TAXONOMY OF MITIGATION STRATEGIES FOR DRIVER DISTRACTION

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Driver distraction can be described as the diversion of driver's attention from the primary task of driving and is one of the most common causes of crashes. Complex technologies that have either been introduced to the driving domain or are planned to be, raise the concern of high levels of distraction, by placing additional demands on drivers. Different mitigation strategies (e.g., warning and vehicle control) have been implemented in the vehicle to reduce driver distraction. However there has not been a clear definition or categorization of these strategies. This paper, therefore, proposes a taxonomy of mitigation strategies for driver distraction and relates the strategies to accumulated research in the areas of automation and adaptive aiding to define important design tradeoffs with each strategy. This taxonomy provides a framework that can guide research and address the driver distraction problem systematically.

INTRODUCTION

Just as computers have transformed the office in the last 20 years, they will transform the car in the next decade. This, combined with societal trends for increased productivity and diffusion of work beyond the traditional office environment, will make these systems a reality. Computer, telecommunication, and automotive companies have begun to develop In-Vehicle Information Systems (IVIS) in anticipation of a $15-$100 billion IVIS market (Ashley, 2001). IVIS require timesharing with the safety critical task of driving. Verwey (2000) suggests that IVIS might jeopardize traffic safety rather than improve it by distracting the driver in critical situations and requiring too much driver attention at less critical ones. The effects of this timesharing requirement on driving safety are critical for system development and need to be considered. When implemented appropriately, these technological advances can improve productivity, satisfaction, and safety. However, if implemented poorly, these functions will be annoying at best and fatally distracting at worst.

Even without the widespread use of complex technologies, between 13 and 50 percent of crashes are attributed to driver distraction, resulting in as many as 10,000 lives lost and as much as $40 billion in damages each year (Stutts, Reinfurt, Staplin and Rodgman, 2001; Sussman, Bishop, Madnick and Walter, 1985; Wang, Knipling and Goodman, 1996). Driver distraction can be defined as the departure of driver attention from the driving task, which reduces safety. Ranney, Mazzae, Garrott and Goodman (2000) have identified four components of driver distraction: (1) visual (e.g., viewing in-vehicle displays that require eyes off the road), (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 the drivers are engaged in may involve one or more of these components. Driver's willingness to engage in a non-driving related task and the workload and attentional demands placed on the driver by that task contribute to the potential for distraction.

THESIS

This paper presents a range of strategies to mitigate driver distraction and organizes them in categories that highlight critical design tradeoffs that should be considered in their implementation. Recent reviews of automation and its effect on human performance provide valuable insights that can highlight the advantages and disadvantages of various distraction mitigation strategies (Parasuraman, Sheridan, and Wickens, 2000; Sheridan, 2002; Lee and See, 2002). Sheridan (2002) 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. These mitigation strategies can be 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 the driver interaction with IVIS. Each mitigation strategy has features that make it beneficial in some situations and not in others. In other words, a mitigation strategy may actually undermine rather than enhance safety. This paper will, therefore, describe each of the mitigation strategies in terms of these levels and the design tradeoffs.

Table 1. Mitigation strategies classified by level of automation and type of tasks.

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

MITIGATION STRATEGIES

The taxonomy of mitigation strategies is based on a comprehensive literature review of driver distraction, adaptive automation, and IVIS functions (e.g., Parasuraman, et al., 2000; Ranney, et al., 2000; Lee et al 2001). Twelve unique mitigation strategies are defined and categorized in terms of a high, moderate or low level of automation. These mitigation strategies are also subdivided into driving related and non-driving related strategies and within these categories, are further 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). These categories are described in the next section and are shown in Table 1.

Driving Related, System Initiated

System initiated strategies under the category of driving related tasks (first column in Table 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 as: *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. The tradeoff of using this strategy too often is that the driver may become too dependent on this function and be more likely to perform non-driving related tasks that the driver normally would not have performed otherwise. Moreover, uncertainty in the driving environment and sensor limits could lead to inappropriate and potentially dangerous responses.

Warning alerts the driver to take a necessary action. A collision avoidance system is a function that employs *warning* as a strategy and encompasses both visual and audio alerts. This is considered a moderate level of automation compared to *intervening* since the driver is still in control of the vehicle. Lee et al (2002) showed that this type of system benefited distracted and non-distracted drivers. However, the behavioral adaptation of the driver should be taken into account since there is a possibility that the driver might rely on the warning system as the primary collision alert rather than as a backup. Such an adaptation might encourage the driver to engage in distraction tasks more often and in turn, degrade safety. Another concern is the deterioration in the system effectiveness. For example, distrust and disuse can result from high false alarm rates. This problem also contributes to driver's response to, and acceptance of the system, which may influence the system effectiveness (Parasuraman, Hancock, & Olofinboba, 1997).

Informing provides drivers 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 roadway sign is not visible. However, if the driver is already aware of the speed limit change, receiving the same information may distract or annoy the driver. One function that uses the strategy of *informing* is the Head-Up Display, which displays images on the driver's forward field of view. This strategy is considered a low level of automation since information is provided that does not require any action or warning by the system. This eliminates the driver's need to shift gaze to receive the information, minimizing re-accommodation times and providing the driver the ability to sustain attention on the roadway. The tradeoff is the introduction of clutter in the forward view, which might obscure critical elements of the driving scene and visually distract the driver (Ward, Parkes, & Crone, 1995).

Driving Related, Driver Initiated

This group of strategies mitigates distraction by having the driver activate or adjust system controls that relate to the driving task. The 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 for which the system takes on the driver responsibility of acceleration control of the vehicle. This strategy can help the driver to share load and therefore, may reduce the attentional and biomechanical demands posed by the driving task. However, it might also transform interactive driving to a vigilant task of monitoring and potentially increase the level of distraction by encouraging the driver to engage in distracting activities.

Warning tailoring strategy refers to the driver's adjustment of the sensitivity, or start-up and shut-down of the warning system depending on the distracting activities the driver expects to be engaged in. This differs from the *warning* strategy described in the previous section because driver input is now required. Allowing the driver to adjust or to activate the system can promote driver acceptance. However, the driver's responsiveness to and realization of the level of distraction will be important factors in the system effectiveness.

Perception Augmenting provides driver information at the driver's request. This will help reduce the driver's demand for locating necessary information (e.g., driver's speed, posted speed) while driving thereby decreasing the level of distraction. Similar to *warning tailoring*, this strategy will also depend 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.

Non-driving Related, System Initiated

Non-driving related mitigation strategies aim to reduce the 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 builds upon the idea that when the driving performance is or will be significantly deteriorated, the system would 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 and *interrupting* can be classified as high levels of automation since interrupting discontinues the non-driving activities and *locking* locks out the system that is associated with these activities, at times when attention to the primary driving task is required. Verwey, (2000) showed reasons why a *locking* and *interrupting* strategy may be desired. In his study, participants were asked to postpone a non-driving related task precisely when an unsafe situation was 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 and the potential for increasing the degree of distraction as the driver tries to continue the non-driving related task that was interrupted or locked, thereby, increasing driver distraction.

Prioritizing and filtering information presented to the driver minimizes the number of non-driving related tasks that can be performed in high load situations and can be grouped 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 (not letting the phone ring) or prioritized (allowing only the calls that are listed by the driver as highly important). 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). Therefore, when approaching a curve the incoming call can be filtered to provide safe driving. Parasuraman et al. (2000) suggest that organizing information sources by prioritization or representing the information by highlighting decreases workload and hence, enhance performance. A potential downside of this strategy is that the driver's attention may be drawn to inappropriate elements of the driving task (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. For example, an "*advising*" background sound could become more intense as vehicle speed and traffic density increase. This strategy is considered a low level of automation since it informs the driver only without taking any action. However, such a strategy may increase driver annoyance as well as distraction if the demands of ignoring the "advice" become a burden.

Non-driving Related, Driver Initiated

The driver initiated strategies rely on the driver to modulate their non-driving tasks according to their subjective degree of distraction. These strategies can further be categorized into similar 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. For example, the driver can pre-set the radio or CD player or the destination on navigational devices and not modify it once in drive. However, the driver may still be tempted to manipulate the controls and therefore diminish the effect of this strategy.

Place keeping minimizes the demand of switching between the driving and the non-driving related tasks. Task switching involves directing attention from one task to another (e.g. talking on the cell phone to braking and back to talking on the cell phone). As the number of tasks a person has to perform simultaneously increase, the more difficult it is for the driver to perform these tasks because task switching requires a certain amount of attention. For example, reading a map from a display significantly degrades the driving performance. If the visual demands on the road increases the drivers tend to glance at the in-vehicle display more, with shorter duration glance times and larger times between the glances to keep their driving safe (Tsimhoni & Green, 2001). Therefore, as the time interval between each glance increases, the need for keeping the place of the driver at the non-driving related task also increases. If not helped, 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 con not be easily identified. Alternatively, the driver may be more likely to persist and extend glances away from the road to a dangerous level. The downside of this strategy is the potential encouragement of 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-deman interfaces (e.g. using steering wheel mounted control, voice activation or hands-free devices) and therefore corresponds to low level of automation. For example, speech-based interaction features use the demand minimization principle. These features require different perceptual (auditory) and response (vocal) resources than the primary driving task does (visual perception and manual response) (Wickens, Gordon, & Liu, 1997). Therefore, 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, Craven, Haake & Brown, 2001).

FINDINGS

Levels and types of automation are a useful way to describe different mitigation strategies for driver distraction. The taxonomy described in this paper provides initial guidance for design and research. High levels of automation in system initiated strategies will differ greatly from the high levels of automation with driver-initiated strategies. The majority of previous research has focused on driver-related strategies such as *intervening* (automatic braking systems), *delegating* (adaptive cruise control), *warning* (collision warning systems), *warning tailoring*, *informing* (speed indicator) 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 merits further investigation include the 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.

DISCUSSION

The dimensions that define this taxonomy reveal general considerations for distraction mitigation strategies. Driver initiated strategies depend on the driver to recognize the 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 drivers' acceptance 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 these 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 (Endsely, 1995). However, situations with time critical elements (e.g. impending crash) would require higher levels of automation (Moray and Inagaki, 2003). If the system senses a near-fatal situation, the level of automation should be higher to take control immediately. That is, if the driver is going to crash regardless, the vehicle should take action.

Driving-related strategies may also induce behavioral adaptation because drivers can become comfortable performing non-driving related tasks typically not performed in critical driving situations because the driver has grown accustom to the increased assistance of automation. There is also a level of uncertainty in the automation since the system may not always respond as expected. The potential impact of a false positive or false negative feedback depends on the level of automation. There is a greater safety risk if the *intervening* strategy does not perform as expected when compared to the *informing* strategy.

Another concern that may arise as system initiated options become more prevalent is workload transition (Huey & Wickens, 1993). When the previously automated function is assigned back to the driver by the system, the driver's workload may significantly increase very quickly. Therefore, the system should provide continual or periodic cues that keep the driver aware of the driving situation, so that the driver can step in quickly to resume control.

Driver's acceptance of the system is also a key issue and dependent on ease of system use, ease of learning, perceived value, advocacy of the system, and driving performance (Stearns, Najm, & Boyle, 2002). These key issues in combination with the previous concerns will influence the effectiveness of mitigation strategies. Therefore, future research will 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.

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