SAVE-IT

SAfety VEhicles using adaptive Interface Technology (Task 1)

CRASHES AND DRIVER DISTRACTION: A REVIEW OF DATABASES, CRASH SCENARIOS, AND DISTRACTED-DRIVING SCENARIOS

Prepared by

David W. Eby, Ph.D.
UMTRI
Phone: (734)-763-2466
Email: eby@umich.edu

Lidia P. Kostyniuk, Ph.D.
UMTRI
Phone: (734)-763-2466
Email: lidakost@umich.edu

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1.0 PROGRAM OVERVIEW

Driver distraction is a major contributing factor to automobile crashes. NHTSA has
Driver distraction is a major contributing factor to automobile crashes. National Highway Traffic Safety Administration (NHTSA) has estimated that approximately 25% of crashes are attributed to driver distraction and inattention (Wang, Knipling, & Goodman, 1996). The issue of driver distraction may become worse in the next few years because more electronic devices (e.g., cell phones, navigation systems, wireless Internet and email devices) are brought into vehicles that can potentially create more distraction. In response to this situation, the John A. Volpe National Transportation Systems Center (VNTSC), in support of NHTSA's Office of Vehicle Safety Research, awarded a contract to Delphi Electronics & Safety to develop, demonstrate, and evaluate the potential safety benefits of adaptive interface technologies that manage the information from various in-vehicle systems based on real-time monitoring of the roadway conditions and the driver's capabilities. The contract, known as SAfety VEhicle(s) using adaptive Interface Technology (SAVE-IT), is designed to mitigate distraction with effective countermeasures and enhance the effectiveness of safety warning systems.

The SAVE-IT program serves several important objectives. Perhaps the most important objective is demonstrating a viable proof of concept that is capable of reducing distraction-related crashes and enhancing the effectiveness of safety warning systems. Program success is dependent on integrated closed-loop principles that, not only include sophisticated telematics, mobile office, entertainment and safety warning systems, but also incorporate the state of the driver. This revolutionary closed-loop vehicle environment will be achieved by measuring the driver's state, assessing the situational threat, prioritizing information presentation, providing adaptive countermeasures to minimize distraction, and optimizing advanced collision warning.

To achieve the objective, Delphi Electronics & Safety has assembled a comprehensive team including researchers and engineers from the University of Iowa, University of Michigan Transportation Research Institute (UMTRI), General Motors, Ford Motor Company, and Seeing Machines, Inc. The SAVE-IT program is divided into two phases shown in Figure i. Phase I spans one year (March 2003--March 2004) and consists of nine human factors tasks (Tasks 1-9) and one technology development task (Task 10) for determination of diagnostic measures of driver distraction and workload, architecture concept development, technology development, and Phase II planning. Each of the Phase I tasks is further divided into two sub-tasks. In the first sub-tasks (Tasks 1, 2A-10A), the literature is reviewed, major findings are summarized, and research needs are identified. In the second sub-tasks (Tasks 1, 2B-10B), experiments will be performed and data will be analyzed to identify diagnostic measures of distraction and workload and determine effective and driver-friendly countermeasures. Phase II will span approximately two years (October 2004--October 2006) and consist of a continuation of seven Phase I tasks (Tasks 2C--8C) and five additional tasks (Tasks 11-15) for algorithm and guideline development, data fusion, integrated countermeasure development, vehicle demonstration, and evaluation of benefits.

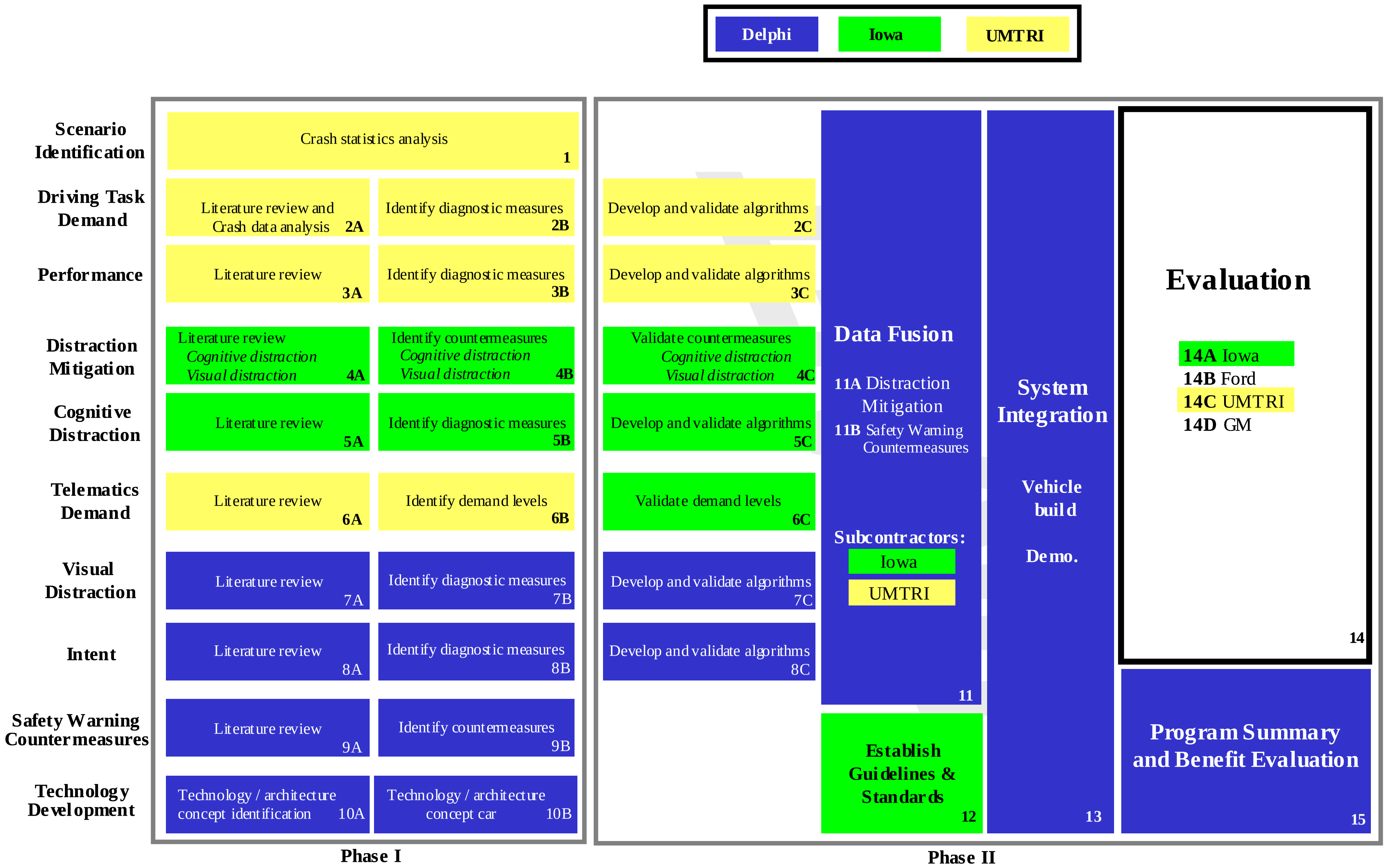

Figure i: SAVE-IT tasks

It is worthwhile to note the SAVE-IT tasks in Figure i are inter-related. They have been chosen to provide necessary human factors data for a two-pronged approach to address the driver distraction and adaptive safety warning countermeasure problems.

The first prong (Safety Warning Countermeasures sub-system) uses driver distraction, intent, and driving task demand information to adaptively adjust safety warning systems such as forward collision warning (FCW) systems in order to enhance system effectiveness and user acceptance. Task 1 is designed to determine which safety warning system(s) should be deployed in the SAVE-IT system. Safety warning systems will require the use of warnings about immediate traffic threats without an annoying rate of false alarms and nuisance alerts. Both false alarms and nuisance alerts will be reduced by system intelligence that integrates driver state, intent, and driving task demand information that is obtained from Tasks 2 (Driving Task Demand), 3 (Performance), 5 (Cognitive Distraction), 7 (Visual Distraction), and 8 (Intent).

The safety warning system will adapt to the needs of the driver. When a driver is cognitively and visually attending to the lead vehicle, for example, the warning thresholds can be altered to delay the onset of the FCW alarm or reduce the intrusiveness of the alerting stimuli. When a driver intends to pass a slow-moving lead vehicle and the passing lane is open, the auditory stimulus might be suppressed in order to reduce the alert annoyance of a FCW system. Decreasing the number of false positives may reduce the tendency for drivers to disregard safety system warnings. Task 9 (Safety Warning Countermeasures) will investigate how driver state and intent information can be used to adapt safety warning systems to enhance their effectiveness and user acceptance. Tasks 10 (Technology Development), 11 (Data Fusion), 12 (Establish Guidelines and Standards), 13 (System Integration), 14 (Evaluation), and 15 (Program Summary and Benefit Evaluation) will incorporate the research results gleaned from the other tasks to demonstrate the concept of adaptive safety warning systems and evaluate and document the effectiveness, user acceptance, driver understandability, and benefits and weaknesses of the adaptive systems. It should be pointed out that the SAVE-IT system is a relatively early step in bringing the driver into the loop and therefore, system weaknesses will be evaluated, in addition to the observed benefits.

The second prong of the SAVE-IT program (Distraction Mitigation sub-system) will develop adaptive interface technologies to minimize driver distraction to mitigate against a global increase in risk due to inadequate attention allocation to the driving task. Two examples of the distraction mitigation system include the delivery of a gentle warning and the lockout of certain telematics functions when the driver is more distracted than what the current driving environment allows. A major focus of the SAVE-IT program is the comparison of various mitigation methods in terms of their effectiveness, driver understandability, and user acceptance. It is important that the mitigation system does not introduce additional distraction or driver frustration. Because the lockout method has been shown to be problematic in the aviation domain and will likely cause similar problems for drivers, it should be carefully studied before implementation. If this method is not shown to be beneficial, it will not be implemented.

The distraction mitigation system will process the environmental demand (Task 2: Driving Task Demand), the level of driver distraction [Tasks 3 (Performance), 5 (Cognitive Distraction), 7 (Visual Distraction)], the intent of the driver (Task 8: Intent), and the telematics distraction potential (Task 6: Telematics Demand) to determine which functions should be advised against under a particular circumstance. Non-driving task information and functions will be prioritized based on how crucial the information is at a specific time relative to the level of driving task demand. Task 4 will investigate distraction mitigation strategies and methods that are very well accepted by the users (i.e., with a high level of user acceptance) and understandable to the drivers. Tasks 10 (Technology Development), 11 (Data Fusion), 12 (Establish Guidelines and Standards), 13 (System Integration), 14 (Evaluation), and 15 (Program Summary and Benefit Evaluation) will incorporate the research results gleaned from the other tasks to demonstrate the concept of using adaptive interface technologies in distraction mitigation and evaluate and document the effectiveness, driver understandability, user acceptance, and benefits and potential weaknesses of these technologies.

In particular, driving task demand and driver state (including driver distraction and impairment) form the major dimensions of a driver safety system. It has been argued that crashes are frequently caused by drivers paying insufficient attention when an unexpected event occurs, requiring a novel (non-automatic) response. As displayed in Figure ii, attention to the driving task may be depleted by driver impairment (due to drowsiness, substance use, or a low level of arousal) leading to diminished attentional resources, or allocation to non-driving tasks[1]. Because NHTSA is currently sponsoring other impairment-related studies, the assessment of driver impairment is not included in the SAVE-IT program at the present time. One assumption is that safe driving requires that attention be commensurate with the driving demand or unpredictability of the environment. Low demand situations (e.g., straight country road with no traffic at daytime) may require less attention because the driver can usually predict what will happen in the next few seconds while the driver is attending elsewhere. Conversely, high demand (e.g., multi-lane winding road with erratic traffic) situations may require more attention because during any time attention is diverted away, there is a high probability that a novel response may be required. It is likely that most intuitively drivers take the driving-task demand into account when deciding whether or not to engage in a non-driving task. Although this assumption is likely to be valid in a general sense, a counter argument is that problems may also arise when the situation appears to be relatively benign and drivers overestimate the predictability of the environment. Driving environments that appear to be predictable may therefore leave drivers less prepared to respond when an unexpected threat does arise.

A safety system that mitigates the use of in-vehicle information and entertainment system (telematics) must balance both attention allocated to the driving task that will be assessed in Tasks 3 (Performance), 5 (Cognitive Distraction), and 7 (Visual Distraction) and attention demanded by the environment that will be assessed in Task 2 (Driving Task Demand). The goal of the distraction mitigation system should be to keep the level of attention allocated to the driving task above the attentional requirements demanded by the current driving environment. For example, as shown in Figure ii, "routine" driving

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[1] The distinction between driving and non-driving tasks may become blurred sometimes. For example, reading street signs and numbers is necessary for determining the correct course of driving, but may momentarily divert visual attention away from the forward road and degrade a driver's responses to unpredictable danger evolving in the driving path. In the SAVE-IT program, any off-road glances, including those for reading street signs, will be assessed in terms of visual distraction and the information about distraction will be fed into adaptive safety warning countermeasures and distraction mitigation sub-systems.

may suffice during low or moderate driving task demand, slightly distracted driving may be adequate during low driving task demand, but high driving task demand requires attentive driving.

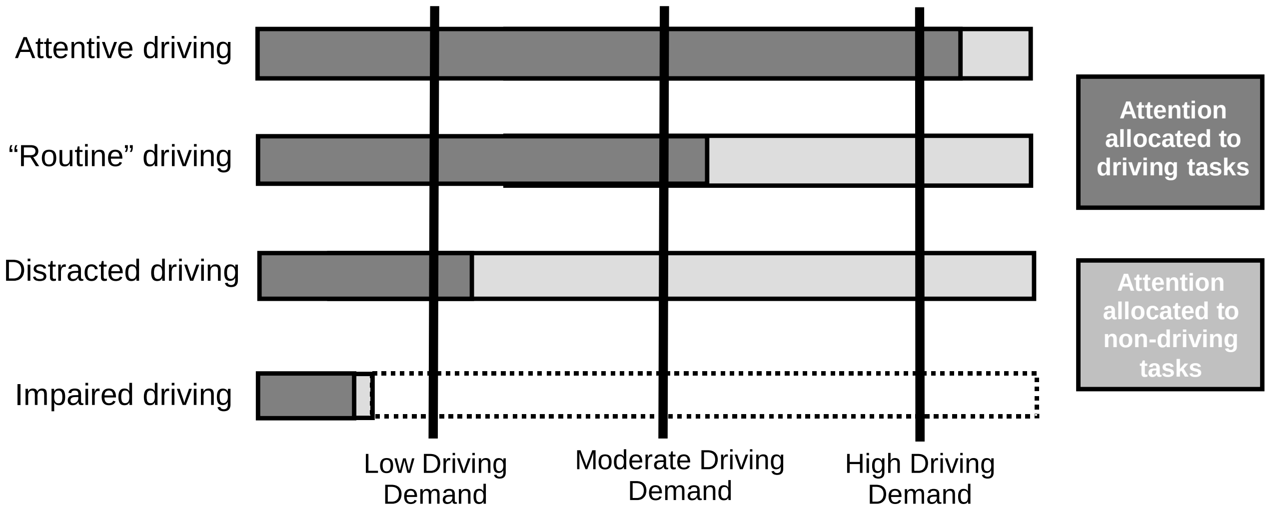

Figure ii. Attention allocation to driving and non-driving tasks

It is important to note that the SAVE-IT system addresses both high-demand and low-demand situations. With respect to the first prong (Safety Warning Countermeasures sub-system), the safety warning systems (e.g., the FCW system) will always be active, regardless of the demand. Sensors will always be assessing the driving environment and driver state. If traffic threats are detected, warnings will be issued that are commensurate with the real time attentiveness of the driver, even under low-demand situations. With respect to the second prong (Distraction Mitigation sub-system), driver state including driver distraction and intent will be continuously assessed under all circumstances. Warnings may be issued and telematics functions may be screened out under both high-demand and low-demand situations, although the threshold for distraction mitigation may be different for these situations.

It should be pointed out that drivers tend to adapt their driving, including distraction behavior and maintenance of speed and headway, based on driving (e.g., traffic and weather) and non-driving conditions (e.g., availability of telematics services), either consciously or unconsciously. For example, drivers may shed non-driving tasks (e.g., ending a cell phone conversation) when driving under unfavorable traffic and weather conditions. It is critical to understand this "driver adaptation" phenomenon. In principle, the "system adaptation" in the SAVE-IT program (i.e., adaptive safety warning countermeasures and adaptive distraction mitigation sub-systems) should be carefully implemented to ensure a fit between the two types of adaptation: "system adaptation" and "driver adaptation". One potential problem in a system that is inappropriately implemented is that the system and the driver may be reacting to each other in an unstable manner. If the system adaptation is on a shorter time scale than the driver adaptation, the driver may become confused and frustrated. Therefore, it is important to take the time scale into account. System adaptation should fit the driver's mental model in order to ensure driver understandability and user acceptance. Because of individual difference, it may also be important to tailor the system to individual drivers in order to maximize driver understandability and user acceptance. Due to resource constraints, however, a nominal driver model will be adopted in the initial SAVE-IT system. Driver profiling, machine learning of driver behavior, individual difference-based system tailoring may be investigated in future research programs.

Communication and Commonalities Among Tasks and Sites

In the SAVE-IT program, a "divide-and-conquer" approach has been taken. The program is first divided into different tasks so that a particular research question can be studied in a particular task. The research findings from the various tasks are then brought together to enable us to develop and evaluate integrated systems. Therefore, a sensible balance of commonality and diversity is crucial to the program success. Diversity is reflected by the fact that every task is designed to address a unique question to achieve a particular objective. As a matter of fact, no tasks are redundant or unnecessary. Diversity is clearly demonstrated in the respective task reports. Also documented in the task reports is the creativity of different task owners in attacking different research problems.

Task commonality is very important to the integration of the research results from the various tasks into a coherent system and is reflected in terms of the common methods across the various tasks. Because of the large number of tasks (a total of 15 tasks depicted in Figure i) and the participation of multiple sites (Delphi Electronics & Safety, University of Iowa, UMTRI, Ford Motor Company, and General Motors), close coordination and commonality among the tasks and sites are key to program success. Coordination mechanisms, task and site commonalities have been built into the program and are reinforced with the bi-weekly teleconference meetings and regular email and telephone communications. It should be pointed out that little time was wasted in meetings. Indeed, some bi-weekly meetings were brief when decisions can be made quickly, or canceled when issues can be resolved before the meetings. The level of coordination and commonality among multiple sites and tasks is unprecedented and has greatly contributed to program success. A selection of commonalities is described below.

Commonalities Among Driving Simulators and Eye Tracking Systems In Phase I
Although the Phase I tasks are performed at three sites (Delphi Electronics & Safety, University of Iowa, and UMTRI), the same driving simulator software, Drive Safety™ (formerly called GlobalSim™) from Drive Safety Inc., and the same eye tracking system, FaceLab™ from Seeing Machines, Inc. are used in Phase I tasks at all sites. The performance variables (e.g., steering angle, lane position, headway) and eye gaze measures (e.g., gaze coordinate) are defined in the same manner across tasks.

Common Dependent Variables An important activity of the driving task is tactical maneuvering such as speed and lane choice, navigation, and hazard monitoring. A key component of tactical maneuvering is responding to unpredictable and probabilistic events (e.g., lead vehicle braking, vehicles cutting in front) in a timely fashion. Timely responses are critical for collision avoidance. If a driver is distracted, attention is diverted from tactical maneuvering and vehicle control, and consequently, reaction time (RT) to probabilistic events increases. Because of the tight coupling between reaction time and attention allocation, RT is a useful metric for operationally defining the concept of driver distraction. Furthermore, brake RT can be readily measured in a driving simulator and is widely used as input to algorithms, such as the forward collision warning algorithm (Task 9: Safety Warning Countermeasures). In other words, RT is directly related to driver safety. Because of these reasons, RT to probabilistic events is chosen as a primary, “ground-truth” dependent variable in Tasks 2 (Driving Task Demand), 5 (Cognitive Distraction), 6 (Telematics Demand), 7 (Visual Distraction), and 9 (Safety Warning Countermeasures).

Because RT may not account for all of the variance in driver behavior, other measures such as steering entropy (Boer, 2001), headway, lane position and variance (e.g., standard deviation of lane position or SDLP), lane departures, and eye glance behavior (e.g., glance duration and frequency) are also be considered. Together these measures will provide a comprehensive picture about driver distraction, demand, and workload.

Common Driving Scenarios For the tasks that measure the brake RT, the "lead vehicle following" scenario is used. Because human factors and psychological research has indicated that RT may be influenced by many factors (e.g., headway), care has been taken to ensure a certain level of uniformity across different tasks. For instance, a common lead vehicle (a white passenger car) was used. The lead vehicle may brake infrequently (no more than 1 braking per minute) and at an unpredictable moment. The vehicle braking was non-imminent in all experiments (e.g., a low value of deceleration), except in Task 9 (Safety Warning Countermeasures) that requires an imminent braking. In addition, the lead vehicle speed and the time headway between the lead vehicle and the host vehicle are commonized across tasks to a large extent.

Subject Demographics It has been shown in the past that driver ages influence driving performance, user acceptance, and driver understandability. Because the age effect is not the focus of the SAVE-IT program, it is not possible to include all driver ages in every task with the budgetary and resource constraints. Rather than using different subject ages in different tasks, however, driver ages are commonized across tasks. Three age groups are defined: younger group (18-25 years old), middle group (35-55 years old), and older group (65-75 years old). Because not all age groups can be used in all tasks, one age group (the middle group) is chosen as the common age group that is used in every task. One reason for this choice is that drivers of 35-55 years old are the likely initial buyers and users of vehicles with advanced technologies such as the SAVE-IT systems. Although the age effect is not the focus of the program, it is examined in some tasks. In those tasks, multiple age groups were used.

The number of subjects per condition per task is based on the particular experimental design and condition, the effect size shown in the literature, and resource constraints. In order to ensure a reasonable level of uniformity across tasks and confidence in the research results, a minimum of eight subjects is used for each and every condition. The typical number of subjects is considerably larger than the minimum, frequently between 10-20.

Other Commonalities In addition to the commonalities across all tasks and all sites, there are additional common features between two or three tasks. For example, the simulator roadway environment and scripting events (e.g., the TCL scripts used in the driving simulator for the headway control and braking event onset) may be shared between experiments, the same distraction (non-driving) tasks may be used in different experiments, and the same research methods and models (e.g., Hidden Markov Model) may be deployed in various tasks. These commonalities afford the consistency among the tasks that is needed to develop and demonstrate a coherent SAVE-IT system.

The Content and Structure of the Report

The report submitted herein is a literature review report that documents the research progress to date (March 1--September 10, 2003) in Phase I. During the period of March-September 2003, the effort has been focused on the first Phase I sub-task: Literature Review. In this report, previous experiments are discussed, research findings are reported, and research needs are identified. This literature review report serves to establish the research strategies of each task.

1.1 INTRODUCTION

Safe operation of a motor vehicle requires that a driver focus a substantial portion of his or her attentional resources on driving-related tasks, including monitoring the roadway, anticipating the actions of other drivers, and controlling the vehicle. A driver may also, however, be engaged in other non-driving activities that compete for his or her attentional resources. As these non-driving activities increase, the driver allocates greater attention to them, or the driver's attentional capacity is reduced (e.g., fatigue), and there is a reduction in the attentional resources necessary for safe driving. Driver inattention has been found to be a major factor in traffic crashes, with 20-50 percent of crashes involving some form of inattention (Goodman, Bents, Tijerina, Wierwille, Lerner, & Benel, 1997; Ranney, Garrott, & Goodman, 2001; Stutts, Reinfurt, & Rodgman, 2001; Sussman, Bishop, Madnick, & Walter, 1985; Wang, Knipling & Goodman, 1996).

One form of inattention is driver distraction which results from a triggering event (Stutts, Reinfurt, & Rodgman, 2001). A distracted driver has delayed recognition of information necessary for safe driving because an event inside or outside of the vehicle has attracted the driver's attention (Stutts, Reinfurt, & Rodgman, 2001). A distracted driver may be less able to respond appropriately to changing road and traffic conditions, leading to an increased likelihood of crash. Driver distraction has been estimated to be a contributing factor in 8 to 13 percent of tow-away crashes (Stutts, Reinfurt, & Rodgman, 2001; Wang, Knipling & Goodman, 1996).

Determining the effect of driver distraction on crash risk has proven challenging. Crash reports from which detailed crash databases are derived often lack good information about distraction-related events leading up to the crash and surrogate measures of distraction-related crashes, such as "rear-end crashes," can be overly subjective and inaccurate. In addition, even when crash data contain good distraction-related information, interpretation of these data is difficult because information about the frequency of exposure to the distraction scenario is not available. However, a recent study on self-reported frequency of distracting behaviors (Royal, 2003) and a study utilizing in-vehicle cameras (J. Stutts, personal communication, 2003) may provide a means for determining distracted-driving-scenario exposure.

Development of technology to reduce distraction-related crashes is proceeding, including the development of a workload/distraction management system in the SAfety VEhicle(s) using adaptive Interface Technology (SAVE-IT) program. In order to determine the potential benefits of systems such as SAVE-IT, it is necessary to understand the crash scenarios in which driver distraction is a likely contributor. This article has two purposes. The first is to review and assess available crash databases to determine which variables are available, feasible, and appropriate for determining distraction-related crash scenarios. The second purpose is to investigate a variety of other distraction-related driving-scenarios that may not appear in crash records directly, but, nonetheless, are likely to be related to distraction-related crashes, such as eating in the vehicle or using a cellular phone.

1.2 CRASH DATABASES

There are a number of crash databases that could be used to identify circumstances in which driver distraction results in vehicle crashes. As a basis for comparing these databases and making judgments about their usefulness in determining distraction-related crash scenarios, we identified three desired areas of information related to crashes. These are: 1) distraction information (including sources of distraction inside and outside the vehicle that may have drawn the driver's attention away from the driving task at the time of the crash); 2) inattention information (including the driver's physical or mental condition at the at the time of the crash for determining the driver's level of attention to the driving task); and 3) driver demand information (including roadway, traffic, and environmental conditions at the time of the crash).

Distraction information is clearly essential because driving distraction and its impact on crashes is the main focus of the study. Inattention information is important because it provides the driver context within which driver distraction takes place. Demand information is important because safe driving demands a certain level of attention that varies not only as a function of driver characteristics, but also roadway complexity, traffic density, and the environment. Improvements and standardization of highway design (American Association of State Highway and Transportation Officials, 2001) and traffic control (Federal Highway Administration, FHWA, 2000) have done much to reduce roadway complexity and to lower the demands of driving. Some roadway segments, however, require a greater level of attention from drivers than other segments. Furthermore, the attentional demand of a particular roadway segment may change with variations in traffic volumes, density, and mix of vehicle types. Driving the same roadway segment in rain, in the dark, or under other inclement conditions may also require increased attention. As the demand on driving increases, fewer attentional resources are available for non-driving tasks leading to a greater likelihood of crashing when the driver is inattentive or becomes distracted.

A combination of the three types of information – distraction, inattention, and demand – is desirable because it will enhance our ability to determine distraction-related crash scenarios, using a method similar to one commonly used for identifying drunk-driving crash scenarios. The methods will involve analysis of distraction-related crashes (and probably inattention-related crashes) to determine the relationship between these crashes and various measures, or combination of measures, of driving demand (roadway, traffic, or environment). By examining the records of crashes in which driver distraction was a contributing factor, it may be possible to identify commonalities in the roadway, traffic, and environment (or some combination of these variables) associated with these crashes. The likely outcome of these analyses would be a relative listing of the frequency of distraction-related crash scenarios.

The ideal crash database for this analysis would include variables related to the three general areas of crash-related information: driver distraction, inattention, and demand. Unfortunately, the ideal crash database does not exist. Researchers, therefore, must carefully select databases for analysis, recognizing their limitations. Here we examine a series of crash databases for the presence of driver distraction and inattention information that is appropriate and important for analyses to determine the frequency of various distracted-driving crash scenarios. We examine crash databases for the presence of demand information in a separate report. We also assess the representativeness of the databases and their usefulness for this project.

1.2.1 National Automotive Sampling System General Estimates System

The National Automotive Sampling System General Estimates System (NASS GES, henceforth referred to as GES) contains crash data representative of all crashes in the United States (US). The crashes recorded in GES are from a nationally representative probability sample selected from the estimated 6.8 million police-reported crashes which occur annually and include all types of crashes involving all types of vehicles. GES is the best crash database for determining national estimates of police-reported crashes. The data records in GES are coded from the original police accident reports by trained personnel (National Highway Traffic Safety Administration, NHTSA, 2002b, 2002c).

1.2.1.1 Data elements on driver distractions and inattention

In 1990, a driver distraction variable was introduced in GES. At that time, there were seven codes for this variable:

- Not distracted
- Passengers, occupants
- Vehicle instrument display (radio, CB, heating)
- Phone
- Other internal distractions
- Other crash (rubbernecking)
- Other external distractions

In 1999, this variable was expanded to include 19 categories:

- Not distracted
- Looked but did not see
- By other occupants
- By moving objects in vehicle
- While talking or listening to phone
- While dialing phone
- While adjusting climate control
- While adjusting radio, cassette or CD
- While using other devices integral to vehicle
- While using or reaching for other devices
- Sleepy or fell asleep
- Distracted by outside person or object
- Eating or drinking
- Smoking related
- No driver present
- Not reported
- Inattentive or lost in thought
- Other distraction or inattention
- Unknown

Examination of this variable in the 2000 GES data revealed that of the 102,566 vehicle/driver records contained in the dataset, information on distraction was not recorded in 83 percent of cases (35 percent were coded “not distracted”, 45 percent “not reported,” and 3 percent “unknown”). When codes were reported for distraction, they were largely concentrated in the categories of “inattentive or lost in thought” (11.5 percent), “looked but did not see” (2.5 percent) and “sleepy or asleep” (1.1 percent). Each of the other codes combined accounted for less than 1 percent. The small number of cases for each type of distraction indicates that care should be exercised when determining national estimates of driver distraction based on the GES. Estimates based on a sample are subject to random errors that are relatively large when the estimated numbers are small. Thus, estimating crashes for each of the many different types of distraction would not be useful, but an estimate of crashes based on larger categories of crashes might be reasonable.

One reason for the lack of reporting on distraction is that information in the GES comes from state police accident reports and most states do not have detailed driver-distraction codes on their crash report forms. As recently as the late 1990s, if inattention information was included on a state crash form it usually did not contain distraction information, including only whether the driver was asleep, fatigued, or ill. However, as concerns were raised about the distraction potential of cellular phone use and other in-vehicle technology, states began to change their crash report forms to include information on driver distraction. To illustrate this point, Michigan had no codes for driver distraction or inattention (other than alcohol and drugs) prior to 2000. In 2000, Michigan added several driver-inattention variables to indicate cellular phone use and whether the driver was distracted, asleep, fatigued, and/or sick. This trend is expected to continue and as more detailed information on driver distraction in crashes is collected by the states, information on driver inattention and distraction in GES should also increase. Thus, it is likely that the value of GES in understanding distraction-related driving will increase in the future.

1.2.2 The National Automotive Sampling System Crashworthiness Data System

The National Automotive Sampling System Crashworthiness Data System (NASS CDS, henceforth referred to as CDS) is a database designed to assist in studies of vehicle crashworthiness. CDS contains detailed information on a representative, random nationwide sample of police-reported crashes involving passenger vehicles (passenger cars, light trucks, vans, and sport-utility vehicles) in which at least one vehicle was damaged seriously enough to require towing from the crash scene. All crashes included in the sample (about 5,000 per year) are studied in detail by field research teams. The data records in CDS come from information and measurements at the crash site and from the crash-involved vehicles, other physical evidence, interviews with crash victims, and review of medical records (NHTSA, 2001a, 2003b).

1.2.2.1 Data elements for driver distraction and inattention

In 1995, a detailed coding of “Driver Distraction/Inattention to Driving” was added to CDS. All distractions that apply are coded. These data elements are:

- By other occupant(s)
- By moving object in vehicle
- While talking/listening cell phone
- While dialing cell phone
- While adjusting climate controls
- While adjusting radio, cassette, CD
- While using other device/controls integral to vehicle
- While using/reaching device/object brought into vehicle
- Inattentive lost in thought
- Sleepy or fell asleep
- Distracted by outside person, object, or event
- Eating or drinking
- Smoking related
- Other, distraction/inattention

Examination of the coding of this variable in the 2000 CDS file showed that out of 7,579 vehicle/driver records, 87 percent did not have distraction/inattention reported (35 percent were coded "attentive and not distracted" and 52 percent were "unknown"). The remaining 13 percent were coded with one of the other distraction codes. The greatest percentage of these (2 percent each) were "other distractions" and "sleepy or fell asleep." All other codes accounted for less than 1 percent each.

1.2.3 Fatality Analysis Reporting System

The Fatality Analysis Reporting System (FARS) contains information on all vehicle crashes in all 50 states, the District of Columbia, and Puerto Rico that resulted in at least one fatality. Trained analysts code FARS records from police accident reports, other information including witness statements, and autopsy reports (NHTSA, 2002a, 2003a). This database is the best source of information available for those interested in traffic fatalities.

1.2.3.1 Data elements on driver distraction and inattention

Driver distraction and inattention is coded in FARS in the "related factors-driver level". At present, this variable has 99 possible codes grouped according to general categories for convenience. Up to four of these related factors can be coded for every driver involved in a crash.

The category "physical and mental condition" of the related factors-driver level variable includes codes related to driver inattention:

- drowsy, sleepy, asleep, fatigued
- emotional (e.g. depression, angry, disturbed)
- inattentive (talking, eating, etc,)

The "inattentive" factor is frequently recorded for drivers. In the 2000 FARS file, 3,949 (7 percent) out of the 57,403 drivers were coded as " inattentive." The other two driver variables were less frequent in the 2000 data, with 2 percent coded as "drowsy, sleepy, asleep or fatigued" and less than 1 percent coded as "emotional."

In 1991, a list of electronic devices was added to the “related factors- driver level” variable under the category “Possible Distractions (inside vehicle)”. These devices are recorded regardless of whether they were in use at the time of the crash. The devices included in this category are:

- Cellular phone
- Fax Machine (1991-2001)
- Cellular Telephone in use in Vehicle (since 2002)
- Computer (1991-2001)
- Computer Fax machines/printers (since 2002)
- On-board navigation system
- Two-way radio
- Heads-up display

Data for these distraction codes are not found frequently in FARS data. Of the 57,403 drivers in the 2000 FARS file, only 108 (.2 percent) had one of the possible distraction codes noted in their record. NHTSA (2002a) noted that in 1998, only 64 drivers out of 56,865 had one of the “possible driver distractions” coded in their FARS record. NHTSA also pointed out that 31 states did not report any driver distractions on their police accident reports and therefore distraction could not be identified and included by FARS.

1.2.4 Highway Safety Information System

The Highway Safety Information System (HSIS) is maintained by the Federal Highway Administration and is used in studies of the relationship between road features and crashes. HSIS contains information on crashes, roadway inventory, and traffic volumes as well as other road geometric features for nine states: California, Illinois, Maine, Michigan, Minnesota, North Carolina, Utah, and Washington. Ohio joined HSIS in 2002. Participation of states in HSIS is based on the availability and quality of their data and the ability to merge data from various files (Highway Safety Information System, 2000a, 2000b, 2000c, 2000d, 2001).

Data for each state comes in a set of relational databases that are different for each state. These data include a roadway inventory, information on traffic volumes for the roads included in the inventory, and crashes that occurred on the roads in the inventory. All roads in a state, however, are not necessarily in the inventory. In Michigan, for example, only the state trunkline roads are included in the inventory and therefore in HSIS.

1.2.4.1 Data elements on driver distraction and inattention

The driver distraction data available in HSIS for each state are the same as those available from each state’s crash data files. Examination of the HSIS codebooks indicates that all the states have some information on driver inattention and distraction, but it is not as detailed as that found in CDS, GES, or FARS. The driver inattention and distraction data are found in the following variables: contributing or apparent contributing factors; physical or apparent physical condition; and driver condition. Most

HSIS states have a variable that can denote driver inattention such as drowsy, asleep, fatigued, or ill. Four of the states have a variable indicating distraction. Two states have one code for some electronic devices. The following list shows each HSIS state and the relevant variables.

- California - drowsy or fatigued, fatigue;
- Minnesota - inattention/distraction, driver on car phone/CB/2-way radio;
- Washington - apparently asleep, apparently ill, apparently ill, inattention;
- Michigan - cellular phone, distracted, asleep, fatigued, and ill;
- Illinois - illness, asleep/fainted, medicated;
- North Carolina - ill, fatigued, asleep, impairment due to medicine;
- Utah - asleep, fatigued, ill;
- Maine - driver inattention, asleep, fatigued.

1.2.5 Regional Geographic Information System Databases

Many states and regions are developing regional Geographic Information System (GIS) databases that include the road network, traffic volumes, crashes, pavement condition, population, and land use. For example, the state of Michigan has developed a GIS database for the Michigan trunkline road system that includes road characteristics and crashes. Other organizations in Michigan have adapted the GIS database for their own purposes. The Southeast Michigan Council of Governments (SEMCOG) is using the GIS database as a tool for planning regional transportation policy. Several counties in southeast Michigan are also in the process of developing GIS databases of their roadways and crashes, including the Traffic Improvement Association of Oakland County and the counties of Washtenaw and Jackson. The databases are used to identify traffic-problem areas, manage resources, and produce maps rapidly and accurately. They were not developed for research purposes, but could be used for that purpose, if needed.

1.2.6 Summary

Each database reviewed has certain advantages and disadvantages relative to identifying and understanding distraction-related crash scenarios. Table 1.1 summarizes the features of the databases reviewed along with the dimensions important for identifying distraction scenarios.

As seen in this table, no single database has all the factors desired for identifying distraction scenarios and estimating their magnitude nationally. The CDS and GES, however, appear to be the best suited for these purposes. Cases in both data systems come from national probability samples. The population of crashes for GES and CDS are different (GES samples from a population of all police-reported crashes of all severities, and CDS samples from all police-reported crashes in which a passenger vehicle sustained enough damage to be towed away), but both can be used to obtain national estimates. Both have a variable with detailed codes for various types of driver distraction.

Table 1.1 Summary of database assessment

Database	Distraction/ Inattention Variables	Nationally Representative
GES	Detailed list of distractions	Yes, national sample of all crashes
CDS	Detailed list of distractions	Yes, national sample of crashes involving passenger vehicles with towable damage
FARS	One general distraction variable. List of electronic devices noted as possible distraction if present.	Yes, but only of fatal crashes
HSIS	General driver conditions or inattention variables, two states have cell phone distraction variable	No, data from eight states. States were selected for data quality, not sampled.
Regional	Tend to use distraction variables available on state police crash reports, which usually are general	No, data are region specific

FARS has driver distraction information but is not as detailed as in GES and CDS. Furthermore, FARS contains only fatal crashes, which limits its usefulness in identifying and estimating the magnitude of distraction scenarios under more general conditions.

HSIS and regional databases have two significant drawbacks for use in identifying and quantifying distracted-driving scenarios. First, the information on driver distraction is very general. Second, neither are nationally representative. Regional databases are by their nature local, while states in HSIS were selected because of data availability, quality, and the ability to merge the various roadway and crash files, and not on their representativeness.

Although GES and CDS appear to be the best suited for the purpose of this study, there are some problems with using these data. The number of cases of driver distraction in these data files is not large and the standard errors associated with national estimates will be large. Thus, estimates of the magnitude of driver distraction will be of low precision. However, from among the crash data systems reviewed, these two have the most detailed information on driver distraction and appear to be the best candidates for the task.

1.3 DISTRACTED DRIVING CRASH SCENARIOS

Due in part to the relatively recent addition of distraction-related variables in crash databases and in part to the incomplete nature of these variables, there are relatively few studies of crash databases that have attempted to determine the relative frequency of distraction-related crashes by crash scenario. This section will review those few studies as a preliminary means for developing a set of crash scenarios for which distraction is an particularly important contributing factor. We organize this section based upon the following crash scenarios that have been utilized in distraction-related crash analyses: Single vehicle run off the road; rear-end; intersection/crossing path; lane change/merge; and head-on.

1.3.1 Single Vehicle Run Off the Road Scenario

Off roadway crashes account for about 23 percent of crashes nationally (Najm, Sen, & Smith, 2002). Campbell, Smith, and Najm (2002) analyzed GES data from 2000 and CDS data from 1997-2000 in a study of factors that contribute to crashes nationally. They found that inattention (defined primarily by distraction variables except for the inclusion of the looked-but-did-not-see variable) was a contributing factor in 12 (CDS) to 14 (GES) percent of single vehicle run off the road crashes. Thus, distraction/inattention was one of the top three contributing crash factors in this study. Other work utilizing 1998 GES data examined light vehicle "pre-crash scenarios" based upon vehicle movements and critical events prior to the run-off-the-road crash for freeways and non-freeways separately (Najm, Koopman, Boyle, & Smith, 2002; Najm, Schimek, & Smith, 2002). This study found that driver distraction was a contributing factor in 4.1 percent of freeway and 6.1 percent of non-freeway single vehicle run off the road crashes. The most frequent pre-crash scenarios differed somewhat depending upon the road type with "initiating a maneuver and losing control" and "negotiating a curve and departing road edge" as the two most common scenarios relative to non-distraction-related crashes for freeways and "going straight and departing the road edge" and "negating a curve and departing a road edge" as the two most frequent pre-crash scenarios for nonfreeways.

Wang, Knipling, and Goodman (1996) have analyzed 1995 CDS data to compare distraction-related crashes to other crashes by crash type. They report that distraction-related crashes account for about 13 percent of crashes nationally. Their analyses by crash type and distraction showed that distraction-related single vehicle crashes (both run-off-the-road and on-road) account for about 18.1 percent of single vehicle crashes and 41.2 percent of all distraction-related crashes. Thus, the single vehicle run off the road crash scenario is a relatively common distraction-related crash scenario.

1.3.2 Rear-End Scenario

Rear end crashes are the most common crash scenario, accounting for nearly 30 percent of crashes nationally (see e.g., Najm, Sen, & Smith, 2002). Analysis of 1995 CDS data found that distraction was a contributing factor in 21 percent of rear-end crashes in which the lead vehicle was moving (LVM) and in 24 percent of crashes in which the lead vehicle was stopped (LVS) (Wang, Knipling, & Goodman, 1996). This study also found that among the distraction-related crashes, rear-end/LVM crashes were found in about 10 percent of cases while rear-end/LVS crashes were found in 22 percent of distraction-related crashes. In addition, rear-end crashes into stationary vehicles were the second most common distraction-related crash scenario (single-vehicle-run-off-the-road crashes were the most frequent). Other work on 1996 GES data found that distraction-related crashes were slightly more frequent for rear-end/LVM than for rear-end/LVS crashes (Wiacek & Najm, 1999).

More recent research on distraction as a contributing factor related rear-end crash scenarios considered data in both GES and CDS (Campbell, Smith, & Najm, 2002). This work considered three rear-end scenarios: LVS, LVM, and lead vehicle decelerating (LVD). The study showed that 36 percent of rear-end/LVS crashes, 37 percent of rear-end/LVD crashes, and 23 percent of rear-end/LVM crashes were distraction related. In all three scenarios, distraction was the most common contributing factor except for rear-end/LVM in which the percent of this type of crash with an unknown contributing factor was greater. Thus, it appears that distracted drivers account for a large proportion of all rear-end crashes, whether or not the lead vehicle is moving.

1.3.3 Intersection/Crossing Path Scenario

Intersection crashes (or crashes where vehicles cross paths) are the second most common type of crash in the US based upon GES data (Najm, Sen, & Smith, 2002). Analyses of intersection/crossing path crashes in 1995 CDS by contributing factor show that distraction is implicated in only about 7 percent of these crashes (Wang, Knipling, & Goodman, 1996). Considering all distraction-related crashes, the study found that about 18 percent were intersection/crossing path scenarios. In a detailed study of specific behaviors and unsafe driving actions that lead to crashes, distraction-related intersection crashes were found in slightly more than 2 percent of crashes analyzed (Hendricks, Freedman, Zador, & Fell, 2001). These data, however, were only for serious crashes and are not nationally representative. Thus, too little data exist for making strong conclusions about the impact of driver distraction on intersection/crossing path crashes.

1.3.4 Lane-Change/Merge Scenario

Crashes involving a vehicle changing lanes or merging account for only about 9 percent of crashes nationally (Najm, Sen, & Smith, 2002). Wang, Knipling, and Goodman (1996) found that distraction was a contributing factor in 5.6 percent lane-change/merge crashes and among all distraction-related crash scenarios, this scenario accounted for less than 2 percent of crashes. More recent research utilizing 2000 GES data has found a much higher incidence of inattention/distraction (29 percent) in lane-change/merge crash scenarios (Campbell, Smith, and Najm, 2002). Further analysis, however, shows that a large proportion of these cases are coded as “looked but did not see” which is often not included as a distraction variable. As with the previous scenario, more research is needed to understand the relative frequency of driver distraction as a contributing factor in this crash scenario

1.3.5 Head-On Scenario

Head-on or opposite direction crash scenarios account for less than 3 percent of crashes based on 2000 GES data (Najm, Sen, & Smith, 2002). Analyses of 1995 CDS data showed that distraction is a contributing factor in these types of crashes in about 7 percent of cases (Wang, Knipling, & Goodman, 1996). However, among the various crash scenarios, head-on crashes were the least likely (2.2 percent) of all distraction-related crashes. Further research on the role of driver distraction and this crash scenario is needed.

1.3.6 Summary

This section reviewed the few studies on driver distraction as a causative factor in various crash scenarios. Several of the scenarios have received only scant research attention making it difficult to draw strong conclusions about the relative frequency of distraction related crashes in these scenarios. Based upon the available data, however, we conclude that single-vehicle-run-off-the-road and rear-end crashes are likely to be the two most common scenarios in which driver distraction is a causative factor. The lane-change/merge crash and intersection/cross path scenarios are likely to follow distantly as the third most frequent driver distraction crash scenarios. It appears that head-on crashes are the least frequent scenario involving driver distraction. Thus, based upon this review, a SAVE-IT system should be designed, at a minimum, to mediate both single vehicle run off the road and rear-end crashes. These crash scenarios are not only two of the most common crash types, but the frequency of these crashes also have a strong distraction component.

1.4 DISTRACTED-DRIVING SCENARIOS

As discussed previously, distracted driving is one form of driver inattention and is distinguished from inattention by a triggering event that can occur either outside or inside of the vehicle. This section describes the literature related to the various events that can trigger driver distraction. This section will omit review of factors related to the forms of driver inattention such as drowsiness/fatigue, medical/emotional impairment, age, individual difference, gender, or daydreaming. We recognize, however, that these factors, in particular age and individual differences, can influence the level of driver distraction and its effects on crash outcomes.

1.4.1 Outside the Vehicle

1.4.1.1 Exterior incident

An exterior incident refers to an event outside the vehicle that draws the driver's attention. A wide range of incidents are possible and include, but are not limited to, crashes, police activity, vehicle actions, and pedestrians. Several studies have found that exterior incidents are the most frequent contributor to distraction-related crashes (General Assembly of the Commonwealth of Pennsylvania, 2001; Glaze & Ellis, 2003; Stutts, Reinfurt, & Rodgman, 2001; Wang, Knipling, & Goodman, 1996). While the frequency with which a driver encounters an exterior incident is unknown, one would think the exposure to this type of potential distractor is quite high (perhaps multiple incidents per trip).

In an attempt to further delineate the most common type of exterior incidents involved in distraction-related crashes, Stutts, Reinfurt, and Rodgman (2001) examined a sample of crash narratives from two years of CDS. They found that the most common exterior incident in distraction-related crashes involved traffic or a vehicle, such as a vehicle swerving or changing lanes, an emergency vehicle, or bright vehicle lights. The next two most common incidents were police activity and an animal in the roadway, followed by, in order of frequency: people/object in roadway; sunlight/sunset; crash scene (rubbernecking); and road construction.

1.4.1.2 Looking at scenery/landmark

Another potential distraction outside of the vehicle is scenery or landmarks. In a recent study by Virginia Commonwealth University (Glaze & Ellis, 2003), researchers analyzed more than 2,800 surveys filled out by police officers at driver-inattention-related crash scenes regarding the main distraction that contributed to the crash. In nearly 10 percent of cases, looking at scenery/landmarks was reported. This distraction factor was second only to exterior incidents.

We could find no human-factors literature utilizing simulators, or other laboratory research, investigating the distraction potential of scenery or landmarks. However, scenery is an integral component of certain US roads, known as "scenic byways" (see

FHWA, 1999)[1]. Analyses of crashes along these byways compared to matched non-scenic byways might provide evidence of the distraction potential of scenery/landmarks.

1.4.2 Inside the Vehicle

1.4.2.1 Passengers

Travel with a passenger occurs in about one-third of automobile trips in the US. Given the incredible variety of human interactions, it is not surprising that some of these interactions can be distracting to an automobile driver, and may lead to an increased risk of crash. For young drivers in the US, at least, analyses have shown that the rate of crashes increases with the number of passengers present in the vehicle, and crash risk is increased even further when the passengers themselves are young (Chen, Baker, Braver, & Li, 2000; Doherty, Andrey, & MacGregor, 1998; Williams, 2003). On the other hand, research on non-teenage drivers has found either no change or a reduction in crash risk when passengers are present (Doherty, Andrey, & MacGregor, 1998; Vollrath, Meilinger, & Krüger, 2002; Williams, 2003). Thus, it may be that young drivers are more susceptible than older people to the distracting influence of passengers or that the interactions that young people have with their passengers are qualitatively different.

Analyses of distraction-related crash data files have found passenger-related distractions to be a relatively common triggering event for the crash (General Assembly of the Commonwealth of Pennsylvania, 2001; Glaze & Ellis, 2003; Royal, 2003; Stevens & Minton, 2001; Stutts, Reinfurt, & Rodgman, 2001). In their analysis of CDS crash narratives, Stutts, Reinfurt, and Rodgman, (2001) found that verbal interaction with the passenger was the most common passenger-related event, followed by tending a child or infant, and the passenger doing something (e.g., yelling, reaching, fighting, etc.).

1.4.2.2 Adjusting entertainment system

The vast majority of motor vehicles are equipped with entertainment systems that include radios, cassette players, and/or compact-disc (CD) players. Operation of these systems usually involves manual manipulation of buttons, knobs, and media, as well as visual input, leading to a potential for physical, cognitive, and visual distraction. Analyses by several researchers have shown that adjusting an entertainment system is one of the leading in-vehicle triggering events for distraction-related tow-away crashes (Stutts, Reinfurt, & Rodgman, 2001; Wang, Knipling, & Goodman, 1996); distraction-related police-reported crashes (Glaze & Ellis, 2003), and distraction-related fatal crashes (Stevens & Minton, 2001).

McKnight and McKnight (1993) used radio tuning as a baseline for comparing cellular phone activities on simulated driving performance. They found driving performance decrements during radio tuning to be similar in magnitude to the decrements found for

[1]Scenic byways have also been designated by the Automobile Association of America, the US Forest Service, and the National Geographic Society.

intense cellular phone conversations, suggesting that the two activities produce similar levels of driver distraction.

1.4.2.3 Music

The most common circumstance in which people listen to music is while driving alone in a motor vehicle (Slobada, 1999; Slobada, O'Neill, & Ivaldi, 2001). In one study (Slobada, O'Neill, & Ivaldi, 2001), subjects recorded where they were and whether they were listening to music at seven random times during the day when cued by a pager. Of the people traveling, 91 percent were listening to music, compared to only 46 percent listening to music while at home.

Whether music listening is a contributing factor to distraction-related crashes is unknown. However, research is beginning to uncover an interesting relationship between music and driver performance. Music is a complex stimulus that includes an intensity level, tempo, and style that collectively elicit a psychological response. The response a person has toward a certain piece of music depends mostly upon that individual's personal characteristics. As such, research to date has focused upon the effects of music intensity level and tempo on driving performance.

With a background noise level in motor vehicles of about 60 decibels (dBA) (Dahlstedt, 2001), it is not surprising that in-vehicle stereos tend to be set with an output of 80 to 130 dBA (Ramsey & Simmons, 1993). Considering the fact that an amplified rock concert has an output of about 115 dBA or greater, in-vehicle music is often quite loud. What is the effect of music intensity on driving? Listening to soft music (about 55-70 dBA) while driving may improve reaction times to unexpected breaking events, perhaps signaling a reduction in driver distraction (Turner, Fernandez, & Nelson, 1996). A similar effect was not discovered at a high intensity (80 dBA). On the other hand, more recent research has shown that under high-demand driving conditions, both soft and loud music decreased reaction times to unexpected centrally-located events, but significantly increased reaction times to peripherally-located events (Beh & Hirst, 1999). Thus, the relationship between music intensity and driver distraction needs further investigation.

The only research to date on the effect of music tempo on driver performance found an interesting relationship between the two (Brodsky, 2002). In this study, the effects of three tempos, ranging from about 60 to 130 beats-per-minute on several measures of driving performance were investigated while music intensity was held constant. Subjects "drove" along a simulated roadway on a microcomputer. The study found that both average driving speed and number of lane crossings significantly increased with tempo, while both the number of missed red-lights and collisions also increased with tempo, but not significantly so. These results led Brodsky to conclude that music tempo increases driving risks perhaps by competing for attentional space. It is, perhaps, premature to draw conclusions about driver distraction and music until further research is conducted with a broader range of subjects and conditions. Brodsky (2002) utilized only music students in his first experiment and undergraduates in the second experiment. The results, however, show that the effects of music on driver distraction is a promising line of inquiry.

1.4.2.4 Cellular phone use

Use of cellular (mobile) phones while driving is a growing traffic safety concern. Cellular phone ownership has been increasing rapidly over the last several years and is predicted to rise to more than 80 percent by 2005 (Telecompetition Inc., 2001). Self-reported data show that about two-thirds of cellular phone use occurs while in a motor vehicle (Gallup, 2001; Bureau of Transportation Statistics, 2000; Insurance Research Council, 1997). Direct observation studies of cellular phone use have found that about 3 percent of the driving population are conversing on a hand-held cellular phone at any given moment during daylight hours (Eby & Vivoda, in press; Eby, Kostyniuk, & Vivoda, in press; NHTSA, 2001b; Reinfurt, Huang, Feaganes, & Hunter, 2001). According to NHTSA (2001b) estimates, this use rate equates to about 600,000 drivers using a cellular phone at any given time during daylight hours in the US.

Evidence obtained from simulated driving (e.g., Alm & Nilsson, 1995; Consiglio, Driscoll, Witte, & Berg, in press; de Waard, Brookhuis, & Hernández-Gress, 2001; McKnight & McKnight, 1993; Serafin, Wen, Paelke, & Green, 1993; Strayer & Johnston, 2001) and on-the-road driving (e.g., Brookhuis, deVries, and de Waard, 1991; Hancock, Lesch, & Simmons, in press; Tijerina, Kiger, Rockwell, & Tornow, 1995) has shown that use of a mobile phone can lead to decrements in tasks required for safe driving. There is general agreement in the literature that the most distracting activities involving cellular phone use are dialing and receiving phone calls (see e.g., Alm & Nilsson, 2001; Brookhuis, de Vries, & de Waard, 1991; Green, 2000; Tijerina, Johnston, Parmer, Winterbottom, & Goodman, 2000; Zwahlen, Adams, & Schwartz, 1988). In addition, use of hand-held phones tend to be associated with greater decrements in driving performance than hands-free phones, but the conversations tend to be equally distracting, especially when the information content is high (see e.g., Consiglio, Driscoll, Witte, & Berg, in press; McKnight & McKnight, 1993; Patten, Kircher, Östlund, & Nilsson, in press; Strayer & Johnston, 2001).

Evidence is also mounting, although still far from conclusive, that the use of cellular phones increases crash risk. In their analysis of the CDS data, Stutts, Reinfurt, and Rodgman (2001) found that cellular phone use or dialing was implicated in about 1.5 percent of distraction-related crashes. One would expect this percentage to increase as the predicted use of cellular phones increases. More recent work in Virginia has found that about 5 percent of distraction-related crashes involve cellular phones (Glaze & Ellis, 2003). Utilizing self-reported data on cell phone crash involvement, Royal (2003) estimates that there are 292,000 drivers in the US who report cell-phone involvement in a crash in the past five years. Results from epidemiological studies in which cellular phone use has been linked with crash records, are beginning to support the hypothesis that use of a cellular phone while driving increases crash risk (Koushki, Ali, & Al-Saleh, 1999; Laberge-Nadeau, et al., in press; Redelmeier & Tibshirani, 1997; Sagberg, 2001; Violanti & Marshall, 1996).

1.4.2.5 Route-guidance systems

Advances in computer and communication technology over the last two decades have led to the development of a wide array of advanced in-vehicle information systems, collectively called telematics. As described by Kantowitz (2000), these systems can be classified into three categories: advanced traveler information systems (e.g., route-guidance); safety and collision avoidance (e.g, automated cruise control); and convenience and entertainment (e.g., in-vehicle Internet). The proliferation of in-vehicle technology has generated concern that these systems, singly and in combination, might cause an increase in driver distraction (see e.g., Tijerina, Johnston, Parmer, Winterbottom, & Goodman, 2000; Westat, 2000).

One of the most widely available in-vehicle advanced technologies is the route-guidance system. These systems provide the driver with information about a route to a destination supplied by the driver. Because these systems use vehicle location technology, such as GPS, route directions can be timed to correspond with the driver's information needs as he or she drives. There is little information about the incidence of route-guidance systems in vehicles or the frequency with which they are used.

Analysis of the crash databases yielded no instances in which use of a route-guidance system was indicated as a contributing factor in distraction-related crashes (Stevens & Minton, 2001; Stutts, Reinfurt, & Rodgman, 2001). In addition, natural use studies of various route guidance systems have found no adverse effect on traffic safety, nor any increase in self-reported distraction (see e.g., Eby, Kostyniuk, Streff, & Hopp, 1997; Kostyniuk, Eby, Hopp, & Christoff, 1997; Kostyniuk, Eby, Christoff, Hopp, & Streff, 1997; Perez, Van Aerde, Rakha, & Robinson, 1996).

Despite these results, there is general agreement in the literature that the function of destination-entry is quite distracting if it involves visual displays and manual controls (see Tijerina, Johnston, Parmer, Winterbottom, & Goodman, 2000 for an excellent summary of this work). While most destination-entry would probably occur in a stationary vehicle, Green (1997) has pointed out that there are several scenarios in which a driver might engage in destination-entry while driving, and in turn be at greater risk for a distraction-related crash: driver is in a hurry and enters the destination after starting the trip; driver changes his or her mind about the destination after starting trip; driver gets other information, such as a radio traffic report, then decides to change the route; driver entered the wrong destination; and the driver does not know the exact destination prior to departure and enters the actual destination later. Thus, there are several scenarios in which use of a route-guidance system could lead to distraction-related crashes.

1.4.2.6 Eating or drinking

Many of us would agree that eating and drinking in the car is a common activity for drivers. Certainly the activity leads to physical distraction, as it requires the driver to hold the food or drink. Eating and drinking in a vehicle can also result in cognitive and visual distraction as the driver attempts to locate items or prevent them from spilling. Thus, eating and drinking in the vehicle may be a contributing factor in distraction-related crashes. Indeed, Stutts, Reinfurt, and Rodgman (2001) have found evidence for the presence of this activity in about 2 percent of distraction-related crashes in the CDS database. In-vehicle eating or drinking has also been indicated in about 5 percent of police-reported crashes in Pennsylvania (General Assembly of the Commonwealth of Pennsylvania, 2001) and a small number of fatal, distraction-related crashes in the UK (Stevens & Minton, 2001).

Jenness, Lattanzio, O'Toole, and Taylor (2002) investigated the distracting effects of eating a cheeseburger during simulated driving. Based upon lane keeping, mimimum speed violations, and glances-away-from-the-road measures, the researchers concluded that eating a cheeseburger was about equally distracting as using a voice-activated dialing system. In-vehicle eating, however, was less distracting than adjusting an entertainment system or reading directions.

1.4.2.7 Adjusting vehicle controls

Motor vehicles have a variety of systems that the driver controls including lights, safety belts, turn signals, windshield wipers, and heating/ventilation/air-conditioning (HVAC). Operation of these systems through steering-wheel or dashboard controls can draw attention away from driving thus leading to distraction. Generally, most systems, except for HVAC, are simple controls that require little attention to operate, at least in a familiar vehicle. However, HVAC systems, which generally have at least two controls with multiple settings, can lead to distraction even in a familiar vehicle. Studies that have investigated distraction-related crashes in various databases have found that adjustment of vehicle controls account for about the same frequency of distraction-related crashes as eating and drinking–about 2-5 percent (General Assembly of the Commonwealth of Pennsylvania, 2001; Stevens & Minton, 2001; Stutts, Reinfurt, & Rodgman, 2001).

1.4.2.8 Objects moving in vehicle

People often transport objects in their vehicles such as groceries, packages, purses, laptop computers, and briefcases. If these objects are not secured, the kinematics of normal driving can cause them to slide along the vehicle floor or fall off the seat. These events can draw attention away from the driving task during braking and/or turning which are critical safety-related maneuvers. People also transport pets, who, if not constrained, can move about the vehicle causing distractions.

An object moving in a vehicle does seem to be a factor in distraction-related crashes. Stutts, Reinfurt, and Rodgman (2001) found that a moving object in the vehicle was the triggering event in about 4 percent of distraction-related crashes in the CDS database, and in some years the percentage was as high as 7.6. In a pilot, focus-group study in Michigan, objects falling off the seat was one of the most commonly cited reasons by drivers as a cause relating to their rear-end crashes (Kostyniuk & Eby, 1998).

Little is known about the frequency of this distraction-related event. However, anecdotally, one would expect that the majority of people transport objects on nearly every trip. The frequency with which these objects move and whether this movement attracts the driver's attention is unknown.

1.4.2.9. Smoking

The Centers for Disease Control (CDC) estimate that about 23 percent of the adult population are current smokers, with little change in prevalence over the last several years (CDC, 2002). We could find no research on the prevalence of smoking in vehicles. However, given that many jurisdictions are banning smoking in public buildings, the vehicle may be one of the few places left, besides at home, where a person can smoke. Thus, smoking while driving may be a frequent activity.

Does smoking while driving lead to distraction? Cigarette smoking has been identified as a contributing factor in about 1 percent of distraction-related crashes in the CDS (Stutts, Reinfurt, & Rodgman, 2001), nearly 5 percent of distraction-related crashes in Pennsylvania (General Assembly of the Commonwealth of Pennsylvania, 2001), and in a small percentage of fatal distraction-related crashes in the UK (Stevens & Minton, 2001). These percentages were similar to those for the involvement of cellular phone use in distraction-related crashes. Analysis of the CDS narratives showed that, in order of prevalence, smoking-related distractions were: lighting the cigarette; reaching or looking for the cigarette; the cigarette blowing back into the vehicle; and dropping the cigarette (Stutts, Reinfurt, & Rodgman, 2001).

Two studies on cigarette smoking and simulated driving were found (Ahston, Savage, Telford, Thompson, & Watson, 1972; Sherwood, 1995). Both studies report mixed results, with drivers who were smoking exhibiting faster reaction times in some conditions and slower reaction times in other conditions. Since both studies were interested in the nicotine level, differences in reaction times may have been due to the introduction of this chemical rather than the physical or cognitive distraction of smoking. In addition, neither of these studies had smokers attempt to light or search for cigarettes while driving. Thus, we conclude that smoking while driving is a potential triggering event for distraction-related crashes and is a topic in need of additional empirical research.

1.4.2.10 Other scenarios

A number of other distracted driving scenarios have been discussed in the literature but little empirical data were available to assess them. These scenarios, however, may be ones in which technologies, or other strategies, are particularly well suited for mitigating driver distraction. We include them here for completeness.

Reading: Clearly driving and reading can lead to visual, cognitive, and physical distraction. Reading printed materials such as a book, newspaper, or mail is considered by 80 percent of people surveyed nationally to distract drivers enough to make driving more dangerous (Royal, 2003). More than one-half of respondents also considered looking at maps or written directions to be activities that make driving more dangerous.

Wireless technologies: Wireless technology is proliferating and includes personal data assistants (PDA), wireless email, pagers, and beepers. One would expect that use of these technologies while driving will become more frequent in the future. Royal (2003) found that remote Internet equipment such as PDAs was the second most frequently selected distracting activity after reading. About 40 percent of respondents thought that pagers or beepers were distracting enough to make driving more dangerous.

Night vision systems: These systems utilize infrared technology to obtain heat signatures of pedestrians or animals on or near the roadway and present this information to the driver via a display. Because the systems are designed for nighttime, they are used in higher-demand driving situations. As with all visual displays, night vision systems can lead to distraction. As described by Ranney, Garrott, and Goodman (2001), a driver looking at the display may have enhanced object recognition over direct object viewing, but the display may distract driver attention from other objects or features not visible in the display.

Personal grooming: This activity involves a range of behaviors and most likely leads to some level of visual, physical, and cognitive distraction. More than 60 percent of respondents in a nationwide telephone survey thought that personal grooming was one of the most distracting activities for drivers (Royal, 2003).

1.4.3 Summary

This section reviewed a number of distracted-driving scenarios that may increase the likelihood of distraction-related crashes. One important question remains: What is the relative contribution of these scenarios to distraction-related crash risk? As discussed in the section on crash databases, the best way to answer this question would be to analyze a database containing reliable and accurate information about crashes and distractions, as well as some way to measure exposure (i.e., the frequency with which various distraction-related scenarios occur during driving). Unfortunately, such a database does not exist.

One could, however, as a first pass, rate scenarios on measures that are known or believed to be related to the likelihood of a crash. There are at least four measures that we believe are related to the likelihood of a distraction-related crash. The first is the frequency with which the event occurs (*exposure*). Scenarios that occur frequently are more likely to lead to distraction-related crashes than scenarios that occur less frequently, all else being equal. The second measure is *volition*. By this, we mean the degree of control the driver has over initiation of the scenario. Some scenarios are completely voluntary, such as the adjustment of vehicle controls, in which case the driver can coordinate the initiation of the scenario with driving situations that require low attentional resources. Other scenarios are generally out of the driver’s control, such as the appearance of an emergency vehicle (exterior incident), in which case the driver must deal with the distraction on top of whatever attentional demands are already required for safe driving. The third measure is the relationship of the scenario to the attentional *demand* of the driving task. Certain scenarios can be caused by changes in driving task demand. For example, objects placed on the seat of a car will move only when the driver brakes or turns a corner, situations in which greater attention to the driving task is likely to be required to prevent a crash. Other scenarios, such as answering a cell phone, have no relationship to the attentional demands of driving. Scenarios that have a close relationship with driving task demand would be more likely to increase crash risk because the distraction occurs at a time when greater attention is needed for driving. The fourth measure is the overall level of *distraction*; that is, the potential for the scenario to result in either/or physical, visual, auditory, or cognitive distraction. The more distracting a scenario, the greater the likelihood that the scenario will result in a crash.

For each of these measures, one could construct a scale where higher numbers indicate a greater likelihood of a crash. Each scenario could then be judged on each measure independently. Preferably, these judgments would be based upon empirical studies. For example, exposure might be assessed using results from direct observation (Eby, Kostyniuk, & Vivoda, in press; Stutts, personal communication, 2003) or self reported data that is weighted to be nationally representative (Royal, 2003). In the absence of good empirical data, however, an alternative approach for assessing these scenarios would be to have a group of experts make the judgments. Scenarios could then be ranked by some combination of scores for each measure to obtain a crash-risk metric for each scenario.

Clearly there are limitations to this method of rank-ordering distraction-related scenarios. Many of the measures will be influenced by the age, sex, and other characteristics of the driver. In addition, the combination of the four measures into a single metric is not trivial. Should some measures count more toward crash risk than others? We present this method here, however, as a framework for better understanding distraction-related crash scenarios and as a first step, in the absence of adequate crash data, to rank the relative contributions of various distraction-related scenarios to crashes.

1.5 DISCUSSION

One purpose of this review was to examine available crash databases to assess their usefulness in determining distraction-related crash scenarios that a workload/distraction management system like SAVE-IT could be designed to prevent. While all databases reviewed had limitations, we concluded that the GES and CDS are the best suited for our purpose. In fact, all recent crash analyses on driver distraction have utilized one or both of these databases (see e.g. Campbell, Smith, & Najm, 2002; Najm, Koopman, Boyle, & Smith, 2002; Najm, Schimek, & Smith, 2002; Stutts, Reinfurt, & Rodgman, 2001; Wang, Knipling, & Goodman, 1996; Wiacek & Najm, 1999). We note, however, as do others, that these databases have important limitations. The first is that the number of crash records coded with a driver distraction variable is small and large standard errors will be associated with national estimates. The second limitation is that only police reported crashes are included in GES and only crashes in which a vehicle is towed away are included in CDS. Thus, neither database is representative of all crashes nationally. Finally, the distraction variable is often self-reported to a police officer. Since drivers may be reluctant to reveal an activity that may suggest personal fault in the crash, driver distraction in crashes may be biased and/or under-represented.

The second purpose of this review was to investigate a variety of scenarios in which driver distraction may be important. We consider scenarios defined by previous crash analyses as well as distraction-related driving scenarios that may not appear in crash records directly, but are likely to be related to distraction-related crashes. We found that few studies have considered distraction in relation to crash scenarios. Those that have, generally find that single-vehicle-run-off-the-road and rear-end crash scenarios have a sizeable proportion of crashes that are distraction related. Several other scenarios were reviewed but generally are lacking enough data for which to draw strong conclusions. Thus, based upon this review we suggest that the SAVE-IT system should be designed to mitigate, at a minimum, these two crash types.

The review of distracted-driving scenarios, based upon events that can trigger driver distraction, covered a wide range of scenarios arising from events both inside and outside the vehicle. For each scenario we assessed the available data on the frequency and distraction potential of the scenario. For some scenarios, such as use of cellular phones, a relatively large volume of research has been conducted. For other scenarios, such as eating or drinking in the car, very little research was available. It is also important to note that empirical exposure measures for nearly all scenarios are lacking; that is, we do not know how frequently certain distraction scenarios occur in the absence of a crash. Without good measures of exposure, it is impossible to calculate the crash risk of a certain scenario. In the absence of good data about these distraction-related scenarios and the resulting crashes, it is difficult to even rank the relative contribution of these scenarios to distraction-related crash risk. As a first pass in rank-ordering these scenarios, we present a simple framework based on an empirical or subjective rating of each scenario on exposure, volition, attentional demand, and level of distraction. Future research, perhaps with experts on driver distraction and crashes, should begin to assess the relationship of these distracted-driving scenarios to crash risk.

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