DEVELOPMENT OF CRASH WARNING INTERFACE METRICS (CWIM)

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ABSTRACT

Based on the findings of a recent field study, Nodine (2011) reported that 88% of forward collision warning (FCW) system alerts in that study were accurate when the lead vehicle was moving. Similarly, 86% of lane departure warning (LDW) alerts activated accurately when the vehicle departed its lane without signaling. However, safety benefits are only realized when the system is both accurate in identifying a crash imminent situation and when the warning presented to the driver elicits a timely and appropriate response (braking or steering). The National Highway Traffic Safety Administration (NHTSA) is conducting studies under the Crash Warning Interface Metrics (CWIM) program to develop valid and sensitive "distracted driver" protocols for the evaluation of the driver vehicle interfaces (DVIs) of FCW and LDW systems on test tracks and in driving simulators as well as examining potential safety-related effects of consistent DVIs for these warning systems. CWIM focuses on distracted drivers because distraction-affected crashes represent a substantial crash risk, including 9% of the fatal crashes and 18% of injury crashes that occurred in 2010 (NHTSA, 2012). The DVI consists of the displays of the warning system, including the warning itself and associated system status displays. Although controls and settings are available for some systems, their usability and effectiveness are outside of the scope of the CWIM program. In this paper, we review some of the prominent results and methodological issues encountered in studies conducted under the CWIM program and describe how they are addressed in the work that is currently underway.

INTRODUCTION

Prominent findings of the CWIM program and their implications for methods to evaluate FCW and LDW DVIs were presented previously at ESV (Robinson, et al. 2011). The prior paper discussed the selection of crash scenarios, the number of warning activations, research participant characteristics, warning system familiarity, crash event expectations, and the secondary (distraction) tasks that were used in CWIM. The present paper considers additional methodological issues that arise with the development of evaluation protocols and with studies of DVI consistency. We review the results of CWIM program research to date and introduce the studies that are currently underway.

BACKGROUND

CWIM began after NHTSA published DVI recommendations for the human factors design of crash warning system DVIs (Campbell, et al., 2007). These voluntary recommendations were often based on expert opinion rather than empirical evidence, but represented the best detailed guidance available. NHTSA then turned to developing a protocol for crash warning DVI evaluation and also began to examine design issues for warning system DVIs that could potentially reduce their benefits.

Evaluation metrics were the first requirement for DVI evaluation. In Phase 1, the CWIM program identified metrics that had been used in earlier research to evaluate the DVIs of FCWs and LDWs. A Federal Register Notice was published to elicit stakeholder feedback about the program (Federal Register, 2008) and follow-up discussions were held.

Phase 2 of CWIM developed test protocols that provided means of obtaining the metrics identified in Phase 1. A protocol was developed in the National Advanced Driving Simulator (NADS) at the University of Iowa. It was then used in a demonstration study to evaluate the effectiveness of two levels of active lane keeping assistance (steering wheel torque) as well as auditory and haptic (steering wheel vibration) LDWs in preventing unintended lane departures by distracted drivers. The protocol permitted sensitive assessment of how quickly drivers responded to the warnings, the amount of lane exceedance that occurred, and subjective assessment of how drivers perceived the warnings. This effort is summarized in Lerner, et al. (2011). A second Phase 2 effort used a test track protocol developed at the NHTSA Vehicle Research and Test Center to compare individual and combinations of visual, auditory, and haptic (seat belt pre-tensioning) FCW DVI. As described in Forkenbrock, et al. (2011), the protocol identified a relatively effective evaluation metric for imminent crash warnings, the end of visual contact with the distraction task.

This test track protocol demonstration and a simulation protocol demonstration with FCWs generated findings that compared driver performance in response to the warnings to a no-warning baseline condition. Additional research questions arose in these studies regarding how some of the test conditions, including the role of incentives, evaluation platform characteristics, and characteristics of the secondary task used to distract the driver when the warning was given, may have affected protocol sensitivity.

In addition to demonstrating test protocols for LDW and FCW, Phase 2 of CWIM examined the potential for inconsistency of the FCW DVI to cause "negative transfer" when drivers encounter an unfamiliar FCW. The results of a simulation study found a sizable negative effect after the drivers became familiar with an auditory/visual FCW "A" and then drove a "different" vehicle with an unfamiliar FCW "B". Both FCWs were displayed at 85 dB. Other groups of drivers transferred from FCW B to A, A to A (same FCW), and B to B (same FCW) when they drove the "different" vehicle. The simulation included realistic auditory phone alerts (70 dB), an auditory check engine alert, and traffic and road sounds including siren (62 dB). Following transfer, drivers in the A to B transfer condition took twice as long (approximately 1.3 s) to respond by braking than drivers who were familiar with the FCW B (approximately 0.5 s). The corresponding change from B to A did not show this strong effect. Evidence indicated that the traffic and vehicle contextual sounds were perceived as more similar to FCW B than to A, suggesting that the driver may have confused the FCW B with one or more of these other sounds when they were not already familiar

with the warning. Additional study is required to clarify whether the negative transfer effect was limited to the specific auditory context used in the study or if it occurs under other conditions (e.g., with haptic or active FCW).

Some of these follow-up investigations have started and are described in more detail in the following section.

CURRENT STUDIES

Common evaluation protocol

The CWIM program is currently conducting empirical studies to address some of the protocol research questions that remain following the investigations that were discussed above and in Robinson et al. (2011). These prior studies included the use of separate FCW and LDW evaluation protocols to examine the effectiveness of DVIs that present the warning in different ways. As Robinson, et al. describe it, their "intent is specifically to have a common method for evaluating the DVI of a commercial system" (p. 11). In the interest of providing a more practical protocol, the current research uses a combined FCW and LDW evaluation drive. Compared to individual protocols, the combined protocol requires only one simulated drive for the evaluation of two different warnings, and it can be used for the evaluation of a combined warning system or either type of warning individually.

In the current Phase 3 CWIM draws upon the findings of the Phase 2 studies to identify potential methodological improvements that will increase the sensitivity and validity of the test protocols, identify sensitive metrics for LDW and FCW timing, and create a framework for DVI assessment that utilizes these metrics. Also, Phase 3 will compare the sensitivity of protocols across test track and simulation platforms that vary in fidelity and motion base to determine the effect of the platform on protocol sensitivity. Full motion may not be necessary to achieve results similar to what can be obtained in a high fidelity simulator (the NADS-1 with 13 degrees of freedom) or test track. Phase 3 will also extend the Phase 2 test track evaluation protocol work to include the development of a test track evaluation protocol for LDWs.

In the current simulation research a combined LDW-FCW evaluation protocol is used to examine a series of additional methodological alternatives that have arisen in the preceding studies.

1. Since the CWIM program has developed test track and driving simulator methods for assessing the effectiveness of FCW DVIs, it is important to determine whether their results are the same. CWIM is approaching this question by conducting a simulation study that compares the sensitivity of the test track and simulation drives by simulating and comparing findings from both situations.
2. The CWIM program assumes that warnings are particularly needed by distracted drivers. The distraction task provides a realistic context for presenting a forward collision and lane departure situations, and it also encourages the drivers to attribute the situation to their own actions instead of to an artificial and arbitrary experimental procedure. The secondary task used for distracting the driver can also produce data loss if the driver is not distracted from the developing collision or lane departure situation and responds prior to the warning. The test track and simulator studies used somewhat different secondary tasks to distract the driver prior to experimentally creating the forward collision situation that triggered the warning (Forkenbrock, et al., 2011; Lerner, et al., 2011). Phase 3 research compares these and other secondary tasks for potential use in distracting the driver. In the current phase, CWIM will also consider the secondary tasks that are emerging from the Connected Vehicles program (NHTSA, 2011) because they may introduce new sources of driver distraction (Lee, et al., 2012) and provide the context within which drivers will encounter FCW and LDW.
3. The protocol can provide an incentive for secondary (distraction) task performance, representing another methodological alternative. If they are unrealistically highly motivated to complete the secondary task, drivers may not respond as quickly to warnings that interrupt performance, in effect setting an unrealistic criterion. In a current investigation, the CWIM program is varying the task incentive to

determine its effects on protocol sensitivity and data loss.

4. The previous test track scenario surprised the participants by not instructing them in advance that the vehicle was equipped with the FCW. The purpose of the surprise protocol is to reduce the effects of artificial factors such as expectancies on their responses. In contrast, the simulation protocol introduced FCW and LDW through PowerPoint training presentations that portrayed the warnings as one of a variety of features that the participants would experience. Currently CWIM is studying how familiarity generated by instructions or prior exposure to the warning affects simulation protocol sensitivity.
5. The timing of the FCW provides a pair of methodological alternatives. The current research directly compares the previously used warning timings with time-to-collision onsets of 2.1 s and 3.5 s.

In each case, the alternative that will be selected for the recommended protocol needs to contribute both to practical goals such as preventing data loss and statistical goals such as enhanced sensitivity.

In addition to methodological alternatives, the CWIM Program has begun to address the current lack of a common test track evaluation protocol for LDW DVIs. Previously, Rudin-Brown & Noy (2002) compared participant responses to LDW on a test track and in a driving simulator, and found similar lane position effects in the two settings. The authors used a secondary task requiring continuous attention to the dashboard and center console to distract the driver and the LDW system generated warnings when the vehicle was 22 cm from a lane boundary. This method would not appear to provide much control over the frequency of LDWs or circumstances in which they are issued. In order to achieve more control over data collection, lateral movement will be created unobtrusively using differential braking of a trailer attached to the rear of the vehicle while the driver is engaged in secondary task performance. It is expected that the driver will in most cases attribute the movement to inattention so that this method will provide a practical, sensitive evaluation protocol for LDW with relatively precise control over data collection and minimal data loss.

Potential safety effects of consistent DVI components

Current research also examines the potential safety effects of consistent DVI components. One study is examining the repeatability and robustness of the "negative transfer" effect, described above, which indicated a slower response when a driver switches to an "unfamiliar" (simulated) vehicle that has a different-sounding FCW. This finding raised several questions that current research is attempting to answer, but the overall aim is to better understand the effect that was observed in the previous experiment. It examines the effect of a rich auditory environment including a siren and an email alert that had to be silenced on the negative transfer finding and whether the effect is found without this environment. It substitutes a peripheral detection task for the centrally located working memory task used in the preceding study to determine whether the effect occurs when attention is required in the visual periphery.

A second study concerns the effect of a less urgent alert on a driver's response to a FCW when the less urgent alert occurs roughly 350 ms or less prior to the warning (Hibberd, et al., 2010). Several simulation studies have found that responses are delayed when the prior alert occurs during this "psychological refractory period". Examples of prior alerts include e-mail alerts that the driver must silence (Wiese & Lee, 2004) and laboratory choice reaction time tasks (Levy, Pashler & Boer, 2006) performed in a driving simulation. The results could suggest the value of muting or delay of other alerts and messages when the conditions are about to trigger a FCW. Studies are replicating the PRP effect with safety-related warnings including verbal and non-verbal auditory alerts and auditory or haptic (automatic braking) FCWs. The verbal alerts are "traffic ahead," "curve ahead" and "construction ahead," and all indicate that the driver should decrease speed.

Acoustic warning research

Further experimental work is planned to define the dimensions and extent to which FCW signals may vary around a prototype FCW signal and still quickly communicate the warning message to drivers, regardless of past experience with other vehicle

systems (i.e., eliminate negative transfer). Phase 3 will thus assist warning DVI designers through studies of the auditory warning features that result in the categorical perception of a sound as an urgent warning and of the external auditory environment that could mask the perception of these warnings.

CONCLUSION

The findings of the CWIM program will provide practical guidance for the future design and evaluation of FCW and LDW systems. Although the approach has continued to emphasize the evaluation of the DVI component of crash-imminent warnings, it has adapted to the evolving vehicle (and connected vehicle) environment within which these warnings need to operate. This is seen in the current FCW and LDW evaluation protocol studies that will adapt the protocol to an environment in which drivers respond to connected vehicle alerts and in the PRP research where these alerts may occur in close temporal proximity to FCW onset. In this way NHTSA is attempting to provide research findings that can potentially be applied to the design of future warning systems as well as to systems that are beginning to be implemented in the current fleet.

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