SAVE-IT

SAfety VEhicles using adaptive Interface Technology (Task 4)

A Literature Review of Distraction Mitigation Strategies

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4.0 PROGRAM OVERVIEW

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.

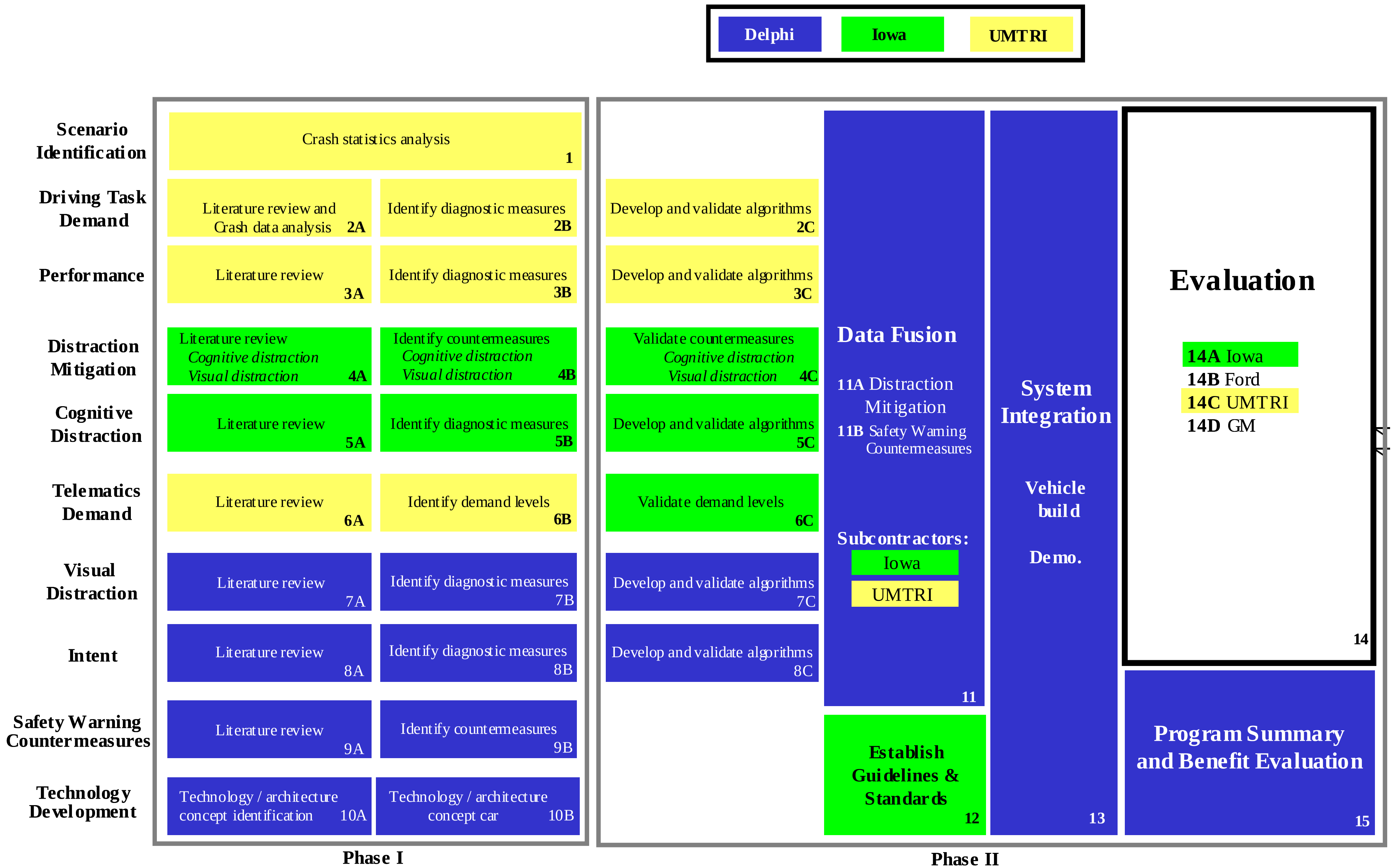

Figure i: SAVE-IT tasks

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

[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.

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 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.

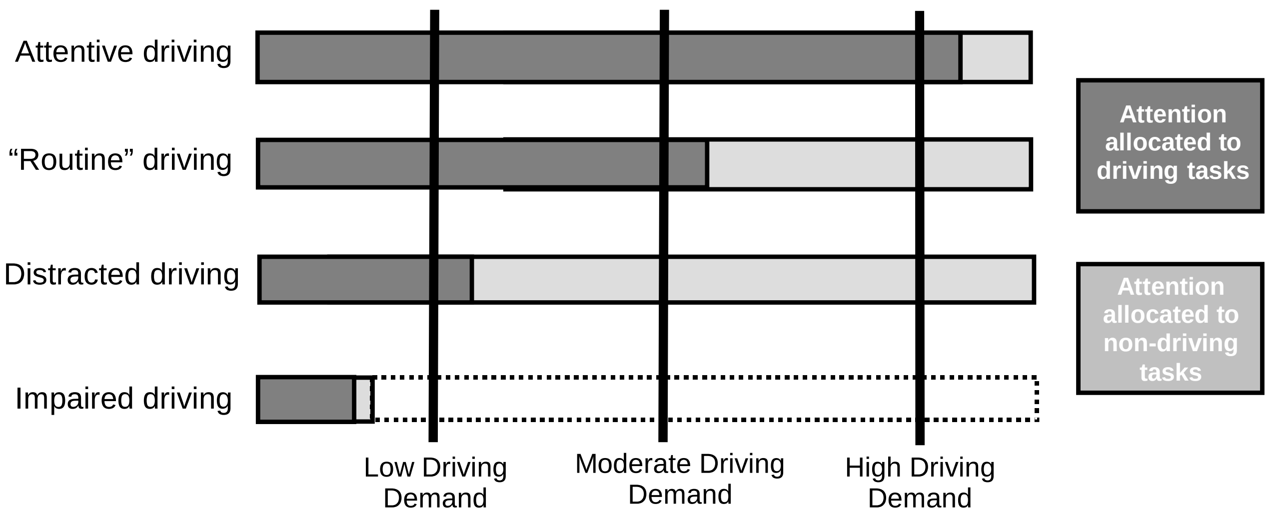

Figure ii. Attention allocation to driving and non-driving tasks

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 un-precedented 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 this period, 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 identified. This literature review report serves to establish the research strategies of each task.

4.1 INTRODUCTION

Just as computers have transformed the workplace in the last 20 years, they will transform the car in the next decade. This, combined with societal trends toward increased productivity and diffusion of work beyond the traditional office environment, will make these systems a reality. Computer companies, telecommunication businesses, suppliers, and the automotive industry have begun to develop In-Vehicle Information Systems (IVIS) in anticipation of a $15-$100 billion IVIS market (Ashley, 2001). However, IVISs require timesharing with the critical task of driving. There is evidence that such systems may reduce driving safety rather than improve it by distracting the driver in critical situations and requiring too much driver attention (Verwey, 2000). The effects of this timesharing requirement on driving safety need to be considered in system development. If implemented appropriately, these technological advances could improve productivity, satisfaction, and safety; poor implementation, however, could render these functions annoying at best and at worst, fatally distracting.

Even without the widespread use of complex technologies in the vehicle, between 13 and 50 percent of crashes are attributed to driver distraction. The results are as many as 10,000 lives lost and as much as $40 billion in damages each year (Stutts, Reinfurt, Staplin, & Rodgman, 2001; Sussman, Bishop, Madnick, & Walter, 1985; Wang, Knipling, & Goodman, 1996). Drivers of all ages are susceptible to in-vehicle distractions, in addition to distractions that come from outside. If not designed to focus on the driver's capacities, IVISs are therefore likely to increase the numbers stated above. A successful design should consider the capabilities of the whole driver population, as well as the differences between individual drivers. For example, the ability to timeshare attention between the primary task of driving and a secondary task is worse for older drivers (Lam, 2002; Mourant, Tsai, Al-Shihabi, & Jaeger, 2000). While this might tempt designers to concentrate on older drivers, thresholds set for older drivers might be annoying to younger ones.

The objective of this review is to extract information from the existing driver distraction research and to identify promising strategies for mitigating driver distraction. The focus will be on reducing distraction and creating guidelines for IVIS design that emphasize enhancing driver capabilities to avoid distractions posed by new technology. Different driver distraction mitigation strategies are defined and categorized according to the level of automation and the type of task required of the driver (or automation). These strategies are further grouped depending on whether they are system- or driver-initiated. Each mitigation strategy is presented with examples; its advantages and disadvantages are discussed in terms of distraction, as well as driver acceptance. Further research issues are then discussed based on the present review.

4.2 CHARACTERISTICS OF DISTRACTION

Driver distraction can be defined as the diversion of driver attention away from the driving task, which may reduce safety (Harms & Patten, 2003; Ranney, Mazzae, Garrott, & Goodman, 2000; Sheridan, 2002a). Driving task is composed of perceptual, motor and cognitive tasks and therefore depends on the corresponding capacities of the driver (Rothengatter, Alm, Kuiken, Michon, & Verwey, 1993). Because vision is such a critical element of driving, one of the most important indicators of distraction is where a driver is looking at any given time. Driving involves constantly scanning the environment (i.e., looking out the forward windshield or side windows, scanning mirrors, and attending to stimuli in the vehicle). However, a person can only look at one thing at a time, since eyes operate synergistically. For example, a driver cannot simultaneously insert a CD into the player and look out the forward window. Drivers must sometimes take their eyes off of the roadway and “attend” to other stimuli when operating in-vehicle controls and carrying on conversations with in-vehicle passengers. Often, one glance is not sufficient to complete an interaction and drivers must return their gaze “head down” or off the forward roadway.

Visual sampling, both in and out of the vehicle, has been modeled previously by Wierwille (1993). This normative, deterministic model (see Figure 1) starts when the driver begins performing an in-vehicle task by glancing to an appropriate location. Information extraction begins as time elapses. If the necessary information can be obtained or “chunked” in one second or less, the driver will return his or her glance to the forward scene. However, if chunking takes longer, the driver will continue to glance at the location for a longer period of time, while feeling time pressure to return to the forward scene. If the glance to the in-vehicle location continues for up to approximately 1.5 seconds and the information cannot be chunked, drivers tend to return their glance to the forward scene anyway, and try again later. Additional samples are handled in the same way, until all required visual information is obtained (Wierwille, 1993).

Wierwille (1993) further states that these driver in-vehicle glances and/or tasks can be separated into five categories that are based largely on the driver resources involved. These driver demands are classified into both visual and manual tasks. Some manual tasks are learned quickly (i.e., after only a few glances) and easily mapped out by the driver. Driver manipulation of light switches, turn signals, and other simple controls are often performed automatically. A subset of this control mapping occurs when the driver looks at a control to obtain position or status information, and then adjusts the control without looking. One example of this is checking to see if the climate control system is set and then manipulating the controls without looking at them. Wierwille (1993) classifies this type of action as *manual primarily* (also referred to as ‘manual only’).

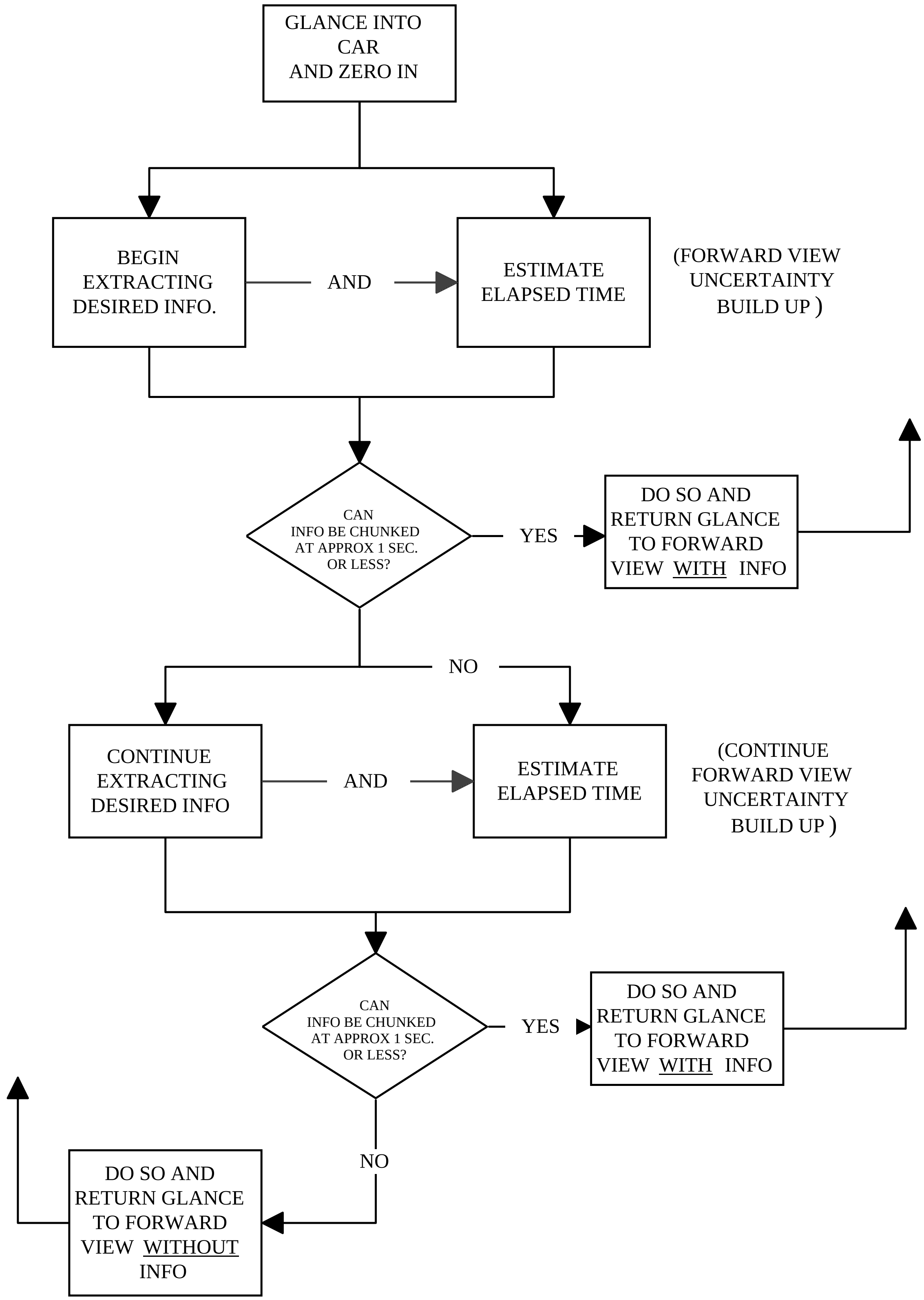

Figure 1. Model of visual sampling for in-vehicle tasks

There are also tasks that are completely or largely visual. Examples of what Wierwille (1993) terms as *visual only* tasks are reading the speedometer, checking the radio station frequency, or glancing at the clock. Wierwille (1993) also categorizes tasks that rely heavily on vision but require a degree of manual input as *visual primarily.* An example of this type of task is determining the radio station frequency when the initial display reads as a clock. The last classification that Wierwille (1993) describes is called *visual–manual*. This type of task is related to interactive activities inside the vehicle and includes tasks that require repeated input and visual attention. Examples of this task type include manually tuning a radio to a specific frequency, operating a cellular phone, and adjusting an outside rear-view mirror.

Each type of task (manual only, visual only, visual primarily, and visual-manual) represents an important kind of distraction and shares similarities with more recent descriptions of distraction. Ranney, Mazzae, Garrott, & Goodman (2000) identified four components of driver distraction: (1) visual (e.g., eyes-off the roadway), (2) auditory (e.g., conversing with other passengers), (3) biomechanical (e.g., manually adjusting the radio), and (4) cognitive (e.g., being lost in thought). Any distracting activity that drivers engage in may involve one or more of these components. A driver's willingness to engage in a non-driving-related task and the attentional demands placed on the driver by that task contribute to the potential for distraction. This brief discussion of distraction combined with a more detailed discussion of cognitive distraction (see Task 5 literature review) leads to the following considerations for distraction mitigation:

- A conflict between driving demands and in-vehicle task demands contributes to distraction.
- Driving demands and in-vehicle task demands can be described as a vector whose elements represent the different types of distraction (visual, manual, auditory).
- Drivers actively manage the division of attention between the roadway and the in-vehicle system—i.e., drivers are not passive recipients of task demands.
- The demands of the in-vehicle system can vary from those imposed on the driver to those selected by the driver—some in-vehicle tasks are driver-initiated and others are system-initiated.

Since driving and in-vehicle tasks are carried out in an interlaced fashion, the two can be viewed as mutually interrupting tasks (Monk, Boehm-Davis, & Trafton, under review). Literature on the disruptive effects of interruptions can provide insights to define strategies to modulate the presentation of in-vehicle tasks in order to minimize these effects on both the in-vehicle and the driving tasks (Dismukes, Young, & Sumwalt, 1998; Latorella, 1998; Monk, Boehm-Davis, & Trafton, 2002; Monk et al., under review). For example, McFarlane (1999) identified four ways in which interruptions can be coordinated: immediate, negotiated, mediated, and scheduled. This generic theory of task interruption can provide insights to driving and in-vehicle task interruptions. An immediate solution refers to the ongoing interruption of a person in a manner that requires instantaneous task switching. A negotiated solution provides information relating to the need for an interruption and then supporting the negotiation with the person. This gives control of when to deal with the interrupting task to the person being interrupted. A mediated solution requests an interaction with the person via a third agent. Finally, the scheduled solution restricts the interruption based on a prearranged schedule. In the driving domain, the interruptions between the driving and the in-vehicle tasks are mostly immediate since the driving environment changes dynamically and the next step in the driving task cannot be easily anticipated. However, the interruption of the driving task by the in-vehicle task may not be necessarily immediate since the in-vehicle task does not involve as high a priority or as much urgency as the driving task. Therefore, this kind of interruption design can be negotiated to let the driver decide when to engage in the in-vehicle task, thus reducing driver distraction. Katz (1995) found, however, that there are overhead costs related to negotiating interactions and that if the overhead cost is not justifiable, an immediate interruption is preferable. A mediated solution, which can also be used in conjunction with a negotiated solution, is promising if it can create intelligent IVISs that can reliably measure and predict drivers' interruptibility. Even if a scheduled solution gives the driver the ability to anticipate when a new in-vehicle task will initiate, it is not realistic in the context of how IVISs actually work (i.e., it is highly unlikely that a new in-vehicle task will initiate periodically).

4.3 AUTOMATION, ADAPTIVE SYSTEMS, AND DISTRACTION MITIGATION

In-vehicle technology to reduce driver distraction can be considered as a form of automation, and so recent reviews of automation and its effect on operator performance provide valuable insights that highlight the advantages and disadvantages of various distraction mitigation strategies (Lee & See, 2004; Parasuraman, Sheridan, & Wickens, 2000; Sheridan, 2002b). Parasuraman and Riley (1997) define automation as the machine execution of a function that was previously carried out by humans, and discuss the problems associated with human-automation interaction using four terms: *use*, *misuse*, *disuse* and *abuse*. *Use* refers to the voluntary activation or disengagement of the automation by the human. When related to the level of reliance on the automation, *use* subsets *misuse* and *disuse* at opposite ends. Overreliance on the automation corresponds to *misuse* whereas *disuse* refers to underreliance on and/or even neglect of the automation. Some of the factors that influence the *use* of automation are trust, perceived risk, workload, fatigue and cognitive overhead (workload resulting from deciding whether to use or not to use the automation) (Parasuraman & Riley, 1997). However, the interactions between these factors and the individual differences between operators make it difficult to predict the *use* of automation.

Many studies show that humans respond socially to technology and treat computers similarly to the way they would other human collaborators (Lee & See, 2002, 2004; Reeves & Nass, 1996). Trust is therefore a particularly important factor influencing reliance and the *use* of automation. As distrust may lead to the disuse of the automation, mistrust can lead to uncritical reliance on it, resulting in a failure to monitor the system's behavior properly and to recognize its limitations, thereby leading to *misuse* of the system. The last term defined by Parasuraman and Riley (1997), *abuse* captures the interaction between the automation and its designer rather than the user. *Abuse* refers to automating functions without regard to the human capabilities. The choices of when, what, and how much to automate are critical for any system controlled by humans and essentially important for systems that might in any way create danger for public safety. One such system is the car, which has already been equipped with automated systems aimed either at easing the driving task (e.g., automatic transmission, cruise control) or enhancing safety (e.g., air bags, automated seat belts). *Disuse* of the automation might compromise profitability; however *misuse* of any automated function might degrade safety (Lee & See, 2004). Expecting conventional cruise control to decelerate the vehicle when the car ahead is braking would be an example of *misuse* creating a hazard. *Misuse* might also lead to confusion and potentially, to cognitive distraction of the driver, as the system might not behave the way the driver expects it to. However, if the automation is not *abused* and is designed to encourage proper *use* by the driver, it should have the potential to lower the attentional demands and the time-sharing requirements of the driver and hence improve safety.

In order to ensure proper *use* and improve performance, productivity and safety, automation should complement not conflict with human characteristics (Rouse, 1994). *Cooperative intelligence* (also termed human-centered automation) as defined by Rouse (1994) refers to humans and automation being complementary to each other, with both agents aware of the other's states and actions. One dimension useful to consider in determining the effectiveness of systems on joint operator-automation performance is the system- or operator-initiation of a functional allocation. Similarly, with driver distraction mitigation strategies, these system- or driver- initiated performances also need to considered. Driver initiation of a strategy may be more acceptable than a system initiated one, however it may also depend on the subjective distraction level of the driver and therefore may be less effective. These concerns should be assessed when designing distraction mitigating systems.

Two of the most frequently used strategies in the aviation domain are management by consent and management by exception (Olson & Sarter, 2000). In management by consent, the automation will act only when explicit operator consent has been given. In contrast, with the management by exception approach, the automation is able to initiate actions without operator consent. However, the operator does have the ability to override or reverse the system's activities. A survey by Olson & Sarter (2000) revealed that the combination of high time pressure, high workload and low task criticality tends to a shift pilots' preferences towards the management by exception approach. Although management by exception imposes less demand on the operator by requiring fewer negotiations, this approach results in a higher risk of decreased awareness of system activities. For example, in modern "glass cockpit" aircrafts, when highly independent systems take actions on their own, pilots sometimes experience automation surprises (Sarter, Woods, & Billings, 1997). Similarly, while system initiation of a mitigation strategy may reduce demand in already highly distracting situations, it also has the potential to startle drivers if the driver who are not aware of how such a system may act.

Another area where automation can be helpful to the operator is that of vigilance. Vigilance is the ability to maintain attention and to respond as needed over a long period of time. Decrement function or vigilance decrement refers to the deterioration of vigilance over time, which results in decreased accuracy and increased response times. Tasks requiring high levels of vigilance not only lower performance but have also been found to be very demanding and stressful (Scerbo, 2001). Boredom can result if a person perceives the situation as monotonous and can in turn become a factor resulting in stress on vigilance when combined with task demands (Scerbo, 2001). In-vehicle entertainment and information through various media could stimulate a driver during periods of boredom and fatigue and help keep attention on the road. It might also, however, generate cognitive distraction and frustration, as well as physical distractions, as a result of the delay in loading information, the dynamic and inconsistent nature of information (e.g., the Internet) and the challenge of designing controls that match the expectations of the driver (Burns & Lansdown, 2000). Driving on rural highways is an example of a monotonous task that could lead to vigilance decrement, boredom and fatigue over time. Taking control away from the driver and automating it might make the task of driving on a rural highway even more monotonous and therefore harder to remain attentive. Providing automated warnings when the driver is distracted, on the other hand, can help the driver regain attention. Therefore, the level of automation to be implemented in a system, which can vary from high (e.g., machine control ignoring the driver) to low (e.g., automation providing information at the driver's request) should be considered in combination with the situational demands and the individual characteristics of the driver (Sheridan, 2002b).

4.3.1 Levels of Automation Appropriate for Adaptive Automation

Sheridan (2002b) has defined eight levels of automation that range from high (e.g., automation takes control and ignores human) to moderate (e.g., automation executes action only if human approves) to low (e.g., human does it all). These distinctions have been used to integrate studies of automation in many domains and can be used to identify design tradeoffs with distraction mitigation strategies.

The workload is generated by the task load imposed on the human but is also mediated by the human's personal characteristics, level of skill, and task management and adaptation strategies (Parasuraman & Hancock, 2001). As a result, a high level of task load does not necessarily mean a high level of workload or deteriorated performance. The relationship between task load and mental workload, as well as the relationship between workload and performance, can be described in terms of associations (increase in one results in an increase in the other), dissociations (increase in one results in decrease of the other, and vice versa), and insensitivity (change in one does not result in change of the other) (Parasuraman & Hancock, 2001). The relationship between the attentional demands imposed on the driver and the level of distraction has properties similar to the task load and mental workload relationship, and is also affected by the factors listed above. One technique to manage workload is adaptive automation (load sharing) in which the capabilities of the operator are used as signals to determine when and what tasks need to be switched off between the operator and the machine. An adaptive system that can trace the level of driver distraction and the situation appropriately and adjust the level of automation accordingly offers a promising approach to managing driver distraction. Parasuraman & Hancock (2001) divide adaptive automation into two types: adaptive aiding (providing computer assistance at appropriate times) and adaptive task allocation (switching task performance to the computer at appropriate times). Aiding represents a relatively low level of automation compared to task allocation. Adaptive aiding and temporary allocation of tasks to the machine should be employed under high levels of operator workload, and the automated task should be allocated back to the human as soon as the human can manage the workload (Parasuraman & Hancock, 2001; Parasuraman, Mouloua, & Molloy, 1996). Similarly, the level of automation should be higher under high levels of driver distraction. However, the surrounding traffic will also have an impact on the level of automation. For example, even if the distraction level is not high, imminent danger from surrounding traffic can prompt the system to take a higher level of control (e.g., panic braking or interrupting a cell phone conversation) to reduce the severity of a crash. Hence, the level of distraction and the level of automation may have an important effect on mitigation strategy effectiveness and on driver acceptance and should be explored.

In addition to the question of *who* should perform a function, *when* and *if* a function should be performed by the driver or the system is also a concern (Andes & Rouse, 1990). Dynamic function scheduling, defined by Hildebrandt & Harrison (2002), emphasizes the temporal characteristics of adaptive automation and proposes scheduling options for adaptation such as postponing, swapping, and dropping of functions. Hildebrandt & Harrison (2002) also suggest prioritizing and ordering concurrent functions by comparing their values. In aviation, for example, safety-related functions should have the highest priority compared to passenger comfort or economy. Similarly, if the driver is approaching a stop sign, this information may be prioritized over an e-mail message that can be postponed for future display. The value of a function may change as the function's deadline approaches (Hildebrandt & Harrison, 2002). If there is a relatively large distance to the stop sign, the IVIS may still safely display the e-mail information. However, the urgency to stop would increase as the driver drew nearer to the sign. If the driver does not safely decelerate to a stop, the IVIS may interrupt or even lock-out the display interaction.

Although distraction mitigation systems have great potential, these systems may also fail to provide expected benefits. As explained above, miscalibrated trust and the potential for misuse and disuse are among the many reasons for such failure. Potential reasons for a system's failure to provide expected benefits can be listed as follows:

- *Miscalibrated trust and the potential for misuse and disuse*
  This issue has been discussed previously in Section 4.3.

- *Conflict between two adaptive agents*
  Possible conflicts between the driver as an adaptive agent and the adaptive automation of the vehicle system may generate system failures. As the system adapts so will the driver, and one may respond to changes faster and more precisely than the other. The impact of this on driver-vehicle performance should be assessed.

- *Driver behavioral adaptation and the usability paradox*
  Driver behavioral adaptation to the system is another concern that may undermine system benefits. For example, the driver may become too dependent on the system to reduce distraction and therefore, may engage in distracting tasks more often. The driver may also adopt riskier driving behavior if he or she perceives the system as the primary agent in preventing collisions rather than as a backup. This phenomenon has previous been defined as *risk compensation* (Peltzman, 1975). Peltzman (1975) found that as the perceived probability of an accident decreases, driving becomes more intense (e.g., higher speed or more thrills). Another concern is the *usability paradox,* which refers to the increased use of a system if the system is designed for ease of use. If an IVIS is designed to decrease the level of demand imposed on the driver by the system, the driver may engage in increased use of the IVIS, and this may in turn lead to increased overall distraction.

- *Information overload in which distraction-related warnings simply exacerbate rather than reduce driver distraction*

Kantowitz & Moyer (2000) categorize IVIS components into three parts: safety and collision avoidance, advance traveler information systems, and convenience and entertainment. For system effectiveness, the distraction mitigation aspect should be embedded in all three system types. Moreover, these systems should be combined to provide information to the driver rather than competing for driver attention. In other words, information that the driver does not need should not be displayed. This approach has been successfully employed in the aviation domain under the principle of the "dark and silent cockpit" (Kantowitz & Moyer, 2000). Kantowitz & Moyer (2000) state that another way to solve the problem of too much in-vehicle driver information is to have the system take a high level of control and remove the driver from the loop when appropriate.

- *False adaptation*
  False adaptation refers to the adaptive system falsely adapting to the driver state and the situational demands. The effects of system falsely adapting to the driver and roadway state should be explored.

- *False or nuisance alarms*
  Alarms that occur when the driver does not perceive there to be a threat. This issue is discussed further in Section 4.3.2: Guiding adaptive automation with imperfect estimated of distraction, and in Section 4. 4. 1: Driving related, System initiated.

- *Workload transition and the out-of-the-loop phenomenon*
  When the adaptive system assigns a previously automated driving task back to the driver, the driver's workload may significantly increase very quickly (an example of workload transition). Therefore, it is important that the system keep the driver aware of the driving situation, that is, in the loop. Situational awareness has long been recognized as one of the most crucial issues in pilot performance. When a high level of automation is implemented in the vehicle, this issue may also become crucial for driving safety. In order to keep a driver's situational awareness at a high level, moderate levels of automation may be preferable for certain driving tasks and situational demands (Endsley, 1997).

- *Costs of adaptation in terms of decreased stimulus-response consistency*
  If the IVIS display is adaptive, the input-output relationship may not be invariant. For example, when the driver reaches down and presses a button, the system may not respond the same way every time. Inconsistent system actions may result in further distractions, and should be explored.

- *Driver acceptance*
  Drivers' acceptance of the system is also a key issue and depends on ease of system use, ease of learning, perceived value, advocacy of the system, and driving performance (Stearns, Najm, & Boyle, 2002). Low levels of acceptance would limit system effectiveness. Driver age may also have an impact on the level of acceptance and therefore the effectiveness of mitigation strategies and

should be explored. One very promising tool to increase user acceptance, as well as ease and efficiency of a system, is Human-Computer Etiquette (Louwerse, Graesser, & Olney, 2002; Miller, 2002; Scerbo, 2002). One of the coiners of this term, Miller defines etiquette as:

> "… the defined roles and acceptable behaviors and interaction moves of each participant in a common 'social' setting – that is, one that involves more than one intelligent agent. Etiquette rules create an informal contract between participants in a social interaction, allowing expectancies to be formed and used about the behavior of other parties, and defining what counts as good behavior" (Miller, 2002, p. 2).

IVISs are intelligent agents that drivers have to interact with while driving. When incorporating different distraction mitigation strategies into these systems, drawing an analogy between them and a front seat passenger is both appropriate and useful. For example, a passenger reading a map is expected to point out the next exit to the driver in a timely and polite manner. It would be highly impolite and annoying if the passenger were to command the driver to 'Turn Right!' at the last possible moment. A passenger who constantly criticized the driving style of the driver would also be very annoying. And while a passenger commanding the driver to 'Stop!' in a hazardous situation conveys very useful information to the driver, he or she also violates the assumptions of a polite society. Miller (2002), among his list of etiquette characteristics, includes the statement: 'etiquette constraints are soft constraints.' Therefore, it can be said that the etiquette constraints are not solid constraints which cannot be violated. Moreover, even if violations of etiquette can be disruptive, they can on occasion, be useful. One important dimension in the driver-passenger interaction context is the initiation of the interaction between the driver and the passenger. A passenger may help the driver if asked, in which case the interaction would be initiated by the driver (such as when the driver requests the passenger to read a map) or the passenger may help the driver without being asked, in which case the interaction would be initiated by the passenger. In the social context, both types of initiation are possible, but also depend on the situation at hand. It could then be argued that a mitigation strategy may also be initiated by either the driver or the system, and that the appropriateness of the choice depends on the situational constraints. In order to assess the acceptance of the distraction mitigation strategies, the analogy of the front seat passenger in the context of computer etiquette will be further used in the following chapters, especially within the discussion of each mitigation strategy.

- Nontransparent mitigation strategies

  The transparency of the mitigation strategies to the driver would play an important role for usability and acceptance. The system's operation and status should be visible and easily understood by the driver. A complex algorithm for predicting and mitigating distraction may confuse the driver. The concerns about social etiquette and other challenges such as unrealistic expectations emerge with an animate IVIS. These problems might be avoided with a system based on simple rules that makes it clear to drivers that a machine is at work.

4.3.2 Guiding Adaptive Automation with Imperfect Estimates of Distraction

There are many different measurements of driver distraction. These various measures are described in detail in Task 5. Distraction measurement is a critical element of any adaptive system meant to mitigate driver distraction. Ideally, such a system would generate a continuous measure of distraction. This measure could then identify driver states in which the driver is too distracted to act safely in critical situations; the information could then be used to warn the driver or even to take control of the vehicle. A particularly promising approach is to use several measures to provide convergent data regarding the degree of distraction of the driver. For example, following the eye movement pattern of the driver (or any other physiological measure), driving performance and the interaction of the driver with the IVIS are among the techniques that can be used to measure distraction. The threshold employed to engage the system would have an impact on the effectiveness and acceptance of the strategies. To promote acceptance and effectiveness of these strategies, it is important to take the adaptive characteristics of the driver into account because novice and experienced users would have different thresholds. For example, in the engagement with IVIS, a driver that is familiar with controls could adjust them according to a mental model of the system without being highly distracted and still engage with the IVIS. Similarly for the driving task, the focus should be on the individual driver's deviations from his/her normal driving behavior rather than on assigning average or worst-case driver thresholds to the whole driver population. The distraction mitigation would probably work better if it were based on a combination of driver's normal driving and the absolute criteria because "normal" may not be safe. The surrounding traffic might also affect the driving style of the driver. For example, a driver may not typically emphasize lane keeping when driving on a rural highway with very low congestion. This may be the driver's normal driving behavior and if a warning was issued in this circumstance, could actually be viewed as an annoyance by the driver.

Although a combination of distraction measures (discussed in more detail in the Task 5 review) may provide a reasonably good estimate of the degree of distraction, the estimate will always be imprecise and the consequences of this imprecision is a critical consideration in developing mitigation strategies. The unreliability of the distraction estimate could impact in particular high levels of automation in the driving task. False alarms, both false positives (an alarm given when no impending collision is present) and false negatives (an alarm not given when an impending collision is present) generated by such a system may create danger even if there is none. In these scenarios, distrust and disuse can result from high false-alarm rates. Due to the low base rate of collision events, the probability of a collision when system takes action can be quite low, while the false-positive alarm rate can be quite high, even if the system is highly advanced. This problem contributes to drivers' response to and acceptance of the system, which may in turn influence system effectiveness (Parasuraman, Hancock, & Olofinboba, 1997). High false alarm rates can also lead to driver frustration, which is itself a type of emotional distraction that can have a negative impact on traffic safety (Burns & Lansdown, 2000). False alarms for system intervention to the non-driving tasks may also generate driver frustration. In addition to the reliability of the distraction estimate, another issue of concern in promoting system effectiveness is adaptation to the degree and type of distraction confronting the driver, as well as to the criticality of the driving situation. Depending on the type of distraction, drivers may lack awareness regarding the degree of distraction (discussed in more detail in Task 5 review). Therefore, when the criticality of the driving situation is high, system-initiation of a strategy can be more effective than driver-initiation.

4.4 TAXONOMY OF MITIGATION STRATEGIES

The taxonomy of mitigation strategies is based on a comprehensive literature review of driver distraction, adaptive automation, and IVIS functions (Lee, Caven, Haake, & Brown, 2001; Parasuraman et al., 2000; Ranney et al., 2000). Twelve unique mitigation strategies are defined and categorized in terms of whether they are related to a high, moderate or low level of automation. These mitigation strategies are further categorized according to whether they address driving-related (e.g., steering, braking) or non-driving-related tasks (e.g., tuning the radio, talking on the cell phone) as defined by (Ranney et al., 2000). Strategies that address driving-related tasks focus on the roadway environment and directly support driver control of the vehicle, whereas strategies for non-driving-related tasks focus on modulating driver interaction with IVIS. Within these categories, the mitigation strategies are subcategorized as driver initiated (i.e., where the driver is the locus of control) and system initiated (i.e., where the system is the locus of control). The categories are described further in the next section and are shown in Table 4.1.

Table 4.1. Mitigation strategies classified by level of automation and type of task

LEVEL OF AUTOMATION	**DRIVING-RELATED STRATEGIES**		**NON-DRIVING-RELATED STRATEGIES**	
	System Initiated	Driver Initiated	System Initiated	Driver Initiated
High	*Intervening*	*Delegating*	*Locking & Interrupting*	*Controls Pre-setting*
Moderate	*Warning*	*Warning Tailoring*	*Prioritizing & Filtering*	*Place-keeping*
Low	*Informing*	*Perception Augmenting*	*Advising*	*Demand Minimizing*

Each mitigation strategy has features that make it beneficial in some situations and not in others. In other words, it is possible for a mitigation strategy to actually undermine rather than enhance safety. The following list of key dimensions can guide the selection and implementation of particular mitigation strategies.

- Degree and type of distraction confronting the driver
- Type of distraction confronting the driver; drivers may lack awareness regarding the degree of distraction (discussed in 4.3.2 and in more detail in Task 5 review)
- Reliability of distraction estimate

- Criticality of the driving situation (discussed in 4.3.1)

These dimensions can also form a basis for system adaptation between strategies, as well as within each strategy. For example, depending on the driver and roadway state, the system may switch from one strategy to another (dynamical adaptation between strategies) or may change the properties of a particular strategy (dynamical adaptation within a strategy) such as the timing of initiation or the degree of urgency conveyed to the driver. As a result, this paper describes each mitigation strategy referring to these key dimensions, design tradeoffs and the appropriate applications.

4.4.1 Driving Related, System Initiated

Driving-related mitigation strategies help the driver in driving-related tasks, such as speed selection and vehicle lateral and longitudinal control. System-initiated strategies that are driving-related (first column in Table 4.1.) aim to enhance safety by directing driver attention to the roadway, as well as by directly controlling the vehicle. These strategies can be separated into three levels of automation: intervening (high), warning (moderate) and informing (low).

Intervening is characterized as the highest level of automation in this category since it refers to the system taking control of the vehicle and performing one or more driving-related tasks during hazardous situations when the driver is too distracted to react in a timely manner. Some of the example functions and features that implement the strategy of *intervening* are:

- Lane change tracker / steering control
- Roadway departure system / steering control
- Full braking control (beyond warning stage) / panic braking
- Distractometer / steering and braking control
- Full steering control (beyond warning stage) / steering control
- Automated speed enforcement system –external vehicle speed control (Carsten & Fowkes, 2000) / braking control

The perfect system able to help the driver to brake or steer under safety-critical situations would enhance safety considerably. However, uncertainty in the driving environment and sensor limits could lead to inappropriate and potentially dangerous responses. For example, system panic braking when there is no imminent danger could create a hazardous situation. Then again, if the driver is aware of a danger and able to respond in an appropriate manner, system panic braking could be both dangerous and annoying. Implementing high levels of automation in the system does not simply mean removing the error by removing the driver (Parasuraman & Riley, 1997). Actually, such a strategy substitutes the designer for the driver and makes the system more vulnerable to designer error. Even if the system were able to accurately detect a hazardous situation, it may not take the most suitable action; when steering to the adjacent lane is safer than braking, the system may panic brake. It is therefore essential for systems that intervene in driving to maximize the rate of correct responses and minimize the rate of misses. The activation must be when the system is most confident that an intervention is appropriate.

In addition to these reliability issues, another problem associated with the strategy of intervention is that drivers may become too dependent on this function and be more likely to perform non-driving-related tasks they would normally not have attempted. They may also potentially take more risks when driving. The salience of the interventions is important in avoiding the problem of behavioral adaptation to automation. If the activation criteria is early than necessary drivers may push the vehicle to its handling limits to see if the system is functioning. Being confident in the system function may also tempt the drivers to push the boundaries of control. Moreover, drivers are usually critical of systems that intervene in their driving, whereas systems that offer recommendations and provide information are deemed considerably more acceptable (Carsten & Fowkes, 1998; Gustafsson, 1997). We prefer to get information and recommendations from the passengers in our cars rather than giving over the driver seat to them if we are uncertain about their driving skills. These issues may be resolved if *intervening* strategies can be made dynamically adaptive to the driver and roadway state. For example, the threshold for the strategy to initiate (such as time to collision for panic braking or the amount of lane drifting) may change according to the level of driver distraction and/or roadway state (such as the presence of a car in the adjacent lane). Interventions can be partial or complete and they can also help to warn the driver. For example, system partially slowing down the vehicle if the driver is too distracted to be aware of a stop sign ahead would also help warn the driver.

Warning alerts the driver to take a necessary action. This is considered a moderate level of automation compared to intervening since the driver is still in control of the vehicle. This strategy expects the driver to utilize the warning provided by adapting his/her behavior to avoid a hazard (Kulmala, 1998). Example functions and features that implement the strategy of *warning* are listed below, many of which are being investigated as part of the Intelligent Vehicle Initiative (IVI) (ITS-JPO, 1999).

- Oncoming red light warning system / flashing red light on the windshield
- Forward collision warning system / seat shaker –wheel shaker –alert algorithm – HUD (show gap distance – continuous information)
- Rear-end warning system / rear light indicator
- Lane change tracker / seat shaker –wheel shaker –alert algorithm
- Roadway departure system / seat shaker –wheel shaker –alert algorithm
- Distractometer / seat shaker –wheel shaker –alert algorithm
- Intersection collision avoidance system/ alert algorithm
- Speed indicator / voice activated command
- Backing aid / alert algorithm
- Advance brake warning system / brake light activation
- Rumble strips

A collision avoidance system is a function that employs *warning* as a strategy and encompasses both visual and audio alerts. These systems use electronic sensors to detect the motion of a lead vehicle, determine if a collision is likely, and either warn the driver to move attention to the roadway (*warning*) or take vehicle control (*intervening*). Operator-centered collision avoidance systems (e.g., Traffic Alert and Collision Avoidance System II) were used for aviation and maritime operations before they were implemented in the driving domain. However, in applying such technology to the driving domain, the limited processing time afforded to the untrained individual who would receive the warnings (compared to the crews of a plane or a ship) should be considered (Parasuraman et al., 1997). The warning should be meaningful to the driver in such a way as to promote immediate response. Otherwise, the confusion may elevate the level of cognitive distraction and hence increase the reaction time to the event.

Among the many means available for warning the driver, the one implemented in the system should be chosen with respect to system function. For example, proprioceptive feedback (steering wheel vibration or force feedback like resistance) is more effective than auditory warnings for lane change trackers since it is meaningful to the driver in the same way that rumble strips are, even if the driver is not informed about the meaning of this warning (Schumann, Godthelp, Farber, & Wontorra, 1993; Suzuki & Jansson, 2003). Therefore, haptic stimulus transmitted through the steering wheel is a promising feature for lane-keeping as the feedback received matches drivers' mental model of lane deviation.

In the simulator study conducted by Suzuki & Jansson (2003) two types of acoustic warnings and two types of haptic warnings were provided when the subjects deviated from the lane: monaural beeps, stereo beeps, steering vibration and pulse-like steering torque. In the unpredicted condition, where the subjects were uninformed about the meaning of the warnings, the steering vibration generated the shortest reaction times. Although the pulse-like steering torque applied to the steering wheel was towards the desired path, half of the subjects turned the steering wheel in the wrong direction to compensate for the torque. The post-experiment questionnaire revealed that incorrect steering strategy resulted from subjects' belief that some lateral disturbance had affected the car. In the predicted condition, when subjects knew what the warnings stood for, both types of auditory warning resulted in shorter reaction times than the haptic feedback. This suggests that if the auditory warnings are meaningful to the driver, they may actually be more effective than haptic feedback. However, there are other problems associated with auditory warnings such as a tendency to be susceptible to masking.

One collision avoidance system, 'the rear end collision avoidance system' (RECAS), was examined by Lee, McGehee, Brown, & Reyes (2002) for driver response to simulated collision scenarios. Lee et al. (2002) showed that this type of system benefited drivers. An early warning resulted in faster reaction times for both distracted and non-distracted drivers than a late warning or no warning, and thereby reduced the number of collisions. However, there are many issues that may degrade the effectiveness of a warning system, one of which is the behavioral adaptation of the driver, as there is a possibility that drivers may rely on the warning system as the primary collision alert rather than as a backup. This is analogous to getting used to our front seat passenger checking the availability of the lane that we are planning to merge into; in trusting that the passenger will do this every time we change lanes, we are likely to become less alert during lane changes. Such a behavioral adaptation might encourage drivers to engage in distracting tasks more often, and in turn, degrade safety. If drivers tended to interact with IVIS more often, the effectiveness of the warning system could be promoted by integrating IVIS and the warning system (e.g., by using an algorithm that adjusts the timing of the warning according to the level of driver engagement in IVIS, which is an example of a within-strategy adaptation based on the driver state).

Another concern that affects user acceptance and appropriate reliance on warning systems are false and nuisance alarms discussed previously in Section 4.3.2. High false alarms can lead to distrust and disuse. However, not all false positive alarms are harmful. Such alarms can be used to train novice drivers, and are also needed to generate driver familiarity with the system. If the first time the driver receives a warning is in a true collision situation, the driver may not respond to it in the amount of time available. False positive alarms may also lead to more cautious driving and thereby result in reduced false alarm rates (Parasuraman et al., 1997). Thus, for a warning system to be effective, an acceptable false alarm rate should be established. These problems related to false positives is most likely why collision mitigation strategies were the first on the market (e.g., Honda in Japan).

One way to promote driver acceptance of warning systems is to employ graded warnings that adapt the intensity of the warning to the criticality of the situation, driver state and/or roadway demand. Designing driver adaptive warning systems that assign thresholds for the individual driver is an alternative method. Traditional warning systems incorporate a fixed warning threshold, which is set for the average or the worst-case driver. As passengers, however, we do not warn every driver in the same manner. For example, we tend to warn inexperienced drivers more than experienced ones. Goldman, Miller, Harp, and Plocher (1995) proposed a driver adaptive warning system that has the ability to tailor the warning threshold to individual differences in driving style and to warn the driver when an event arises that poses imminent danger and/or when the driver's behavior does not match his/her behavioral profile model (e.g., when the system registers that the driver is fatigued or distracted). This technique can also be implemented in systems that take vehicle control (*intervene*) to promote acceptance.

A warning strategy can also be used to help other vehicle drivers. For example, the *Advance Brake Warning System* uses a warning strategy to alert the driver of the following vehicle. This system detects very rapid accelerator pedal releases and activates the brake light before the driver starts braking. It thereby increases the reaction time limit of the following driver who, if distracted, otherwise may not react in a timely manner. It is possible that a high false-positive alarm rate for such a system could generate uncertainty for the driver of the following car, in turn producing a time delay as the driver decides whether the light indicates real braking or not (Shinar, 1995).Shinar (1995) suggests, however, that relative to the actual brief braking actions

(10.8 % of total); the false alarm rate of a representative system (2.4 %) is negligible and hardly noticeable.

Informing provides drivers with necessary information that they typically would not observe if distracted. For example, a speed limit indicator might provide information on changes in posted speed limits. This is helpful if the driver is too distracted to notice the roadway sign or if the sign is not visible. However, if the driver is already aware of the speed limit change, receiving the same information may be distracting or annoying, similar to a passenger who announces every speed limit change. This strategy is considered a low level of automation, since information is provided that does not require any action on the part of the driver or constitute a warning by the system. Functions and features that implement this strategy include:

- Vehicle speed indicator / Head-up display (continuous information) or voice activated command
- Speed limit indicator / Head-up display (continuous or discrete information) or voice activated command
- Deer passing zone / Head-up display (continuous or discrete information) or voice activated command
- Oncoming red light warning system / Head-up display (discrete information) or voice activated command
- Parking aid / alert algorithm or voice activated command
- Peripheral event indicator / voice activated command or Head-up display (discrete information)

The dynamic model of stress and vigilance developed by Hancock & Warm (1989) suggests that the combination of information rate and information structure (meaning sought by the person) determines the attentional resource capacity in vigilance. Large deviations (either increases or decreases) from the optimized combination of these two factors results in, sequentially, discomfort, stress (when the deviations exceed the psychological adaptability of the individual), and performance deficits. The information rate and structure presented to the driver should therefore be optimized to promote driver acceptance of and high levels of attention for an informing system. Performance improves when the operator has control (information activating) on either one or both of these two factors (Hancock & Warm, 1989).

One feature that uses the strategy of *informing* is the Head-Up Display (HUD), which displays images in the driver's forward field of view. This eliminates the need for drivers to shift gaze to receive the information, reducing reaccommodation times and allowing drivers to keep their vision closer to the central roadway. The tradeoff is the introduction of clutter in the forward view, which may obscure critical elements of the driving scene and visually distract the driver (Ward, Parkes, & Crone, 1995). While information presented with a synthetic voice may be the answer to the visual clutter problem, it is also highly likely that the informing voice could be masked by ambient noise or by conversations in the car (Wickens, Gordon, & Liu, 1997). Redundancy in the modality of information has been investigated by Tominaga et al. (2003), who studied the effects of simultaneous presentation of auditory and visual information on driver response. The results showed that when visual information is used together with an auditory stimulus, the eye reaction time to receive the information from the display is reduced.

Depending on the criticality of the distraction situation, the driver-related, system-initiated system would adapt to the most appropriate level of automation to mitigate distraction (i.e., a between-strategy adaptation). For example, if the system decides that the driver's engagement with IVIS is a distraction when approaching a stop sign, *informing* might be appropriate in order not to annoy the driver if he or she has already noticed the sign. An example of *informing* can be an oncoming "STOP" on a HUD. If the system detects that the driver is not decelerating while approaching the stop sign, a *warning* might then be initiated. If the system senses an impending collision with an oncoming vehicle, an *intervening* strategy might start braking smoothly for the driver and then give control back if the driver takes over braking. If the driver does not take any action or the system detects that the driver would not be able to stop in the required amount of time, the system might even start panic braking. As depicted in this example, there is a continuum for the three strategies. That is, an *informing* strategy can escalate to a *warning* which can change into an *intervening*. In situations where the driver is thought to be too distracted, system may fine-tune messages based on the urgency of the situation and the roadway demand. For example, if a driver is going over the speed limit, *informing* may provide speed information at some regular, specified interval. If the driver is speeding *and* distracted, *warning* may change the interval of the speed information displayed by flickering with more urgency (Hoedemaeker, de Ridder, & Janssen, 2002). If the driver is disregarding the *warning* and creating a hazardous situation *intervening* can slow down the vehicle.

4.4.2 Driving-Related, Driver-Initiated Strategies

This group of strategies mitigates distraction by having the driver activate or adjust system controls that relate to the driving task. The driving-related, driver-initiated strategies that correspond to high, moderate and low levels of automation are classified as: *delegating*, *warning tailoring* and *perception augmenting*, respectively.

Delegating is driver initiation of automatic vehicle control to share the task of driving with the system, such as adaptive cruise control in which the system takes on the responsibility of controlling vehicle acceleration to maintain a driver-specified headway time to the impeding vehicle (Bogard, Fancher, Ervin, Hagan, & Bareket, 1998). The ultimate idea behind this strategy is giving over full control of the driving task to the system, as though one were switching the driver seat with a passenger that knows how to drive. In other words, the system delegates the driving task with driver permission. For example, driver start-up of lane assistance would be an example of delegating. Other example functions and features that employ this strategy are:

- Cruise Control / Acceleration and Braking Control
- Adaptive Cruise Control / Acceleration and Braking Control
- Full Steering Control / Steering Control

Delegating allows the driver to share the load and therefore may reduce the attentional and biomechanical demands posed by the driving task. However, it might also transform interactive driving to a task that requires vigilant monitoring and potentially increase the level of distraction by encouraging the driver to engage in distracting activities. When the driver is engaged in other activities the detection of automation failures will be poor. If the automation fails to take the appropriate actions and the driver can not act in a timely manner, safety will be compromised (Parasuraman et al., 1996).

The warning tailoring strategy refers to giving the driver the ability to adjust the sensitivity or start-up and shut-down of the warning system depending on the distracting activities the driver expects to be engaged in. Headway settings for a rear-end collision avoidance warning system will be an example for this strategy. This differs from the warning strategy described in the previous section in that driver input is now required. Allowing the driver to adjust or to activate the system can promote driver acceptance. However, the driver's realization of and responsiveness to the level of distraction will be important factors in determining the system's effectiveness.

Perception augmenting provides driving information at the driver's request. It helps reduce the resources needed to locate necessary information while driving (e.g., driver's speed, posted speed), thereby decreasing the level of distraction. Like *warning tailoring,* this strategy depends on the driver's realization of the need for the information. For example, if the driver is too distracted to be aware of how fast he or she is traveling, the driver may also be too distracted to activate an information system that can provide this information.

Driving-related, driver-initiated strategies are a promising way to gain driver acceptance, since the driver has control with these strategies. In safety-critical situations of imminent danger, however, the effectiveness of driver-initiated strategies is in doubt compared to their system initiated counterparts. This shortcoming might be resolved by an adaptive system able to switch over to a system-initiated strategy depending on the driver and roadway state, as well as on the hazardousness of the situation.

When used together with a driver distraction measure, the driver-related, driver-initiated strategies could take into consideration the input by the driver, but adjust the information provided based on the perceived distraction level. For example, if the system perceived that the driver was not distracted, but wanted some level of roadway information, *perception augmenting* could provide posted speed information at the driver's request. If the system detected that the driver was somewhat distracted (e.g., eyes were not on the road for an extended period of time), then *warning tailoring* could provide warning information at the sensitivity level set by the driver. Finally, if the system detected an impending collision based on the headway setting input by the driver, the system might switch to *delegating* and assist in braking if that was the preferred setting of the driver. Obviously, the effectiveness of these driver-related, driver-initiated systems depends on how the driver adjusts the settings. Therefore, an extension to these strategies would be to incorporate driver-related, *system-initiated* strategies with the driver-related, *driver-initiated* strategies. That way, for example, if the driver has set the forward collision warning system to activate at a specific headway and the system senses that the driver will not take action, the adaptive system can switch to *intervening* and take over braking and steering (rather than merely assisting in braking).

4.4.3 Non-driving-related, system-initiated

Non-driving-related mitigation strategies aim to reduce driver distraction from the perspective of reducing attention to the in-vehicle system rather than directly influencing the driving task as in the driving-related mitigation strategies. Like the driving-related strategies, these strategies can also be subcategorized as system-initiated and driver-initiated.

System-initiated, non-driving-related strategies build upon the idea that when driving performance has been or will be significantly impaired, the system can take action and change the nature of the non-driving-related task that the driver is engaged in. *Locking & interrupting*, *prioritizing & filtering,* and *advising* are the non-driving-related, system-initiated strategies that respectively correspond to high, moderate and low levels of automation.

Locking & interrupting can be classified as high levels of automation since *interrupting* discontinues the non-driving activities and *locking* locks out the system associated with these activities at times when attention to the primary driving task is required. Ideally, the system should be able to switch between *locking* and *interrupting* depending on the driver and roadway state in order to pick the best strategy, since *interrupting* is a lower level of automation than *locking* and would have different effects on reducing distraction. Verwey (2000) showed why a *locking* and *interrupting* strategy may be advantageous. In his study, participants were asked to postpone a non-driving-related task precisely when they felt an unsafe situation was about to occur. He found that participants could not properly judge the situation. The disadvantage of this strategy is the potential increased annoyance level of the driver, especially if the system unnecessarily takes action. There is also the potential that the degree of distraction may increase as the driver tries to continue the non-driving-related task that was interrupted or locked. In addition to the safety issues related to driver distraction, with this strategy there is also a productivity decrement associated with the in-vehicle task interruption. *Locking* and *interrupting* fall in the immediate interruption category in task interruption theory defined by McFarlane (2002). Ballas, Heitmeyer, & Perez (1992) identified that there is an initial decrease in performance as the interrupted task is resumed. Therefore, secondary task interruption may result in an initial decrease in performance as the task is resumed. This issue should be considered in system development. McFarlane (2002) showed that people actively avoid mid-task interruptions because they are associated with a greater cost for task resumption. Therefore, if the interruption were to occur before a new task or subtask, it would be easier for the driver to resume the in-vehicle task. The resumption of a task is also easier if the task is a repetitive action (Monk et al., under review). For example, resumption of a radio-tuning task would be easier for the driver than a text-message-reading task. These arguments suggest that if the IVIS have clearly defined subtasks (especially non-repetitive ones) that can be carried out in short, attention-switching intervals, then the productivity provided to the driver by the IVIS can increase (or at worst, not decrease) while safe driving is maintained.

Prioritizing & filtering information presented to the driver minimizes the number of non-driving-related tasks that can be performed in high-load situations, and these strategies can be grouped together as a moderate level of automation compared to interrupting and locking. For example, under high-demand driving conditions, depending on the criticality of the situation, the incoming calls can either be filtered (the phone is not allowed to ring) or prioritized (only calls listed by the driver as highly important are allowed). Visual demands on the driver increase linearly with the road curvature, and maximum demand occurs near the point of curvature (Nowakowski, Friedman, & Green, 2002; Tsimhoni & Green, 2001).When approaching a curve, incoming calls could be filtered to ensure safe driving. Parasuraman et al. (2000) suggest that organizing information sources by prioritization or representing the information by highlighting decreases workload and hence, enhances performance. Moreover, unlike *locking* and *interrupting* strategies which are immediate interruptions, p*rioritizing* and *filtering*, which fall in the mediated interruptions category in McFarlane's (2002) task interruption theory, do not pose a performance decrement with secondary task resumption. A potential downside of *prioritizing* is that the driver's attention may still be drawn to inappropriate elements of the driving task. For example, if information provided by a navigational system is prioritized depending on the roadway condition, the driver may still be able to interact with the system when there is a roadway demand that requires appropriate action (e.g., notification of the next exit when the car ahead is braking).

Advising gives drivers feedback regarding the degree to which they are engaged in a non-driving task. A background sound on a cellular telephone conversation could remind both parties that one is driving. This sound could be modulated according to the driving situation and/or the driver's state (i.e., within-strategy adaptation). For example, the *advising* of the background sound could become more intense as vehicle speed and traffic density increase. This strategy is considered a low level of automation since it only informs the driver, without taking any action. However, such a strategy may increase driver annoyance and distraction if the demands of ignoring the "advice" become a burden, such as when a passenger constantly nags the driver to watch out for traffic.

In this section, each strategy was demonstrated with the non-driving task of talking on a cell phone. Another example of how an adaptive system can be used with non-driving-related, system-initiated strategies relates to in-vehicle text messages. If a driver is using e-mail and the system perceived that the driver is not focused on the driving task, the system can provide an *advising* strategy to remind the driver that he or she is still driving. If the same person is approaching a more visually demanding roadway (e.g., a curve) and is still perceived to be distracted, the system would then activate the *prioritizing and filtering* strategy by either prioritizing the information that could be viewed at that moment (e.g., only messages from specific individuals can be received), or filtering the information presented (e.g., only messages that were four words or less).

Finally, if the driver has not had his or her eyes on the road for an extended period of time and is too close to a lead vehicle, the system can change to a *locking and interrupting* strategy that will stop further messages from appearing and lock him or her out of the system until the impending danger is over.

4.4.4 Non-driving-related, driver-initiated strategies

Driver-initiated strategies rely on drivers to modulate their non-driving-related tasks according to their subjective degree of distraction. These strategies can further be categorized into high, moderate and low levels of automation as *controls pre-setting*, *place keeping*, and *demand minimizing*.

Controls pre-setting is categorized as the highest level of automation for a driver-initiated option for the non-driving-related scenarios. The driver can, for example, pre-set the radio or CD player or the destination on a navigation device and not modify it once during the drive. Drivers may, however, be tempted to manipulate the controls and therefore diminish the effect of this strategy.

Place keeping minimizes the demands of switching between the driving- and non-driving-related tasks. Task switching involves directing attention from one task to another (e.g., talking on a cell phone to braking and back to talking). As the number of tasks a person has to perform simultaneously increases, the more difficult it becomes for the driver to perform these tasks, because task-switching requires a certain amount of attention. For example, reading a map (either paper or display) significantly degrades driving performance (Dingus, Antin, & Hulse, 1989). If the visual demands on the road increase, the driver's tendency is to glance at the in-vehicle display more frequently but for shorter durations and with longer times between glances to keep driving safe (Tsimhoni & Green, 2001). In such circumstances, the driver's need to keep place in the non-driving-related task also increases. Without help, the driver might become distracted trying to relocate the point in the task he or she was performing, and may even have to start over if returning cues cannot be easily identified. Alternatively, the driver may be more likely to persist and extend glances away from the road to a dangerous level. As was stated for the *locking* and *interrupting* strategy, these issues may be resolved by designing IVIS which have clearly defined subtasks (especially for non-repetitive ones) that can be carried out in short attention-switching intervals. The downside of this strategy is its potential to encourage the driver to engage in more non-driving-related tasks by making the task easier to carry out.

Demand minimizing reduces attentional demands associated with non-driving-related tasks by creating low-demand interfaces (e.g., using steering wheel mounted control, voice activation or hands-free devices, and manual-only interfaces), and therefore corresponds to a low level of automation. Example functions and features that implement this strategy include:

- Hands-free devices / Speech Recognition
- Steering wheel mounted controls / Buttons

- Physically conspicuous controls that are easily mapped (manual-only interaction)

Nowakowski, Friedman, & Green (2002) investigated demand minimizing strategy by presenting the caller ID on a HUD. This resulted in better lane-keeping performance compared to receiving a call on a current phone interface. Speech-based interaction features also use the *demand minimizing* strategy. Such features require different perceptual (auditory) and response (vocal) resources than the primary driving task (which calls for visual perception and manual response) (Wickens et al., 1997). As a result, a hands-free device can minimize the visual and manual demands placed on the driver. However, such a system might still pose a cognitive distraction to the driver, by demanding resources associated with thinking about the driving task (Lee et al., 2002).

A hands-free cell phone is an example of a hands-free device currently in use. It can be hypothesized that talking on a hands-free cell phone has the same effects as talking to a passenger. However, a careful passenger can follow the traffic and adjust the conversation according to the demands imposed on the driver. Nunes & Recarte (2002) demonstrated that when the same cognitive tasks are presented to the driver by a passenger and a hands-free cell phone, the effects are of the same magnitude. Also, regardless of the presentation method, the non-driving-related cognitive tasks affect the information processing capacity of the driver, which in turn influences speed control, visual search behavior, detection and decision-making capacities. Listening to and responding to complex auditory messages are significantly detrimental to driving performance, especially when the driver encounters uncommon events. Commonly encountered traffic-signal-related choices, on the other hand, tend to result in conservative decision making if the driver can process the relevant information (Cooper et al., 2003). For example, when the driver is not distracted, the decision to turn through a gap in an on-coming vehicle stream is influenced by age, the gap size, the speed of the on-coming vehicle, and the road condition (e.g., wet pavement). However, when attention is being given to complex messages, drivers do not factor these road conditions into their decision and can therefore make unsafe decisions (Cooper & Zheng, 2002).

Lee et al. (2002) showed that given a collision scenario, a highly visually demanding interface generates only slightly higher reaction times than a speech-based interface. This is supported by Verwey (2000), who showed that presenting information by speech versus maps does not have a significant impact on safety reduction. Moreover, speech recognition is more prone to errors. Another study by Lee et al. (2001) evaluated the effect of a speech-based e-mail on drivers' response to a lead vehicle's periodic braking. A 30% (310 ms) higher average reaction time was recorded for the treatment group that received the speech-based e-mail than for the control group that did not. Although the response data of the groups that received the complex e-mail versus the noncomplex one did not show differences, the subjective cognitive workload ratings were higher for the former group. A poorly designed speech-based interaction with IVIS therefore has many of the characteristics of a mobile phone communication, and would impair driving performance (Lee et al., 2002). For example, a poor quality synthetic voice would impose more cognitive distraction on the driver. Combined with the complexity of the driving task, this might deteriorate driving performance. Under high-attention-demanding situations, the use of such a system should be minimized. This may be accomplished by integrating the speech-based interaction system with a system that monitors the level of driver distraction and surrounding traffic information.

In contrast to the system-initiated strategies that transform non-driving-related tasks by making them more difficult or impossible to perform, driver-initiated strategies aim to ease performance of these tasks. Therefore, these strategies would likely increase the level of IVIS use. Thus, even if these strategies decreased the level of distraction, as IVIS-usage-time accumulated the probability of driver distraction would rise. The system can adapt between non-driving-related, driver-initiated and non-driving-related, system-initiated strategies to overcome this problem. For example, the system can lock the interaction if the drivers are not aware of their distraction level and do not take action to initiate a non-driving related strategy. However, such adaptations may generate issues of their own should the system start behaving inconsistently, or if it were unsuited to driver expectations, and as a result, could create new distractions for the driver.

Examples of adapting to non-driving-related, driver-initiated strategies can also be demonstrated with in-vehicle text messages. For these strategies, drivers preset the settings before they begin their drive. However, it should be noted that these presettings may not actually help in a distraction situation even though they are perceived by the driver as a benefit while driving. For example, drivers may set limits on what messages they want to see while driving (*controls pre-setting*). When they approach a curve, or are in high-demand traffic, they may put a place marker in the text until they are ready to read the messages again (*place-keeping*). The use of speech recognition to hear their messages rather then view their messages may also be incorporated by the driver (*demand minimizing*). It should also be noted that such an adaptation is not initiated by the system and therefore the system does not improve its functionality during the drive but provides different options for the drivers to choose from based on their preferences to receive help with their non-driving related tasks.

4.5 DISCUSSION

Levels and types of automation are a useful way to describe different mitigation strategies for driver distraction. The taxonomy described in this review provides initial guidance for design and research. High levels of automation in system-initiated strategies will differ greatly from high levels of automation with driver-initiated strategies. The majority of previous research has focused on driving-related strategies such as *intervening* (automatic braking systems), *warning* (collision warning systems), *informing* (speed indicator), *delegating* (adaptive cruise control), *warning tailoring* and *perception augmenting*. Of the non-driving-related strategies, only *demand minimizing* has been investigated as a potential means of reducing distraction (Lee et al., 2001). The strategies that clearly merit further investigation include non-driving-related strategies such as *locking & interrupting, place keeping, prioritizing & filtering*, *controls pre-setting* and *advising*. Therefore, it is crucial to investigate the impact of non-driving-related issues as well, because trade-offs exist with all mitigation strategies and it is important for designers and researchers to understand the impact of implementing each strategy and the effects of interactions between strategies when used in combination.

The dimensions that define this taxonomy reveal general considerations for distraction mitigation strategies. Driver-initiated strategies depend on the driver to recognize his or her degree of distraction and react appropriately. More importantly, these strategies may be susceptible to behavioral adaptation in which making the system easier to use increases the safety of individual transactions, but leads drivers to increase the number of transactions, resulting in an overall higher level of distraction.

System-initiated strategies depend on the driver's acceptance of and appropriate reliance on the system. Potentially hazardous situations can occur if the driver relies too much on the system and the system fails to provide the necessary information or take the necessary actions. Moreover, over-reliance on the system might amplify the risk-taking behavior of the driver as the driver places more trust in the automation. In situations of over-reliance, the failure of high levels of automation might lead to more severe safety problems than lower levels of automation. High levels of automation may also lead to lower situation awareness (Endsley, 1995). However, situations with time-critical elements (e.g., impending crash) require higher levels of automation (Moray & Inagaki, 2003). If the system senses a near-fatal situation, the level of automation should be high enough to take control immediately. That is, if the driver is going to crash regardless, the vehicle should take action.

Driving-related strategies that involve high levels of automation may also induce behavioral adaptation because if drivers grow accustomed to the increased assistance of automation, they may become comfortable performing non-driving-related tasks typically not performed in critical driving situations. This is an example of risk compensation defined by Peltzman (1975), which refers to the trade-off between driving intensity (e.g., speed, thrills) and the perceived probability of death or injury from accident. There is also a level of uncertainty with automation, since the system may not always respond as expected. The potential impact of false-positive or false-negative feedback depends on the level of automation. There would be a greater safety risk, for example, if the *intervening* strategy does not perform as expected compared to the *informing* strategy. Moreover, driving related strategies in general address a broader range of distraction situations than their non-driving related counterparts. This may have an impact on the effectiveness of strategies and should be explored.

Another concern that may arise as system-initiated options become more prevalent is workload transition (Huey & Wickens, 1993). When a previously automated function is assigned back to the driver by the system, the driver's workload may significantly increase very quickly. The system should therefore provide continual or periodic cues that keep drivers aware of the driving situation so that they can step in quickly to resume control. Another issue related to an adaptive system that allocates tasks between the automation and the driver is the system's incorrect adaptation to driver state and traffic condition. An example of false adaptation would be the implementation of a high automation level when the level of driver distraction is low and an imminent danger does not exist.

Driver acceptance of the system is also a key issue and depends on ease of system use, ease of learning, perceived value, advocacy of the system, and driving performance (Stearns et al., 2002). Another factor that affects driver acceptance of a mitigation strategy is driver age. A preliminary look at the focus group findings (Task 4-B) reveals that younger drivers distrust high levels of automation that *intervene* in their driving, whereas driver-initiated strategies that ease the task of driving (*delegating*) and correct *warnings* are found to be useful among these drivers. However, *warning tailoring* is still preferred over *warning*. Likewise, for the non-driving-related strategies that modulate IVIS interaction, a driver-initiated, low level of automation is preferred over a system-initiated high level of automation. In contrast to younger drivers, older ones tolerate the strategy of *intervening* and also find this strategy valuable. Older drivers also prefer to transform a non-driving-related task that is detrimental to driving performance into a task that is more difficult to perform, rather than easier, so that drivers might be willing to engage in the activities less. A useful tool to predict driver acceptance of a strategy is concept of Human-Computer Etiquette, in other words, approaching the acceptance issue by keeping in mind that humans respond to technology socially, and their reactions to computers may be similar to their reactions to humans (Lee & See, 2004).

In addition to the safety considerations associated with the interruption of the primary task of driving by an in-vehicle task, productivity issues may also arise as in-vehicle tasks are in turn interrupted by the driver's need to shift attention back to the driving task. Therefore, even if the main objective of the distraction mitigation strategies should be to enhance safety, a successful design should also aim to enhance the productivity provided to the driver by the IVIS, or at least protect it from deteriorating. These key issues in combination with the previous concerns will influence the effectiveness of mitigation strategies. Therefore, future research should investigate potential functions that can be developed with each mitigation strategy and the most promising combination of strategies that would work best based on the driver's characteristics.

4.6 PRELIMINARY DESIGN RECOMMENDATIONS

This section presents preliminary design recommendations on distraction mitigation strategies. However, the reader should keep in mind that literature is limited in the driving domain for the aforementioned strategies. As a result, these recommendations may only point to the more promising approaches based on the related information gathered from literature and presented in this review. More concrete guidelines for design will be explored by the experimental design of Task 4-b.

Based on a comparison of the entries of the taxonomy presented, preliminary design recommendations are as follows:

- If the driving-related system-initiated strategies (*intervening, warning, informing*) are successfully implemented in an adaptive system, such a system would enhance safety, regardless of the degree or the type of distraction (e.g., IVIS engagement or being lost in thought or even unconscious).
    - However, there are uncertainties associated with these systems:
        - The focus group findings (Task 4-b) show that the driver acceptance of the higher levels of system-initiated strategies (e.g., intervening) are less than lower levels (e.g., informing).
        - Driver dependence on higher levels would generate more risky driving behavior than driver dependence on lower levels of automation.

- The driving-related driver-initiated strategies do not promise as great a potential as their system-initiated counterparts since these strategies heavily rely on drivers' awareness of the degree of their distraction. However, these strategies may complement system-initiated strategies in reducing distraction, since some of these strategies give the driver the opportunity to personalize the interaction with the system and thus increase the level of acceptance. For example, *warning tailoring* would allow the driver to adjust the sensitivity of the warning system.

- For the non-driving-related system-initiated strategies, high levels of automation (e.g., *locking and interrupting*) would be required under safety critical situations. However, using a driving-related strategy, such as *warning*, under these circumstances (or *intervening* if the situation is more critical) may direct a driver's attention to the impending danger better than interrupting his/her interaction with IVIS.

- The moderate level of automation in the non-driving-related system-initiated category (*prioritizing and filtering*) may be more appropriate for high-attention-demand situations than safety critical ones. However, one issue with *prioritizing and filtering* is this strategy does not stop driver initiation of an interaction with the IVIS. For example, if the driver is determined to make a phone call, the driver can perform the task no matter what. Therefore, this strategy also is very dependent on driver awareness of the degree of distraction.

- The low level automation in the non-driving-related system-initiated category (i.e., *advising*) has a potential to redirect driver attention back to the primary task of driving before the degree of distraction reaches a state where an *intervening* or a *warning* strategy is needed. For example, when approaching a highly congested area, the system might *advise* the driver to discontinue a cell phone conversation. The driver's response to the advice could, thereby, eliminate a potentially hazardous situation from occurring.

- Although the non-driving-related driver-initiated strategies have great potential to reduce distraction by posing less demand on the driver, these strategies may also increase the overall distraction. Regardless of the situation, these strategies aim to decrease the distraction that IVIS create. However, when the system is easier to use, the driver may start using the system more often. Thus the question of what options to offer should be researched. For example, should a system be designed so that it is easier to use and imposes less demands on the driver or should designers make in-vehicle systems harder to use to decrease the likelihood of use in traffic? One alternative is to combine these strategies (which would decrease the level of demand posed by the IVIS) with more preventive strategies (e.g., *locking and interrupting*) and change the nature of IVIS interactions depending on the criticality of the situation. For example, IVIS might advise the driver to discontinue an IVIS interaction and keep the driver's place while the driver averts attention to the driving task. This, actually, might also promote driver acceptance of such a system.

4.7 RESEARCH ISSUES

Based on this literature review and the advantages and disadvantages presented in this document, twelve design issues relating to distraction mitigation strategies need to be addressed and explored further.

1. The level of distraction and the level of automation may have an important impact on the effectiveness of the distraction mitigation strategy and on driver acceptance:
   Hypothesis: To increase system acceptance as well as effectiveness in mitigating distraction, the level of automation should match the level of distraction. However, if there is an imminent danger, the system should take high levels of driving control regardless of the driver state.
2. System initiation vs. driver initiation (locus of control):
   Hypothesis:
   - Driver initiation of a strategy is more acceptable than system initiation. However, are driver-initiated strategies more helpful in distraction situations and does the driver perceive them to be more helpful?
   - Driver initiation of a mitigation strategy depends on driver awareness of the level of distraction.
3. The impacts of degree and type of distraction on the effectiveness of a system.
4. Consistency over time (behavioral adaptation) :
   Does prolonged use of the system impact the system's effect on the driver?
5. Risk compensation
   Hypothesis: Driver dependence on the system as the primary agent to prevent a collision would result in riskier driving.
6. Usability paradox (non-driving-related tasks):
   If a system is designed for ease of use, would people tend to use it more often and in turn would the probability of being distracted then increase (overall increased distraction)?
7. False adaptation of the system
   - For adaptive systems that allocate tasks between automation and the driver: What are the effects of the system falsely adapting the level of automation to the driver state and traffic condition?
   - For within-strategy and between-strategy adaptation:
     Hypothesis: False adaptation of the system would result in distrust.
8. Workload transition (for adaptive systems):
   What are the impacts of assigning a previously automated function back to driver?
9. System dynamically adapting within and between mitigation strategies based on the driver and roadway state:
   Inconsistent system actions may result in further driver distraction.
10. Driver acceptance may be a key variable influencing the effectiveness of distraction mitigation strategies:
    Hypothesis: Low levels of acceptance would limit system effectiveness.
11. The impact of driver age on acceptance and the effectiveness of system to mitigate distraction:

Hypothesis: Age has an effect on acceptance and effectiveness of a distraction mitigating system.

12. Reliability of distraction estimate:

    Hypothesis: Unreliable distraction estimates will reduce system effectiveness more if the level of automation is high and/or the system is the locus of control.

13. Driving-related vs. non-driving-related strategies:

    Hypothesis: Driving related strategies address a broader range of distraction situations.

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