate coverage and sufficient forward preview of upcoming roadside objects for the required purpose of estimating roadside maneuvering room. Seeing both the left and right roadside 30-60m ahead requires more than one forward radar sensor. The RDCW system uses an adapted version of the Visteon 77GHz radar developed primarily for adaptive cruise control and forward crash warning applications. The FOT vehicles employ a pair of Visteon forward radars to gain sufficient azimuthal coverage of both sides of the road.

Side Radars

This module senses the lateral proximity of the subject vehicle in order to detect the offset from topographical features on the roadside, including parked vehicles or guardrails. This information is used by the Situation Awareness module to estimate available maneuvering room to each side of the travel lane, as well as to refine the position and offset of objects detected by the forward radar(s) for subsequent designation as a "static" object. Visteon's commercial side-looking radar is used to see, beside and ahead of, the vehicle to a distance of approximately 10 m, complementing the forward radars' detection zone.

Lane Tracking / Drift Detection Camera and Processor

This module serves a dual role in the countermeasure system. It serves as a sensor, for the detection of the vehicle's state relative to the lane (i.e. lateral offset and yaw angle), and for the detection of certain road characteristics (lane width, paved shoulder width, limited curvature preview). It communicates this sensor data to the Situational Awareness module, along with its confidence in its estimates, where the data is merged with other information to build a representation of the local environment.

At the same time, this module serves as the lane drift detection processor. This function involves assessing the danger of a road departure event, based on the vehicle's position in the lane, the vehicle's trajectory, and importantly, the available maneuvering room adjacent to the travel lane. Figure 8 presents a visual depiction of the LDW crash warning system in action. The last piece of information, provided by the local map, provided by the Situation Awareness Module, will be used to modulate the drift warning algorithm's sensitivity. In other words, a lane drift event will be signaled earlier, if limited maneuvering-room is available for recovery, perhaps due to a narrow shoulder or the presence of a roadside object. It is important to note that the maneuvering-room data will serve a modulatory role in the drift warning algorithm. The drift warning system will continue to operate (with reduced accuracy) in the absence of reliable maneuvering room information, however. This is important for purposes of commercial deployment, since it is likely that the first commercial lane drift warning products will not have a sophisticated method for estimating roadside maneuvering room. An AssistWare Technolology SafeTRAC™ lane and drift detection algorithm was built in order to implement the Lane Tracking / Drift Detection Processor. Prior versions of SafeTRAC*™* were tested successfully as part of the Off-road specification program.

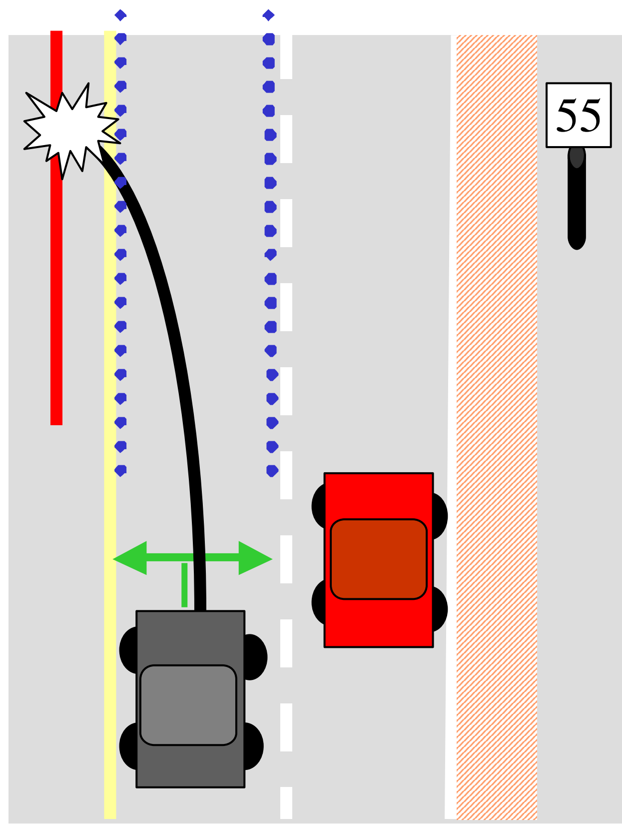

Figure 8: The Lateral Drift Crash Warning Countermeasure

Functional Scenario – Lateral Drift Warning

- Vehicle Drifting Laterally
- Without signaling, then results in
- Driver alert timed, scaled to threat of off road crash

The Lateral Drift Countermeasure Will Identify

- Lane Boundary Positions and Types
- Vehicle position in lane
- Shoulder width
- Crash obstacles, left and right
- Projected path relative to obstacle locations

GPS-Map / Curve Speed Processor

This module plays the same roles for the curve-speed warning function as the Lane Tracking / Drift Detection Processor plays for the lane-drift warning function. In particular, it serves as a sensor, estimating upcoming road geometry based on vehicle position and heading from a GPS system, combined with road information from the digital map database. Figure 9 presents a visual display of the CSW crash warning system in action. This road geometry information is communicated to the Situational Awareness Module, where it is combined with other sensory data, to build a representation of the local environment.

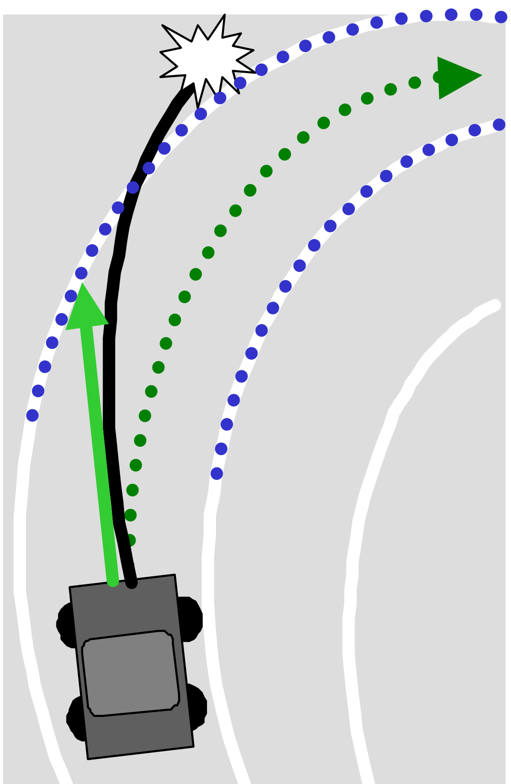

Figure 9: The Curve Over speed Countermeasure

Functional Scenario: Curve Speed Warning

- Vehicle Traveling Too Fast For Upcoming Curve
- Driver alert calls for speed reduction
- Will Identify:
- Curve site geometry and conditions
- Current vehicle path, deceleration, and speed
- Aggregate threat based on the above

Based on information about the upcoming road geometry, and the current vehicle speed provided by the Situational Awareness Module, the GPS-Map / Curve Speed Processor estimates the danger of a speed-induced road departure on the upcoming curve. The GPS-Map / Curve Speed Processor was implemented on the commercially available Visteon NavMate GPS navigation platform. Embedded on this platform is the latest, most accurate NAVTECH® map database called ADAS

Product 1.0. Also running on the NavMate® platform is a modified version of the curve speed warning algorithm developed by AssistWare. A prior version of this algorithm was tested successfully as part of the NHTSA Run-Off-Road specification program. CSW algorithms estimate a maximum safe speed for upcoming curves based on GPS digital maps, with support from the LDW camera and the Situational Awareness Module, and make use of available information on pavement condition (wetness, temperature). Drivers are warned to slow down if the approach speed is perceived as unsafe.

Warning Arbiter / Driver Interface

This module provides the driver with a unified, consistent interface to the roadway departure countermeasure. Its first role is to arbitrate between lane drift warning signals and curve speed warning signals based on the severity of each threat, to avoid driver overload/confusion. It also supports the driver-vehicle interface (DVI), which may include status information during times of low road departure danger, as well as, urgent warnings of an imminent road departure. The details for the status and warnings were determined early in the program based on an extensive set of human factors and proof-tests, and include combinations of visual, auditory, and/or haptic feedback signals. Finally,

a form of limited driver adjustment, of the system sensitivity of the warning algorithm, was provided to achieve a higher level of driver acceptance. Accordingly, this module implements the driver controls for the system sensitivity tuning, the results of which, are communicated to the respective warning processors.
The Warning Arbiter / Driver Inteface functions were implemented on the commercially available Visteon NavMate® system, which is equipped with a high quality display, ideal for showing visual icons/messages. NavMate® also provides a sophisticated sound output capability for generating auditory tones and/or voice feedback. The driver interface for the countermeasure system was developed and implemented by UMTRI and Visteon human factors engineers. It has the “look and feel” of an integrated, production system.

Data Acquisition System

The data acquisition system (DAS), designed and implemented by UMTRI, is designed to acquire and store the data collected onboard each of the field test vehicles. The architecture of the RDCW DAS system affords convenient DAS access to almost all desired data variables through the Situational Awareness Module.

Field Operational Test (FOT) Preliminary Results

The **FOT** was conducted over a time period of 10-months and utilized 78 (Picked to be representative of the driver population) drivers and an 11-vehicle fleet built for the FOT and equipped with the run-off-road crash warning FOT system. Each driver was able to drive a FOT test vehicle for one-week as a baseline with the FOT system operational but unavailable to the driver. The test driver was then allowed to drive the FOT test vehicle with the run-off-road crash warning system operational and available to the driver. Figure 10 is a graphic depiction of a portion of the trips made by test drivers for 3 weeks.

Each test driver was interviewed at the

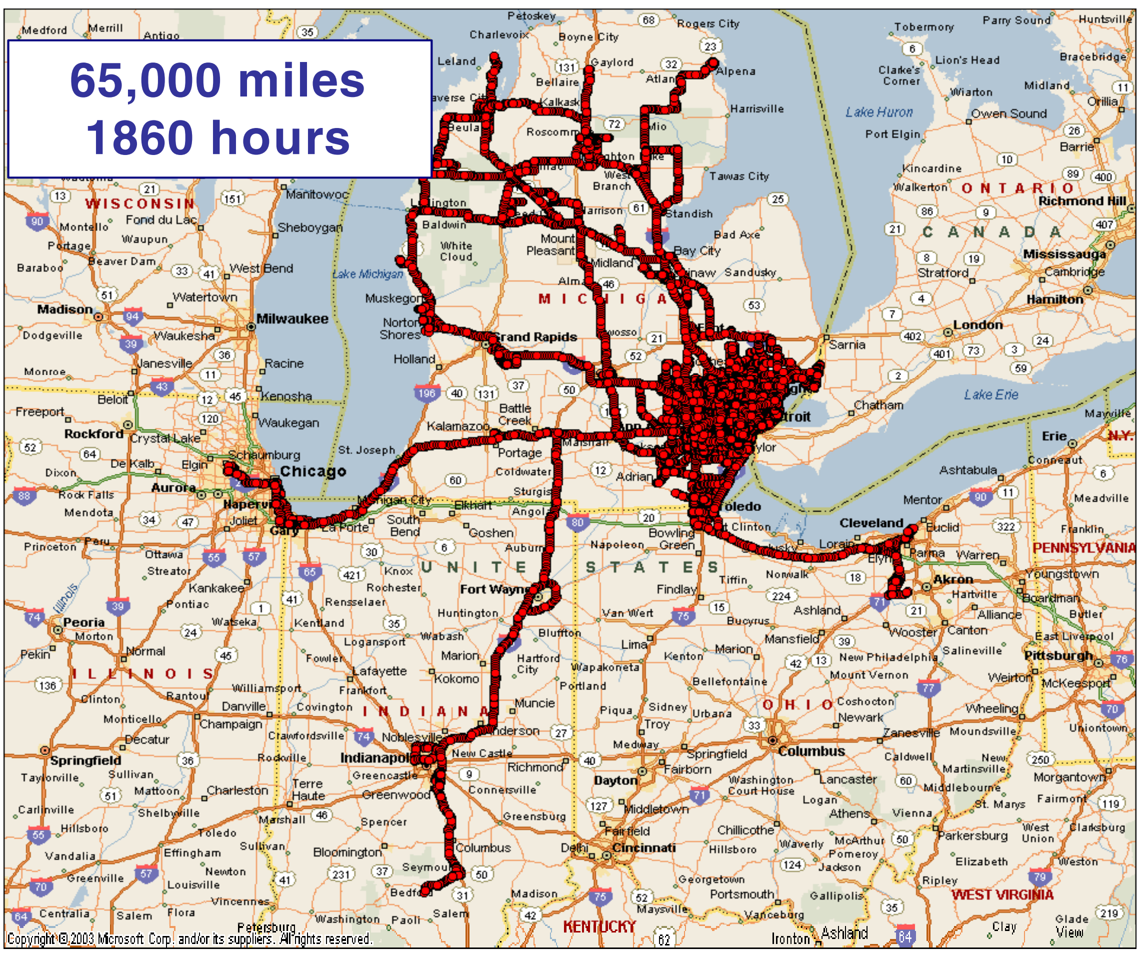

Figure 10: FOT Travel (First 56 Drivers)

conclusion of the 4-week test drive to determine how the driver evaluated the over all performance of the FOT system.

Figure 11 shows the increase in turn signal usage, as a function of time and direction, when performing a lane change maneuver. Use of the FOT run-off-road crash warning system, resulted in an 11% increase in turn signal usage when turning left and a 14% increase when turning right. It is presently believed that the system trained the driver to always use the turn signal when making a lane change.

Preliminary results in Figure 12 show a significant reduction in lane departures and near-departures, compared to baseline, during the three week driving period the FOT system was turned on for the test drivers. Quantitative results and definitions will be available in the final report

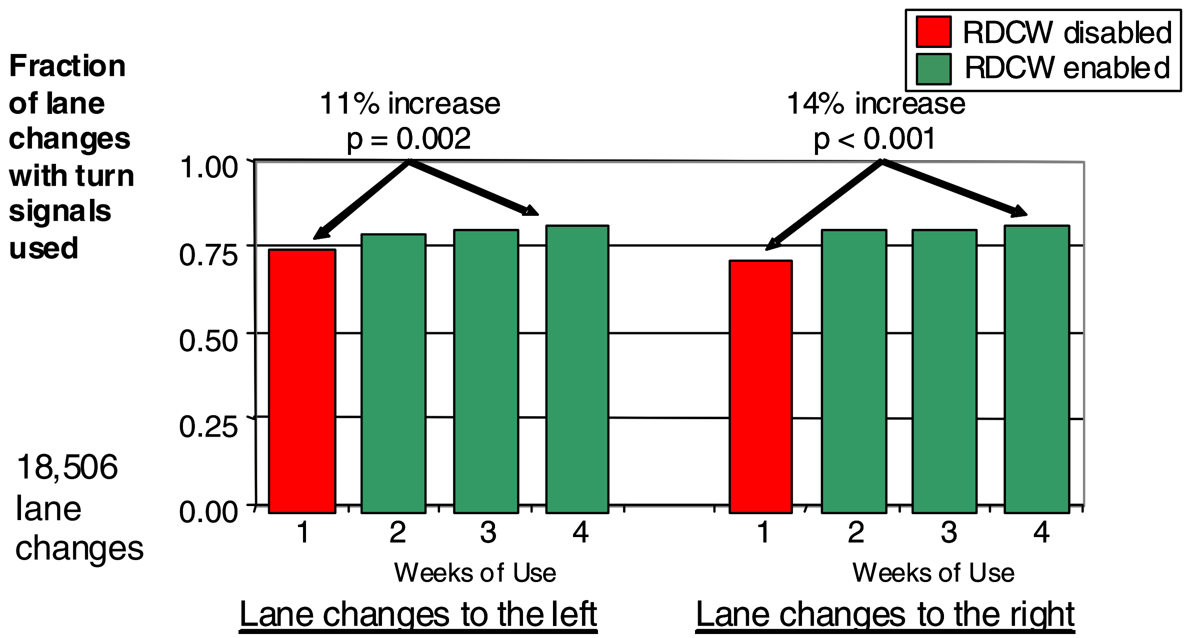

Figure 11: Preliminary Data-Driver Turn Signal Usage

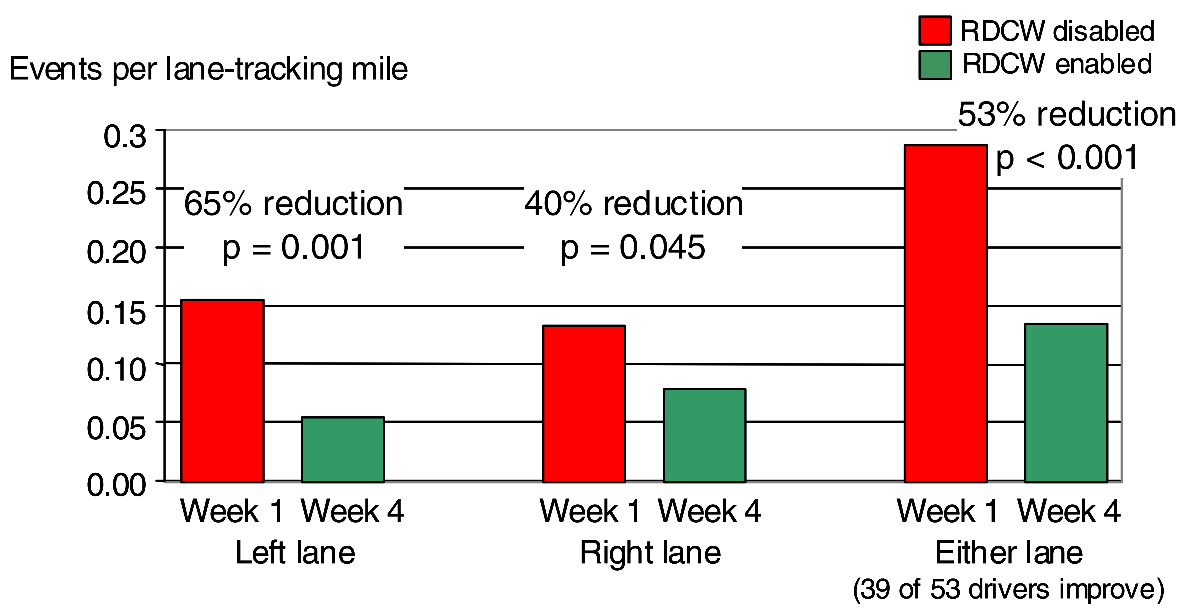

Figure 12: Preliminary Data- Rate of Lane Departures and Near Departures

Preliminary results in Figure 13 show the majority of test drivers believed they received the LDW warning an appropriate number of times. Quantitative results and definitions will be available in the final report

Figure 14 shows that the majority of test drivers believed the operation of the FOT system enhanced the driver's awareness of the vehicle position on the roadway

…..Overall, I received LDW Warnings…..

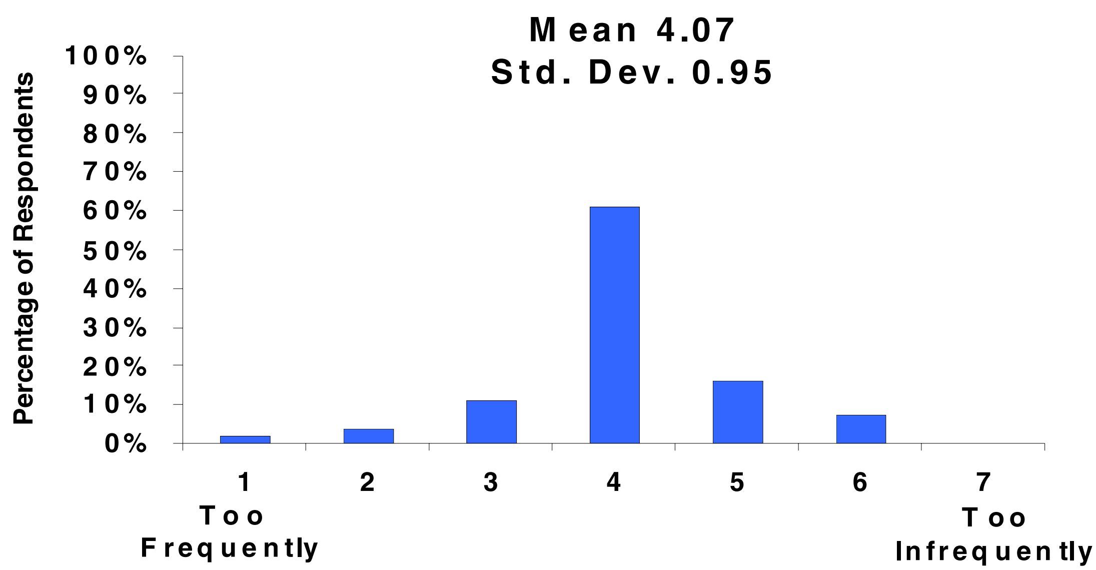

Figure 13: Preliminary Subjective Data- Lane Departure Warnings

Driving with the LDW system made me more aware of the position of my car on the road.

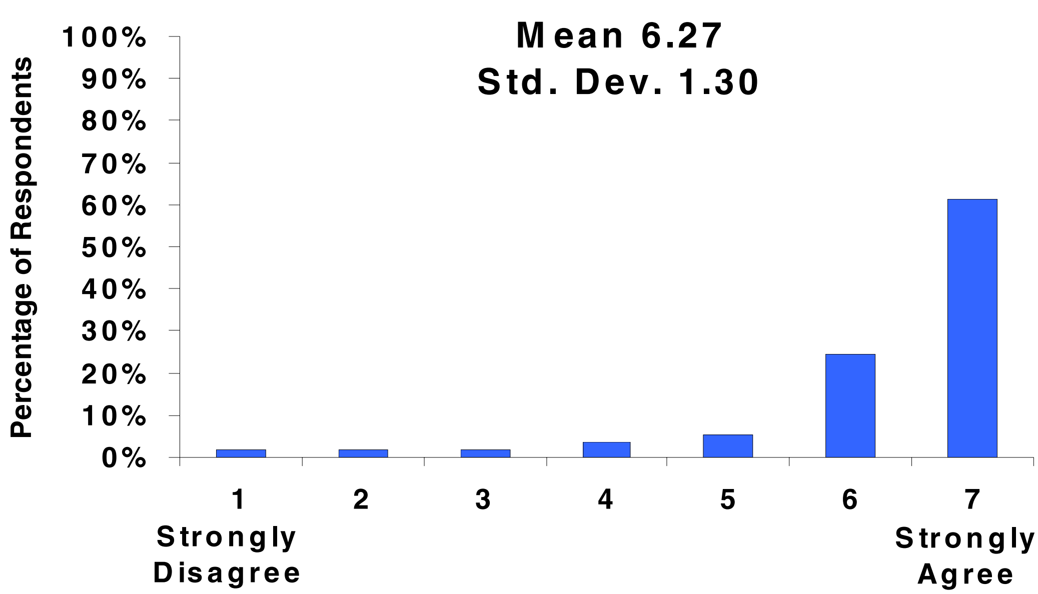

Figure 14: Preliminary Subjective Data- Vehicle Position Awareness

Figure 15 shows that the majority of test drivers believed they received CSW warnings an appropriate number of times.

Figure 16 shows that the majority of test drivers believed the CSW system enhanced their awareness of the upcoming curves.

…..Overall, I received LDW Warnings…..

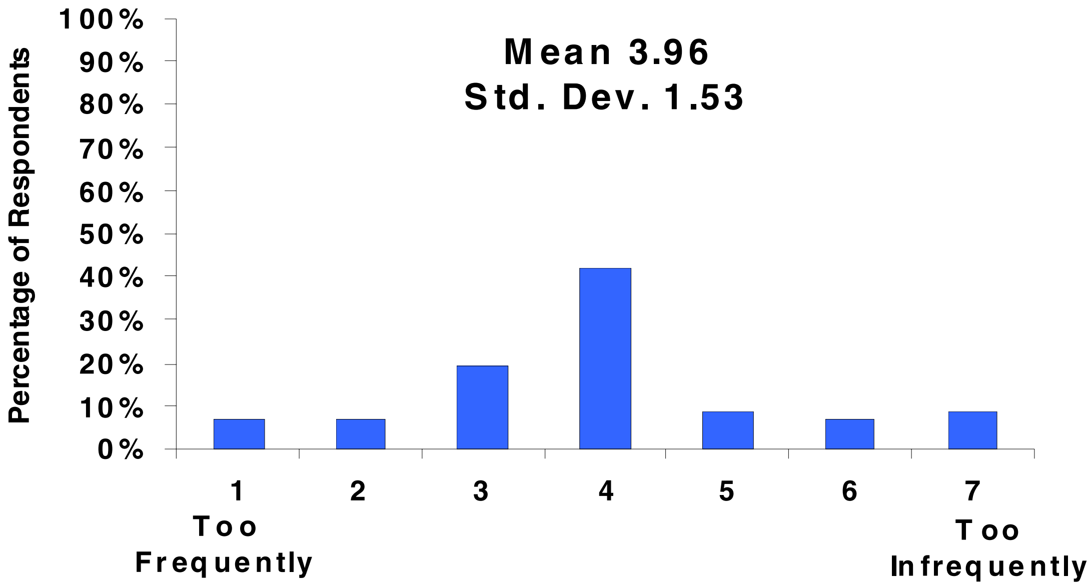

Figure 15: Preliminary Data- CSW Driver Acceptance

Driving with the CSW system made me more aware of upcoming curves…..

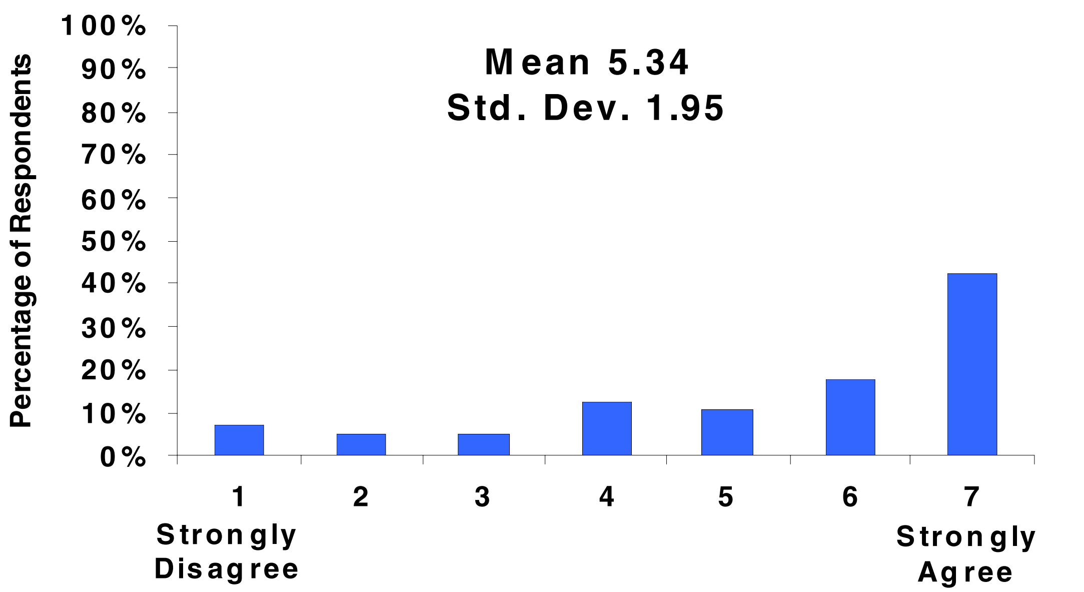

Figure 16: Preliminary Subjective Data- CSW Driver Awareness

Figure 17 shows that the FOT driver/vehicle interface warning system device of a vibrating seat was easy to recognize by the majority of test drivers.

Figure 18 shows that the majority of test drivers believed the presence of a run-off-road crash warning system will increase driving safety.

It was easy to recognize what warning condition the FOT system was attempting to convey from the seat vibration warnings

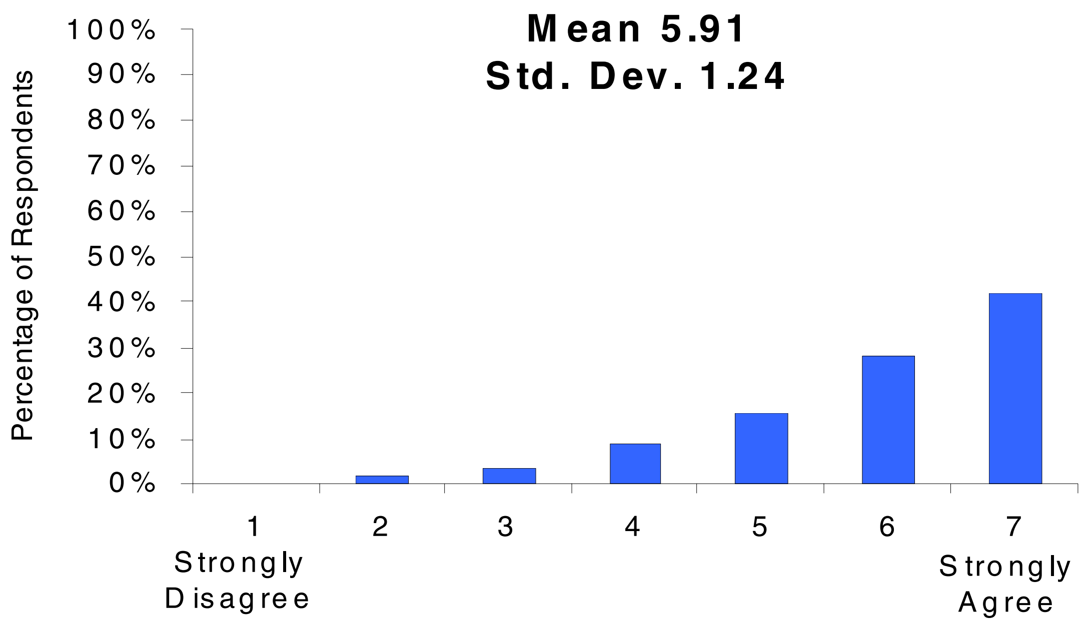

Figure 17: Preliminary Subjective Data- Recognition of Haptic Warnings

I think the Run-Off-Road Crash Warning System is doing to increase driving safety

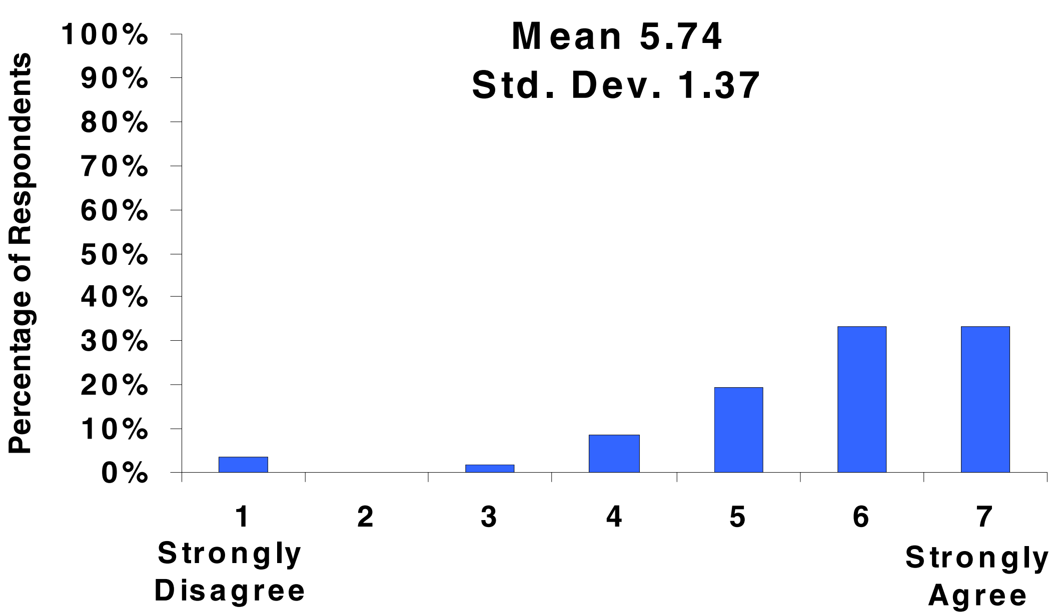

Figure 18: Preliminary Subjective Data- Driver Belief in FOT System Providing Increased Safety

CONCLUSIONS AND BENEFITS

The FOT preliminary test results shown in this paper indicate positive benefits for highway safety. Analysis of final FOT test results will be performed by the project partners and an independent government evaluator. Estimations of possible safety benefits, including crashes prevented and lives saved, provided by run-off-road crash warning systems will be derived and made available at the conclusion of the contract. The final report for the project is scheduled to be completed by July 31, 2005.