3.11 General Discussion

Results indicated differences in both objective (performance) data and subjective (questionnaire-oriented) data across the crash alert types examined. It should be stressed that each of the crash alert modality components of the crash alert types tested were chosen to represent realistic production constraints (e.g., the direct view high head-down display could not be placed higher and more central in the driver's field of view without interfering with a short driver's view of the road), and were well-received by the drivers. The key findings with respect to crash alert modality effects were as follows.

First, the crash alert types including a non-speech tone component resulted in faster brake RTs relative to the crash alert type including a speech component. It should be stressed this RT effect was observed under expected braking conditions during which drivers were experienced with the various crash alert types, as well as under unexpected braking event (Surprise Moving Trials) conditions during which drivers were completely unaware the vehicle was equipped with a FCW system. Together, these data provide compelling evidence against the use of speech crash alerts.

Second, drivers rated the crash alert types including either a speech or brake pulse component as more annoying relative to the remaining crash alert types, under the assumption that FCW system crash alerts would occur in non-threatening situations between once a day to once a week. Driver annoyance is an extremely important consideration in terms of driver acceptance, particularly in the initial introduction of FCW systems.

Third, the brake pulse alert provided a "vehicle slowing" advantage during the delay time interval (i.e., between when the crash alert timing was violated and when the driver braked). Thus, under some conditions, the driver was in a more conservative kinematic scenario at braking onset in the crash alert type condition including a brake pulse component. Furthermore, adding a non-speech tone component to the brake pulse alert significantly reduced the relatively slow brake RTs initially observed in the HHDD + Brake Pulse condition (to remind the reader, HHDD refers to the High Head-Down Display). However, unlike the visual and auditory alerts examined here, there are important unresolved implementation and driver behavior issues surrounding the brake pulse alert. These issues include alert activation on slippery surfaces, onset delays, consequences of moving the driver (and their foot) from their "normal" position in the car, inhibiting more appropriate steering responses, and driver annoyance associated with nuisance alerts. It should be noted that these concerns are equally true for other (relatively immature) haptic alerts which have been suggested. These alerts include accelerator pedal pushback, steering wheel vibration, and seat vibration. If these issues surrounding the brake pulse could be satisfactorily resolved, these exploratory results suggest that the "vehicle slowing" advantage might be beneficial, and that the brake pulse should be "explained" by coupling it with an auditory and visual alert component. Furthermore, it appears the brake pulse cue as implemented in the human factors studies reported in Chapter 3 would be a reasonable candidate for a specific brake pulse implementation.

Fourth, although there were no performance differences associated with the relevant HHDD versus HUD comparisons, subjects indicated a strong preference for the head-up display (or HUD). In a related finding, for a 1-stage crash alert approach, drivers indicated a strong preference for a multi-modality alert approach (particularly a dual-modality crash alert) over a single-modality crash alert approach. Although a dual-modality crash alert approach is supported in terms of accommodating driver preferences, it should be noted the possibility exists that drivers' lack of experience with single-modality alerts may have influenced the observed pattern of driver preferences.

Fifth, after the surprise braking event was experienced by naive drivers, nearly all drivers reported noticing non-speech tone, speech, and brake pulse components of these crash alert types examined, and significantly more drivers noticed the Flashing HHDD and steady HUD relative to the steady HHDD. It should be stressed that each of these drivers were completely unaware the vehicle was equipped with a FCW system crash alert during the testing phase in which the crash alert was first experienced. This data provides direct evidence that the auditory alerts and brake pulse profile established during pilot testing met the goal of providing an alert that would be clearly noticed by naive drivers. In addition, overall, about 3 of 4 subjects indicated that the radio should be muted during the alert. However, it should be noted that these drivers had no direct experience with various types of in-path ("too early") and out-of-path nuisance alerts, which could change this preference for radio muting.

The drivers' ability to notice the visual alerts under surprise conditions varied considerably across the crash alert types. However, it should be stressed that these visual alert noticeability results should be treated somewhat cautiously, since under more typical conditions in which the driver would be aware his/her vehicle was equipped with a visual crash alert, the probability of noticing these visual alerts may increase substantially. Given this caveat, data suggested that flashing the HHDD may be prudent in order to improve the noticeability of the HHDD (which may also be true for a flashing HUD, which was not examined here). This would be particularly true when this alert is coupled only with an auditory crash alert, since some drivers may not hear the alert sound either due to hearing impairments (e.g., older, hearing-impaired drivers or deaf drivers) and/or competing noises coming from either inside or outside the vehicle. Additional important reasons for including a visual alert modality component in any FCW crash alert modality approach are to potentially facilitate the driver to look ahead in response to the crash alert if they are not currently looking ahead at the forward scene, and to help explain the auditory or brake pulse crash alert components to the driver. With respect to this latter point, it is currently common industry practice to provide a visual indicator for most telltale-related sounds.

In addition to these crash alert modality effects, there were also key findings with respect to developing a crash alert timing approach. First, brake RTs observed under the surprise technique resulting in the highest upper percentile values (i.e., the Study 4 head-down visual search task), yielded 85^{th} and 95^{th} percentile (i.e., slower) RTs of 1.2 and 1.5 seconds, respectively. These values are being considered for the assumed driver brake RT in response to the crash alert during the development of crash alert timing requirements for the minimum crash alert timing setting (i.e., latest, most aggressive setting for a FCW system.). These upper percentile values correspond well to the 85th-95th percentile driver perception-response time value of 1.5 seconds recommended by Olson (1996) for "reasonably" straightforward situations. (Olson (1996) provides a review of the driver-perception response time literature). More specifically, these values generally accommodate other relevant sources of previous "surprise" driver brake RT data (Johansson & Rumar, 1971; Olson & Sivak, 1986). Johansson and Rumar (1971) measured 5 driver's brake reaction times to an auditory stimulus (a "buzzer") which was implemented in the driver's own personal vehicle. Four of these drivers were between 25 and 35 years old, and the fifth driver was 50 years old. This buzzer was presented a total of 10 times at random intervals during their normal driving. The interval between buzzer presentations ranged between 1 hour and "more than a week". Drivers were instructed to immediately respond to the buzzer by tapping the brake pedal (without bringing the car to a stop). The first three stimulus presentations were considered practice, and were not reported or included in the driver brake RT analysis. The obtained driver brake reaction times ranged between 0.5 and 1.1 seconds. Olson and Sivak (1986) measured 64 drivers' brake RTs to a 6-inch high by 3-foot wide yellow foam object encountered after cresting a hill on a 2-lane public road. These drivers were led to believe that the purpose of their drive was to become familiar with the route for a study conducted the following day. 49 of these drivers were between 18 and 40 years old, and 15 of these drivers were between 50 and 84 years old. Observed 85^{th} and 95^{th} percentile driver brake reaction times to the obstacle were about 1.3 and 1.6 seconds, respectively. The slightly faster (100 ms faster) upper percentile driver brake RTs obtained in the current study compared to the Olson and Sivak (1986) study may be due to several factors, including drivers associating increased crash risk with the surprise scenario employed in the current study relative to the surprise scenario employed in the Olson and Sivak (1986) study.

Second, results clearly indicated that the timing approach employed was subjectively rated by drivers (on average) as "just right" timing under a wide range of combinations of driver speed and lead vehicle decelerations under both expected and unexpected (surprise) lead vehicle braking event conditions. Most importantly, this crash alert timing approach allowed nearly all drivers to respond to the crash alert in a manner which allowed them to avoid impacts during Surprise Moving Trials with the surrogate lead vehicle. During 3.7% of the Surprise Moving Trials conducted (four of 108) across all three interface studies, the passenger-side experimenter intervened to assist the driver in coming to a stop. In 3 of these 4 cases, the driver contacted the brake first. It remains unclear in any of these 4 cases whether these drivers could have avoided impact with the surrogate target (if given the opportunity) without the assistance of the passenger-side experimenter. Overall, these findings provide strong evidence that the deceleration-based crash alert timing approach directly derived/modeled from the CAMP Study 1 findings does an excellent job from a driver performance and preference perspective under both alerted and surprise braking event conditions (i.e., not too early/not too late). These crash alert timing findings are extremely important from a methodological validity standpoint, since *how* to present crash alert information is intimately related to *when* this information is presented. Put in another way, these findings bolster the validity of both the objective and subjective data gathered with respect to the various crash alert types examined, since the crash alert types were presented at an appropriate perceived timing.

Third, it has been argued that a driver following a lead vehicle at a short time headway may be more alert, and hence, have faster brake RTs than a driver following a lead vehicle at a longer (i.e., more conservative) headway (Farber, 1997). These data provide clear evidence against such an assumption, and more generally, against any crash alert timing approach that assumes drivers' brake RTs are related to time headways. Across all studies employing Surprise Moving Trials, the Pearson correlation coefficients (r) between drivers' brake RTs and time headways at lead vehicle braking onset were extremely low. (The corresponding r-values for Study 2, Study 3, and Study 4 were + 0.07, -0.18, and –0.18, respectively.)

Finally, results from a “name the system” questionnaire favored the inclusion of “Forward Collision” as part of the system name (rather than for example, “Rear-End Collision”), in spite of the instruction that the system was not designed for detecting pedestrians (and hence, not everything in the forward scene). However, it should be stressed these naming data are strictly based on driver preferences, and do not provide direct data on what driver expectations (in terms of system performance) would be associated with each of these proposed names. An “open-ended” questionnaire employing naive subjects would provide more direct data for assessing the association between system name and driver expectations.

In summary, the crash alert timing approach developed in CAMP Study 1 (the CAMP required-deceleration based algorithm) received strong validation in these three interface studies. This timing approach appears very promising, and merits future closed-course and in-traffic testing. Of the 1-stage, FCW crash alert types examined, the “Flashing HHDD + Non-Speech Tone” is recommended as a near-term approach (Replacing the flashing HHDD with a “steady” HUD” is also supported by these findings.). The “Steady HHDD + Non-Speech Tone” crash alert type provided good all-around performance in terms of both objective data (e.g., fast driver brake RTs) and subjective data (e.g., low driver annoyance). The recommendation to flash the HHDD is primarily based on improving the noticeability of the HHDD for drivers who may not hear the non-speech tone either due to hearing impairments and/or noises coming from either inside or outside the vehicle. Other considerations include potentially facilitating the driver to look ahead in response to the visual crash alert, and using this visual alert to help explain the non-speech tone to the driver. The recommended visual display format (a “car-star-car” crash icon with the word “WARNING” printed below) and non-speech tone correspond to those tested in these three interface studies. Prior to these studies, the visual display formats and the auditory alerts were down-sized from numerous alternatives based on questionnaire studies (following ANSI procedures) and laboratory studies, respectively.

Although a multiple-stage alert is allowed under the proposed requirements, a 1-Stage alert is recommended based on the current discovery of a proper “single-point” crash alert timing approach, compatibility with Adaptive Cruise Control system driver alerts being considered, simplicity/elegance from a customer education (mental model) and production implementation perspective, minimizing nuisance alerts, and the rapid (potentially confusing) sequencing of multi-stage alerts in many closing scenarios likely to trigger crash alerts. Indeed, one could argue that multiple-stage (e.g., 2-stage) alerts should be avoided unless the advantages of using such alerts outweigh the disadvantages of such alerts.

A critical consideration in recommending the “Flashing HHDD + Non-Speech Tone” alert as a near-term FCW crash alert approach is that this alert type has favorable qualities from an industry-wide, international implementation perspective relative to the HUD, brake pulse, and speech crash alert components examined (in any case, the speech alert component performed poorly in terms of both objective and subjective data). In the near-term, HUDs will not be implemented industry-wide. Furthermore, as discussed above, there are important unresolved implementation and driver behavior issues surrounding the brake pulse alert (and haptic alerts in general).

Based primarily on data from these three interface studies and the previous baseline study (CAMP Study 1), a set of minimum driver interface requirements were developed, which are discussed in Chapter 4.