Driver-Vehicle-Interface (DVI) Development of a Drowsy Driver Detection and Warning System for Commercial Vehicles

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CMU-RI-TR-05-46

September 2005

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ACKNOWLEDGMENTS

The work detailed here was funded by the U. S. Department of Transportation. This Tech Report is the Carnegie Mellon University contribution (Subtask B, Phase II) to following the unpublished final report:

Wierwille, W. W., Hanowski, R. J., Olson, R. L., Dinges, D. F., Price, N. J., Maislin, G., Powell, J. W., Ecker, A. J., Mallis, M. M., Szuba, M. P., Ayoob, E., Grace, R., and Steinfeld, A. (2003). NHTSA Drowsy Driver Detection and Interface Project. DTNH 22-00-D-07007, Task Order No. 7. Submitted to National Highway Traffic Safety Administration. Blacksburg, VA: Virginia Tech Transportation Institute.

EXECUTIVE SUMMARY

Driver drowsiness poses a major threat to roadway safety and the problem is particularly severe for commercial motor vehicle (CMV) drivers. High annual mileage, 24-hour operations, exposure to demanding environmental conditions, and demanding work schedules make drowsiness a major cause of combination-unit truck (CUT) crashes. Drowsy driver crashes cost $12 billion and contribute to up to 35% of the 4,400 annual truck driver deaths. Fatigued drivers are often unaware of their condition, frequently driving for 3-30 seconds with their eyes closed.

This work is a culmination of years of research to develop an effective in-vehicle countermeasure to drowsy driving. Previous work has developed an effective and independently validated measure of drowsiness, PERCLOS (Wierwille et al, 1994, Dinges et al, 1998), which has been incorporated into a drowsy driver monitor (Grace & Stewart, 2001). This effort seeks to develop an associated drowsy driver interface that enables effective, user-centered interactions with the underlying system.

The drowsy driver interface has been designed through a careful participatory design process that included both design experts and CMV drivers. Two focus groups were held. The first was with product design and usability experts. There are many issues surrounding the design and usability of a drowsy driver detection and warning system. The experts connected the design of the warning interaction and interface with user perceptions about intended use. The expert focus group interaction provided structure that was taken forward to the driver focus group.

The driver focus group provided insight into the task of driving a commercial vehicle, the nature of drowsiness episodes, and a detailed view of the features that the drivers desire in a drowsy driver interface. The drivers were given a blank slate and a list of features that could be added to the design. The drivers consistently chose features that gave them control over the device.

The drivers' primary focus was to provide alerting stimuli when drowsiness was identified. This desire is in conflict with the scientific literature that concludes that alerting stimuli are either ineffective or transitory The drivers focus was also in conflict with other recommendations from the design experts.

The conflict that arose between the drivers' desires and the desires of the scientific community is that the drivers viewed the system as a loyal servant that would alert the driver when he became drowsy, while the scientific community viewed the system as a trusted advisor that would encourage the driver to stop and rest. The final design, illustrated in Figure I, has many features to address both of these views. The drivers can control or select many of the features of the interface to correspond to their specific driving environment and individual desires. These features include sound selection, volume control, and sensitivity selection.

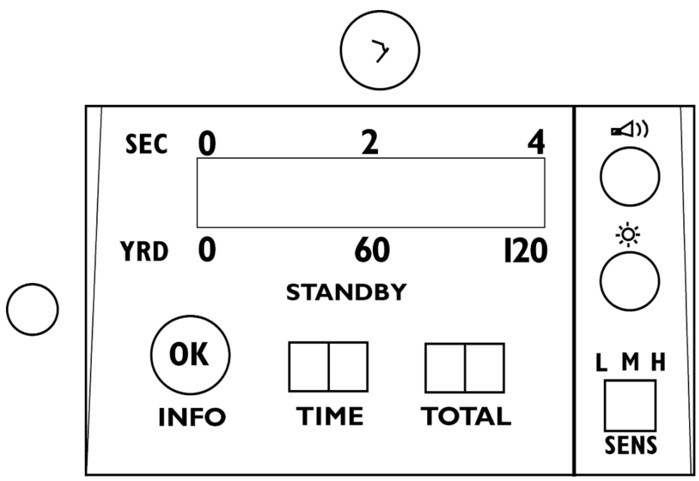

Figure I: Drowsy driver Interface

The informational warning displays or "advisor" portion of the interface, that is the warning display, gives the driver valuable information in terms that emphatically point out the inherent danger in driving while drowsy. Drivers often convince themselves that – "my eye where closed for just a second" while research shows that eye closures up to 30 seconds are observed. It is hoped that by displaying eye closure times, together with the total distance traveled with eyes closed, the driver will be convinced that he/she is driving in an unsafe condition and make a wise choice – stop and rest.

The warnings are triggered based on a simple threshold applied to PERCLOS. Once PERCLOS crosses the threshold a warning sound is given and the primary information display is lit. A bar graph showing the length the longest single eye closure observed during the integration period is displayed. The display units are seconds and yards traveled. This measure was chosen for display over PERCLOS as being less abstract and more relevant to the drivers' experiences.

Once the OK button is pressed to respond to the warning the sound is terminated and a secondary display is lit. The secondary display shows the time since the last warning and the total number of warning given. Both the primary and secondary displays are dimmed after 10 seconds or after the OK button is pressed a second time. After each warning the sensitivity is raised, PERCLOS is zeroed, and the PERCLOS calculation is resumed. For example, if the driver has selected the low sensitivity, the setting will be changed automatically to the medium setting after the first warning and PERCLOS calculation will resume from zero. The high sensitivity setting corresponds to an integration time of 1 minute and a threshold of 8%. The medium sensitivity setting corresponds to an integration period of 2 minutes and a threshold of 10%. The low sensitivity setting corresponds to an integration period of 3 minutes and a threshold of 12%.

TABLE OF CONTENTS

INTRODUCTION

This task is intended to build upon previous technical advances in the Intelligent Vehicle Initiative (IVI) program human factors problem area of Driver Condition Warning, part of the U.S. Department of Transportation. The National Highway Traffic and Safety Administration (NHTSA) has been working for years toward developing an effective, validated drowsy driver detection and warning system for use by commercial motor vehicle drivers (CMVs). Specifically, the current target user profile is:

> A CMV driver with a valid commercial drivers license (CDL), who drives more than 200 miles per day with some nightime driving.

Using PERCLOS (Wierwille et al, 1994) as the primary method for determining drowsiness, the objectives of this research are to:

- Establish appropriate measures of effectiveness
- Determine the logic applied to PERCLOS that minimizes nuisance alarms and maximizes effectiveness while maintaining simplicity of operation
- Determine the most appropriate design of the DDI

The problem of drowsy driving exists within the commercial trucking industry for a variety of reasons. Twenty-four hour operations, high annual mileage, exposure to demanding environmental conditions and demanding work schedules make drowsiness a major cause of combination-unit truck (CUT) crashes. Often these circumstances are outside of the control of the drivers. Targeting the drowsiness state of drivers and informing them of their condition so that they can take action is one crucial step in a series of preventative measures that are necessary to address this problem.

BACKGROUND

Driver drowsiness poses a major threat to roadway safety and the problem is particularly severe for commercial motor vehicle (CMV) drivers. There are approximately 1.6 million truck tractors and 3.6 million trailers used in the motor carrier industry today.

CUTs are involved in approximately 200,000 crashes each year. A recent analysis (FHWA, 1998) of the problem size estimates that fatigue related crashes constitute:

0.71% to 2.7% of all police reported crashes involving CUT's
3.2% to 7.6% of all fatalities associated with CUT crashes
15% to 36% of all crashes fatal to the CUT driver

As evident in these statistics, fatigue crashes tend to be severe. A typical fatigue related crash involves the CUT drifting off the roadway without brake application (run-off road crash). These crashes often occur early in the morning (between 2:00 AM and 6:00 AM) in light traffic conditions.

Considerable progress has been made in measuring drowsiness and understanding its effects upon human performance in the laboratory and in simulated and operational driving conditions. Wierwille, et al (1994) have generated a measure of drowsiness, PERCLOS, associated with degradation in driving performance in a simulated roadway environment. Experimental studies performed by Dinges, et al (1998) to test the validity of PERCLOS and other new technologies for drowsiness detection showed that PERCLOS was able to accurately predict fatigue-induced lapses in vigilance. Carnegie Mellon's (Grace et al, 1999) studies of overnight commercial trucking operations have produced a real-time monitor capable of detecting driver drowsiness in an operational setting. Furthermore, this monitor used in conjunction with a driver feedback system has been shown to decrease drowsiness and improve driver performance in simulated driving conditions (Mallis et al, 2000). These advances, for the first time, make accurate detection and management of drowsiness feasible.

THE PROBLEM SPACE

Drowsiness

Drowsiness is primarily caused by a lack of sleep. However, it can also be induced by extended time on task, certain medications, and by sleep disorders such as obstructive sleep apnea and narcolepsy. It is known that daily circadian rhythms contribute to drowsiness at typically 2:00 am – 6:00 am and 2:00 pm – 6:00 pm.

"Drowsy drivers typically do not 'drop off' instantaneously. Instead, there is a preceding period of measurable performance decrement with associated psychophysiological signs." (Knipling & Wierwille, 1994). The progressive onset of drowsiness can last for an hour or more. To assist the driver with the problem of drowsiness, any system must be carefully developed to provide an interface and interaction that make sense for the user. Such a system must account for various contingencies and must also minimize distraction from the driving task under normal circumstances.

Napping strategies can reduce drowsiness and improve performance (Rosekind et al, 1994). After a long nap, drowsiness may be present for some time (sleep inertia). Shorter naps of less than 20 minutes produce little sleep inertia. Sleep is the only known long-term countermeasure for drowsiness. To address the problem of drowsy driving, many research efforts have focused on short-term countermeasures, countermeasures other than sleep.

Countermeasures

Several studies have been conducted to present and test countermeasures other than sleep. They generally fall within three categories: driver induced, vehicle induced and external. Wierwille investigated a number of countermeasures that can be employed while driving. Countermeasures considered in this study included, seat vibration, scent, fresh air, A/O task, lane minder and glasses-worn eye monitor. These countermeasures were evaluated both subjectively (Wierwille, Lewin, & Fairbanks, 1995) and objectively (Wierwille, Lewin, & Fairbanks, 1996c) to identify the most promising countermeasures. The final proposed drowsy driver warning system proposed by Wierwille (Wierwille, Lewin, & Fairbanks, 1996a) included scent, fresh air, lane minder and glasses-worn eye monitor.

Other countermeasures that have been utilized while driving include caffeine (Bonnet & Arand, 1994a, 1994b), social activities (CB radio, cellular telephone) and physical activity including isometric exercises, etc. Countermeasures can also be employed during rest breaks. These include strategic use of caffeine and naps (Rosekind et al, 1994; Bonnet & Arand, 1994a, 1994b), social activity and physical activity.

Further explorations reveal that

- Caffeine is most effective if used sparingly (Dinges et al, 1989)
- Many self-alerting behaviors are ineffective or effective for only short periods of time (Mallis, et al, 2000)
- Vehicle-based countermeasures are ineffective or effective for only short periods of time (Mallis et al, 2000; Noy, Vincent, & Liang, 1998; Wierwille et al, 1996b)
- Physical activity in the form of postural changes are effective but transitory (Mallis, et al, 2000)

The main question to the driver is which of the driving time countermeasures and rest time countermeasures are desirable, practical and/or useful. It is known that countermeasures other than sleep may be ineffective or effective for only short periods of time (Mallis et al, 2000). Despite this, anecdotes or myths about personal habits may instill drivers with false confidence about the effectiveness of their personal method.

Behavioral Issues

Any IVI system has the potential to cause crashes as well as prevent crashes. Unanticipated consequences can arise from unpredictable changes in behavior. This is a concern, for example, with adaptive cruise control systems. If the driver is no longer responsible for adjusting headway, he/she may not be aware of the front vehicle suddenly stopping. Risk compensating behaviors are also a concern. With the aid of technology, drivers may change normal driving habits in a manner that would cancel much of the potential benefit of the IVI technology. For example, if a driver with a forward looking collision warning system feels he/she can “safely” reduce his/her headway – the benefits from the IVI technology may be reduced.

Risk compensating behavior is of particular concern for a drowsy driver warning system. More specifically, the countermeasures associated with the warning system can only be effective for a short duration (Mallis et al, 2000). If the deployment of a drowsy driver warning system promotes more sleep and more rest breaks it is likely to be beneficial. If, however, it promotes dependence on the technology thereby extending awake periods and increasing sleep debt it is likely to have a detrimental effect. Therefore it is beneficial to build into the interface components that may induce the desired safe behavior.

Acceptance of the system by the driver is also of great importance for a drowsy driver warning system. A driver must have confidence that the system is providing timely and accurate information regarding his/her state of drowsiness. It is common knowledge within the scientific community (Dinges, 1989; Wylie, 1996; Brown, 1997) that self-assessment of drowsiness is unreliable. Hence, a driver may decide to disregard the warning from the feedback system based on his/her own flawed perception. .

Although drivers' annoyance with warning systems is very subjective and situational, research suggests that they will tolerate a certain number of nuisance alarms if there is a perceived benefit. Their annoyance and tolerance can change over time and with repeated use, with the frequency and types of alarms having a major influence on annoyance (Lerner et al, 1996).

There is general consensus within the psychological field that experience plays a critical role in the formation and evolutions of ideas (Rachlin, 1970). There may be an opportunity with emerging technologies, such as drowsy detection, to influence the situated learning that occurs while on shift, especially as it relates to driving while struggling with a drowsiness episode or making the decision to pull over.

Drowsy Driver Warning Systems

The concept of a drowsy driver warning system has been studied by a number of researchers (Wierwille, Lewin, & Fairbanks, 1996a; ; Noy, 1998, Mallis et al, 2000

Vincent, & Laing, 1998). Although these systems differ greatly, but they share a common theme – the intent to re-alert the driver. However, research has shown that alerting stimuli are ineffective or transitory.

It is clear that providing alerting stimuli alone is insufficient to avoid drowsy driver crashes. To obtain a significant safety improvement drivers must decide to stop driving when they are drowsy. Providing feedback that can encourage drivers to alter their normal behavior and seek properly scheduled rest breaks is an area worth further exploration.

PERCLOS

PERCLOS is a mathematically defined measure of eye closure that can be accurately estimated by a frame-by-frame analysis of video of the driver's eyes. The strict definition is the fraction (or proportion) of time that the driver's eyes are 80 to 100% closed over the measurement interval. The initial measurement interval is usually one minute. The instantaneous percentage of eye closure is obtained by determining the normal, alert eyes open and the eyes closed position. A linear percent scale is then superimposed on the distance difference between these two positions, where 0% is the alert-open position and 100% is the closed position.

Eye closure is determined through using a structured illumination approach to identify the driver’s eyes. Two consecutive images are taken using a single camera. The first image is acquired using an infrared illumination source at 850nm that produces a distinct glowing of the driver’s pupils (the red-eye effect). The second image uses a 950nm infrared illumination source that produces an image with dark pupils (Grace et al, 1999). These two images are identical except for the brightness of the pupils in the image. A third image enhances the bright eyes calculating the difference of these two images. The driver’s eyes are identified this third image by applying a threshold to the pixel brightness.

Thresholds for decision making regarding drowsiness are usually set at PERCLOS values between 0.050 and 0.150, corresponding to between 3 and 9 seconds of closure per minute. As the threshold is moved from lower to higher, the number of false alarms will decrease and the number of missed detections will increase.

Longer time averages of one minute PERCLOS values result in higher values of correlation with performance decrements due to drowsiness. This relationship is known to hold up to 20 minutes of averaging. However, as the averaging time increases, the likelihood of not warning the driver in a timely manner increases. Three minute averages (averaging of three consecutive one-minute values of PERCLOS) provide a good compromise between measure statistical instability and responsiveness to drowsiness changes.

One-minute values of PERCLOS might be used to provide the driver with rough estimates of his/her level of drowsiness, but such a measure must be recognized as slightly lower in accuracy than longer averages in assessing the level of drowsiness. In a sleep deprivation study, Dinges, et al (1998) tested the validity of PERCLOS against Psychomotor Vigilance Task (PVT). The results showed a correlation of 0.9 with lapses for 20 minute averaging compared to a correlation of 0.7 with lapses for one minute averaging.

PERCLOS has been demonstrated in both driving and non-driving tasks to be a valid indicator of drowsiness and performance deterioration due to drowsiness.

APPROACH

Fundamentally, this research is based on years of prior research toward developing an effective drowsy driver detection and warning system for commercial vehicles. The research objectives stated in the introduction, however, lend themselves to a more broad-based, qualitative approach that is a necessary part of the development cycle if this system is to become an accepted, fully adopted technology with its user base.

OBJECTIVES

One: Establish Appropriate Measures of Effectiveness

The word *appropriate* is inherently subjective and contextually dependent. What is appropriate in one situation may not be in another. For a safety critical system, however, one effectiveness measure that can be applied is whether or not system provides timely and accurate warnings. In this context, accurate means that the warning has a direct correlation to the driver's eye closure as it relates to drowsiness and that the warning is issued without delay. Assuming that this is the case, this leaves the characteristics of effectiveness in the qualitative realm of user acceptance and behavior.

For example, does the driver:

- Heed or ignore the warning system?
- Believe in the accuracy of the system against self-assessments of drowsiness?
- Perceive benefits of warnings and accept false alarms?
- Take mitigating measures and/or stop driving when necessary?
- Make behavioral changes both on- and off-road to decrease the likelihood and frequency of drowsiness episodes?

Introducing new technology into a community can lead to change within that community (Ehn, 1993). This change has a direct relationship with the effectiveness of the system.

Objective Two: Determine the Logic Applied to PERCLOS that Minimizes Nuisance Alarms and Maximizes Effectiveness While Maintaining Simplicity of Operation

There are varying thresholds for PERCLOS, for example, 1- minute averages and 3-minute averages have been explored. The warning system may be triggered repeatedly over time (or may be triggered suddenly over one time). One thought is that graded warnings may result in more tolerance for false alarms, which may in turn allow for a lower threshold of PERCLOS.

Like all other systems, there are inevitable technical limitations under which the system simply will not operate. Assuming that the system engineering is state of the art and that the operation is as seamless as technology allows, meeting this research objective also relies on qualitative user issues, for example tolerance and nuisance.

Driving is primarily a visual activity. Commonsense dictates that this activity cannot be safely accomplished while the eyes are closed. There is ample anecdotal evidence from drivers, commercial or otherwise, about near misses and struggles with drowsiness. Likewise there are the countermeasures that drivers routinely employ to help mitigate the effects of drowsiness.

As communities of use become more familiar with the drowsy driver detection and warning system and confidence builds in the accuracy of PERCLOS, the system may become a catalyst for changing attitudes about the safety of continuing to drive while receiving repeated warnings. These ideas are underexplored as they relate to the tolerance/nuisance issues and effectiveness of a safety critical warning device such as the one being discussed. Once again, effectiveness may very well depend on behavioral and cultural influences that might not be so easily measured and quantified.

"What we design is not just artifacts but by intervention a changed or reformed practice." (Ehn, 1993)

Objective Three: Determine the Most Appropriate Design of the DDI

There are extensive literature, guidelines, and standards surrounding both traditional design and design as it applies to the transportation industry. These take into account usability, safety, and aesthetic considerations. Examples from past drowsy driver research include the following:

> The progressive onset of drowsiness can last for an hour or more, so the driver may need to interact with the drowsy driver interface for an extended period of time (Grace & Stewart, 2001) and require a feedback or reset mechanism.

The interface for a drowsy driver monitoring system can include both sound and silent modes of advising/alerting. Because sound is an effective stimulus that does not require the driver to take eyes off the road, it can be used whenever the advising/alerting stimulus does not disturb a sleeping team driver. [A good silent mode of alerting is seat vibration. This mode has the same advantage as sound in that the driver does not have to take eyes off the road to sense the stimulus, and the stimulus is effective when the driver is not alert. The driver should be able to select the option.]

A mean single glance length of 1.25 seconds or less (Wierwille, 1992) and a limit of six glances is one target for an acceptable, safe interaction with an in-cab device. Longer glance durations and increased glance frequencies may be acceptable under low demand driving conditions. It is at the driver's discretion to determine the situation and adapt his/her behavior.

Overview of the Design Process

The activity of this program followed this process:

- Apply user-centered design principles to brainstorm and develop new/alternate concepts
- Conduct some informal field visits to understand context of use
- Revisit the underlying system flows and means of user interaction that were previously proposed for this system
- Present four preliminary concepts and related ideas to an expert focus group for discussion and consultation
- Present design concepts and options to a user focus group
- Make any necessary adjustments and refinements
- Develop specifications that address the function, design, and use of the system

Earlier sections in this report demonstrated an abundance of research surrounding drowsy driving. Despite this history and progression into this effort, the project has several of the circumstances present for warranting focus groups as defined by Krueger (1994). The following are exact excerpts for when to consider using focus groups:

- The purpose is to uncover factors relating to complex behavior or motivation. Focus groups can provide insight into complicated topics where opinions or attitudes are conditional or where the area of concern relates to multifaceted behavior or motivation.
- The researcher desires ideas to emerge from the group. Focus groups possess the capacity to become more than the sum of their participants, to exhibit a synergy that individuals alone cannot achieve.
- The researcher needs additional information to prepare for a large-scale study. Focus groups have provided researchers with valuable insights into conducting complicated and often quantifiable investigations.

USER-CENTERED FOCUS

The underlying warning system and corresponding interface must be designed in accordance with known principles of usable design to minimize driver difficulties and maximize ease of use and adoptability.

After surveying design usability principles from Jakob Nielsen and other experts in the field, the 10 basic principles from *An Introduction to Usability* (Jordan, 1998) were used to guide the design.

One of the most important design principles for this study is User Control.
Users, in this case the drivers, must feel that they have control over the warning systems' actions and their interactions with it. For example, some systems permit drivers to adjust display lighting levels for more comfortable nighttime driving (Steinfeld & Tan, 2000).

The drowsy driver detection and warning system is a new technology with behavioral implications. An example pertinent to this was an attempt by a company to implement software that would inform management of break schedules, sales, etc., and issue demerits if goals were not met (Bravo, 1993). They were hoping to increase worker productivity but instead negatively affected worker health as their rights and control were completely disregarded.

Consistency, quite simply interpreted means that familiarity counts. Similar tasks across similar activities should be treated in similar ways so that users can generalize what they already know. For example, introducing a volume control knob to the drowsy driver interface provides the same context of use as the volume control knob on a radio or CB radio interface.

This principle is closely connected to the next principle, **Compatibility**. Similarities in like products and their operation can be used to take advantage of user expectations and existing mental models. Jordan (1998) discusses the idea of population stereotyping within this principle. Because the users of the drowsy driver warning system are within a specific population, the design must take into consideration their assumptions and associations with like products. One way to deal with driver acceptance may be to explain the system in terms that minimize the actual method and component ry and maximize comparisons to "diagnostic" warning systems, such as engine temperature.

Consideration of user resources means that a product must take into consideration users' ability or limits when using a variety of modalities to process information. While driving is a very visually intense activity, the visual workload for nighttime driving is relatively low so the driver may be able to process additional information in that modality without compromising safety.

Every action that a user takes with a product has a consequence. Users must be made aware of these through meaningful **Feedback**. A simple act, such as switching the system on, requires feedback to let the driver know that the monitor is working. An alert that sounds when the driver closes their eyes beyond the allowed threshold is another example. And providing drivers with more detailed feedback for self-management of drowsiness is yet another example. Even though feedback can serve multiple purposes, all forms of feedback must be logically connected and understandable to the user.

Error prevention and recovery is another important principle, especially for a warning system. While every effort will be made to minimize the likelihood of user or system errors, they are unavoidable. Means for quick easy recovery must be included in the design of the system. One example is to provide a reset button for software failure, should it occur. The system should also be able to recognize hardware failure.

The information inherent in the interface and the display should be clear, concise and easy to see and use. This is known as **Visual Clarity**. Issues to consider include size, distance, color, placement, labeling, environment (darkened or dimmed cab interior) etc.

Related to this is the **Prioritization of Functionality and Information**. The drivers need to see the main information and understand the main functionality first. An example of this is to position the on/off control apart from any other groupings.

Explicitness refers to the clarity of operation. For example, cues that are inherent in the interface for what it is and how it works. The on/off button is another good example here as well. Another example is how the camera is mounted and adjustable to signal where to point it.

Finally the **Appropriate Transfer of Technology** should always be a consideration because most technology designed for a specific purpose for an intended group of users usually can be extended and applied beyond that initial group with a bit of thought to enhance the usefulness of another product.

DESIGN GROUP

OVERVIEW

This session was an expert focus group and that contained elements of a structured, cognitive walkthrough, especially as the experts reviewed conceptual prototypes. One of the reasons for conducting this session (and the subsequent user focus group) was that it has been well established in the usability world that users are not designers and designers are not users and that each can bring insights to the design process. Because the experts were new to the interaction design challenges of a drowsy driver warning system, they also brought a fresh perspective. Neilsen (1994) discusses how “knowing” is one-way and that once you “know information” about a system you cannot go back to not knowing. This in turn may make it difficult for those designers close to the work to assess the understandability of information from a novice user’s perspective.

By talking with the experts first, less usable or conceptually flawed ideas could be eliminated and the remaining concepts could benefit from their advice. The experts also might raise issues, question thinking, and provide insight at a conceptual level from a different vantage point than the team integral to the research.

The activities were organized around the themes that emerged from the team’s research and design approach:

- Human connection
- Choice
- Engagement
- Integration
- Driver awareness
- Association

These themes informed the design concepts at a high-level and influenced the purpose behind how the day’s activities were designed:

Short film, tour of a truck cab, high-level briefing

The purpose of these activities was to set the context of use for those unfamiliar with the problem, provide a realistic example of what the environment is like for the users of this device, and provide enough background information about work done to date toward solving the problem of drowsy driving.

Interaction flow model exercise

The purpose of this activity was to assess the interaction flow sequencing from an expert opinion of what would be most useful to a driver and usable by a driver. The intention was to eliminate and/or consolidate the four concepts into two concepts, to address issues that were in violation of design principles and to call out those issues that needed to be pursued with the driver focus group.

The flow models were intentionally varied in their levels of user interactivity and functionality (see Appendix C for detailed models). All of the flow models embody to one degree or another the six themes mentioned above.

- *Model One, Audio Only,* was adapted from an existing prototype developed by Grace et al. (Grace & Stewart, 2001) The flow of the prototype was varied to add the option of user-selected sound.
- *Model Two, Hierarchy,* was adapted from a sequence proposed by Wierwille, Lewin, & Fairbanks (1995) that featured countermeasures that are accessible through a hierarchy of use. The model was adapted to introduce additional countermeasures that focus on human connection.
- *Model Three, Sensitivity,* was a new concept that introduced the idea of a user controlling the sensitivity of the system based on their drowsiness state.
- *Model Four, Modality,* was a new concept that introduced the idea of a user being able to specify a modality preference

All four of the interaction flow models contained similar user features such as volume control. Each one was accompanied by a rough 3-D prototype, a black and white printout of a prospective interface, and a printout of discussion points. These were used to reinforce that this was not an aesthetic or style review. The prototypes and printouts varied enough to demonstrate that there could be many visual solutions but that the underlying functionality and user interactions needed to be fundamentally sound.

Random Spot Signaling

Much work has been done to explore the use of haptic feedback as an alerting mechanism, whether for a lane tracking system or as a drowsiness countermeasure. The random spot signaling exploration was designed to approach this countermeasure in a new way by linking it with another countermeasure, physical activity. The question to be explored is whether or not a haptic interface can be used to stimulate postural changes by the driver.

Sound Exploration

Likewise, much has been done to explore the alerting and alarming qualities of varying tones as well as the consideration of how many in-cab noises a user can discern. The purpose for testing the sounds was not to rate favorites or to determine decibel ranges but rather to investigate the power of suggestion and how well the sounds matched the descriptive categories labels. It served as a way to explore the idea of user choice and association. The use of two low frequency transducers and the amplifier also introduced a new component to sound, that of feeling the bass vibration as well as hearing the sound.

Closing Discussion

The purpose of this discussion was to generate comments independent of the structured exercises so that the team could revisit the interaction model flows, use of sound, use of vibration, interface issues etc. The experts would have another chance, after experiencing all of the activities, to provide further comments and suggestions for the next steps for the team.

PARTICIPANTS

The expert focus group consisted of seven design and human factors practitioners from academia and business. They collectively have experience with

- wearable computers
- industrial design
- human factors
- interaction design
- cognitive psychology
- usability
- experience design

An eighth expert from the automotive industry was scheduled but a last-minute conflict prevented that person's participation. There were four men and three women. Their ages ranged from late 20s to early 50s. The participants were asked to read and sign individual informed consent forms before the focus group began. See Appendix A for a copy of the form that was used.

Four experimenters were present for the focus group, two women and two men. One woman acted as the main facilitator, with the other experimenters providing assistance as necessary and depending on the activity. All experimenters participated in the closing discussion.

MATERIALS

Conference Room Configuration

- Large conference room with table and seating for 12 people (up to 8 participants and 4 experimenters)
- Whiteboard
- Space for the sound platform (see Design Activities Materials below)
- Space for the display boards (see Design Activities Materials below)
- Space for the vibrating seat (see Design Activities Materials below)
- (6) easels for the display boards
- Electrical outlets
- Power strips and extension cords, if applicable

Warehouse space

- Large enough space for a Model CH613 truck cab
- Exhaust ventilation system

Presentation Equipment

- Projection system
- (1) Apple G4 laptop
- Video cables

Participant Equipment

- (7) clipboards
- (7) Ultra fine point black sharpie markers
- Blank paper for notetaking

Data Collection Equipment

- (2) Digital8 camcorders with built in microphones
- (2) tripods
- (8) 60-minute tapes
- (1) digital camera

Design Activities Materials

- (7) copies of the IRB forms (Appendix A)
- 54-second video in Apple iMovie format of a person pretending to be a drowsy CDL driver
- 7 slide overview briefing in PowerPoint (Appendix B)

- (7) copies of the high-level user interaction rating form for each model (Appendix C)
- (7) copies of the sounds rating form (Appendix D)
- (7) copies of the random spot signaling via vibration rating form (Appendix E)

- Haptic interface test station

  A BackPleaser seat by Homedics retrofitted to hold (2) AP-700 Bed Shakers by Ameriphone (between cushions in seatback; 3 Watt, 12V at 250mA/motor with an offset weight) and (2) SS12V Super Shaker Bed Vibrators by Sonic Alert (between cushions in seat pan; 4.2 Watt, 12V at 350mA/motor with an offset weight). Both types of bed vibrators provide steady, high frequency signals designed to wake up a hearing impaired person in conjunction with an alarm clock although the Ameriphone vibration is at a gentler intensity.

  The power to the seat was controlled by (1) controller that has (4) Switch settings: (1 switch/motor) to control the top and bottom motors in the seat back and the back and front motors in the seat pan

- (4) 4' x 7' black foam core boards each with a shelf to hold a drowsy monitor prototype
- (4) blue foam drowsiness monitor prototypes
- 44" x 34" black and white printouts (1 each) of 4 interaction flows (Appendix C)
- 8.5" x 11" black and white printouts (1 each) of 4 interfaces (Appendix C)
- 8.5" x 11" black and white printouts (1 each) of discussion points (Appendix C)

- Low frequency audio test station

  A wooden platform with two Clark Synthesis transducers mounted to the underside and an amplifier plus (7) plastic and metal chairs positioned in a row on the platform with approximately 2' of clearance to the front and back of each chair, (1) Apple G4 laptop, cable from laptop to amplifier, and a database of sound files

The sounds were collected from a variety of websites including: Steve's Freeware[1], Wav Central[2], and Tintagel[3]. Twenty sounds were selected equally across five categories:

1. Practice
2. Aggressive
3. Percussive
4. Suggestive
5. Vocal

(Sounds were adjusted to be of comparable volumes and incorporated into a custom Director interface for easy sound playback and transducer control during the focus group.) The sounds were played from a laptop computer through an amplifier. The amplifier powered two Clark Synthesis transducers mounted inside a wooden platform. The experts sat in a row on rigid chairs that transmitted bass vibrations from the wooden platform. Each sound was played a single time, looped for 3 seconds, with a bass vibration track (40 and 60 Hz simultaneously), and looped with bass vibrations.

Sound order and descriptions

Table 1 describes the order and characteristics of the sounds utilized in the sound exploration phase of this focus group.

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[1] http://www.geocities.com/Vienna/7018/alerts.html

[2] http://www.wavcentral.com/

[3] http://www.tintagel.net/resources/Multimedia/Audio/

Table 1. Sound Order and Characteristics

Order	Category	Sound	Description
p1	Practice	reville	Trumpet playing reveille
p2	Practice	caralarm	Horn and siren car alarm
p3	Practice	chew_roar2	Chewbacca roaring
p4	Practice	Birdwhsl	Bird whistling
1	Suggestive	thunderrumble3	Thunder rumbling
2	Vocal	dont_try	Eric Idle “Don’t Try That”
3	Percussive	chimes	Grandfather clock chime
4	Aggressive	navywhistle	Navy three note attention whistle
5	Vocal	hello	Grandpa Simpson “Hello!”
6	Percussive	joop	Electronic beat with a reverb effect
7	Aggressive	buzzthruloud	Abrasive buzzer
8	Suggestive	aooga	Old fashioned car horn
9	Percussive	notify	Electronic chime
10	Aggressive	googler	Rapid electronic tones
11	Suggestive	bird_rooster	Rooster crowing
12	Vocal	homer-doh	Homer Simpson “Doh!”
13	Aggressive	whistleshort	Short whistle
14	Suggestive	glasbk	Glass breaking
15	Vocal	warn1	*Lost in Space* “Warning! Warning! Warning!”
16	Percussive	temple	Single beat musical chime

PROCEDURE

The design experts were emailed a high-level agenda for the focus group several days before the scheduled date so that they could plan their schedules accordingly.

As the design experts arrived the day of the focus group, they were led into a conference room and introductions were made as each expert arrived. When everyone was seated, they were asked to confirm that they had been introduced to each other and, if not, general introductions were made. One experimenter then explained the informed consent approval process and distributed the informed consent forms. Each expert was given a clipboard with the form attached. They were each given a pen as well and told that the clipboard and pen were to be used for the remainder of the focus group and were provided to make it easy for them to walk around the room and write at the same time for some of the later activities.

As the participants read the forms they were assured that their comments would be confidential and that the results would be coded and kept in a secure place separate from any record of their names. They were also informed that they could terminate their participation at any point without explanation. The duration for this activity was approximately 10 minutes.

Once all of the informed consent forms were collected, the facilitator made general introductions and explained the other team member roles as well as reminding them of the agenda that they had received via email. A 54-second movie depicting a drowsy truck driver (an actor) at night on the highway with some statistics about the problem was presented. The video was rough in nature, revealing the vibrations, sounds, lighting and other issues that a nighttime driver faces.

The experts then were given the opportunity to climb into an idling truck cab to begin to experience the noise levels of a truck and understand the context of use firsthand (Figure 1). This activity took place in the high bay of the facility where the design focus group was conducted. The experts determined the order and climbed into the truck cab one at a time, taking as much time as they needed to familiarize themselves with the interior environment. The experts not in the truck cab surveyed the truck cab from the outside and asked general questions about the context of use, variability between models, etc.

Figure 1. Experts with truck cab

This activity was videotaped as were all activities except the informed consent approval process. This activity took approximately 15 minutes.

After a quick break, the experts were taken back to the conference room and asked to sit around the conference table. They then were given a high-level PowerPoint briefing that covered

- The objectives of this project
- The intended user
- A brief overview of PERCLOS
- A brief review of research related to this effort
- The research teams' efforts to date
- The themes around which the work was organized

To see the complete briefing, refer to Appendix B. The experts were given a chance to ask any questions before beginning the interaction flow model exercise.

Interaction Flow Model Exercise

The interaction flow models were presented to the experts as a group. The facilitator explained that the flows were based on two existing approaches (Weirwille, Lewin, & Fairbanks, 1995; Grace & Stewart, 2001) plus two alternate approaches. Each flow model had a corresponding blue foam model, a black and white printout of a potential interface, and a list of discussion questions. See Appendix C for each interaction flow model and corresponding material.

It was explained to the experts that the interface printout and model were there only to demonstrate that there could be many aesthetic solutions and that the visual choices (button style, typeface selected, color palette) would be subject to any manufacturing and branding considerations. They were reminded that any purely visual decisions made during the remainder of the project were to support the usability of the interface for research and further testing. They were then asked to refocus their attention on the underlying interactions and if they could not help but make a visual suggestion to please note it on the blank pieces of paper that were provided.

The experts were shown the four interaction flow models as a group. The facilitator stepped through the interaction process and asked the experts to think about the discussion points. After the group walkthrough, they were asked to review each model again on their own or in impromptu teams and rate the different models using the provided forms (Figure 2). They had an opportunity to provide feedback about the interaction both on the forms and verbally. The experimenters were available to answer clarifying questions during this activity. After they were finished the experts then addressed the team with their thoughts and suggestions about the interaction flows and the discussion points. Finally, the experts turned in their rating forms and were encouraged to take a quick break before the next activity began.

Figure 2. Experts reviewing flow interaction model

Random Spot Signaling Exploration

The experts were asked to form a line and then take turns sitting individually in a seat that was designed to vibrate randomly in predetermined spots. They were each handed a rating form for their clipboards while waiting in line. The rating form had a generic image of a person from a back view with the zones identified that matched the vibrating spots in the seat. They were asked to note the zones that they recommended and were asked at the bottom of the form to speculate on the effectiveness of a spot vibration both as a warning and as a means to induce physical movement.

Sound Exploration

Finally the experts listened to, and rated, a database of sounds that were organized into categories. Unbeknownst to the experts, all Practice sounds were played first. Practice sounds were selected as being likely candidates for the other categories but impractical or unsafe for this application. Sounds were presented four different ways in the same order: once, looped for 3 seconds, once with the transducer activated, and looped for 3 seconds with the transducer activated. Short pauses were provided between each presentation for notetaking and form completion.

Each sound was rated 1-10 (Not at all – Very) for each category (Aggressive, Percussive, Suggestive, and Vocal). In addition, the experts were asked to select the most appropriate type of playback (Single, Loop, Bass, Loop+Bass) for the context of this application. Participants were given an opportunity to suggest new categories as well.

Closing discussion

The focus group ended with an open discussion about the interaction flows, positioning of the device to the users, for example, educational or informational, strategies for dealing with user annoyance and acceptance of the warning system, technology considerations etc. The discussion was loosely structured with no set agenda. They were thanked for their time and any additional comments that had been written down on the notepaper were collected along with the pens and clipboards.

The total session lasted approximately four hours.

ANALYSIS

Interaction Flow Model Exercise

The ratings forms were reviewed and the answers were entered into a unified spreadsheet. Means, standard deviations, and other basic statistical analyses were quickly computed to see if there were any anomalies. Mainly, the written and spoken comments were sorted into patterns of thinking and/or recurring themes, documented for elimination of ideas, and in-depth feedback was noted.

Random Spot Signaling Exploration

The raw expert choices for suitable locations were classified into categories. Expert answers to the three yes/no questions were counted and any additional comments were recorded exactly as they appeared.

Sound Exploration

Responses on the sound exploration forms were entered into a unified spreadsheet and basic statistical analysis was conducted. Expert comments about the suggestive power of the sounds were pulled from their written and oral comments.

Closing Discussion

The videotapes, transcript, and experimenter notes were reviewed and distilled into general themes and excerpts. There was a strong overlap between this activity and the interaction flow model exercise.

RESULTS

The first three activities (short film, visit to truck cab, and PowerPoint briefing) were not results oriented. They were used to help set the context for the experts. The interaction flow model exercise and subsequent activities provided the first opportunity to collect comments from the experts, most of which were qualitative in nature.

Interaction Flow Model Exercise

Expert handwritten comments on the interaction rating forms covered a wide range of issues. However, there were commonalities present in the written comments across all four models:

- [Is it] drowsy signaling vs. stay awake vs. pull over?
- Educational/informational, diagnostic, monitoring, or snooze alarm?
- How and when should it turn on?
- Does it learn/adapt over time?
- Consider showing drowsiness information in an explicit manner
- Do the drivers want to collect information about themselves?

The major comments and concerns with the interaction flow models are paraphrased below in Table 2. For more detailed comments, see Appendix C.

Table 2. Summarization of Flow Model Feedback

Model One: Audio	Appropriateness of sound types Suitably "safe" choices Simple and straightforward interaction
Model Two: Hierarchy	Countermeasures are interesting Overall model is reversed. The system should become progressively less taxing on a sleepy driver as opposed to more taxing It seems punitive or stigmatizing
Model Three: Sensitivity	How smart is the system? The idea is interesting. Could sensitivity reside with the system, not the user?
Model Four: Modality	The randomness is a concern Appropriateness is an issue Wrong degree of choice Haptic is interesting but challenging

The experts also provided comments about semantics of the different types of warnings. They addressed some form factors and implementation issues at a superficial level.

Random Spot Signaling Exploration

The spot vibration exercise revealed a preference for vibrations in certain areas. It also showed expert reactions to the intensity of the vibration. The totals for each region are illustrated in Appendix E as are additional comments that the experts wrote on the forms.

The experts were split three (yes) out of four (no) as to whether or not spot vibrations alone would induce movement. Six out of seven generally agreed that sound would enhance the usability of haptic feedback for the user. Finally, the experts were split three (yes) and three (no), with one abstention, as to whether or not visual cue would enhance the usability of haptic feedback for the user.

Sounds

The categories (Aggressive, Percussive, Suggestive, and Vocal) were somewhat distinct yet the experts rated the sounds mostly into the categories that they were classified into by the experimenters. For an extended discussion of the sound results see Appendix D.

The experts made casual suggestions for new sounds and speculated that the alerting task may be improved if the sound is personally meaningful to the driver. They also noted that making a warning sound progressively louder or more aggressive raises issues beyond the actual characteristics of the sound.

Closing Discussion

The experts spend much of the closing discussion on the type of device the warning system is perceived as, for example, a snooze alarm. They speculated about what types of warning dynamics would support or defuse this perception and how informational these warnings could be and still remain immediately meaningful.

They reached consensus that while the countermeasures in the second interaction flow model, Hierarchy, were interesting the flow itself was flawed. Likewise, the flow for Model Four: Modalities, was deemed to be flawed because the warning system is inherently multimodal.

They also cautioned that while the use of vibration is "interesting and immediate" there are implementation issues that need to be carefully considered before this could be used in a realistic setting.

DISCUSSION

There are many issues surrounding the design and usability of a drowsy driver detection and warning system. What is interesting is how the experts connected the design of the warning interaction and interface with user perceptions about intended use.

Four major ways the users could perceive this system emerged from researching previous work in this area and the subsequent discussions with the experts.

Diagnostic

Track eyelid closure, Calculate, Diagnose

User progresses to a diagnosable state (analogy to an x-ray: broken or not)

Informational/Educational

Blink rate, heart rate, temperature

Nearest rest area, distance to next one

Time to destination, crash statistics, connect to other drowsy drivers on the road

Provide some metric of drowsiness (analogy to a gas gauge)

Response Based

Track eyelid closure, Alert, Reset, Drive, Repeat

It is a device with a safety component (analogy to a snooze alarm)

Sudden Detection

No gradual progression indication

(analogy one: check engine light)

(analogy two: smoke detector: smoke, fire, take action or else)

These themes were deemed worth exploring further through questions to the drivers about warning characteristics and by describing example warnings to them and allowing them to state their preferences. There are only so many ways that the warning information can be displayed given the limits the technology and the design constraints.

The criteria is for any system is that it be as technically “smart” as possible, not taxing or burdensome to the driver when they are at their drowsiest, not compromise the fact that it is a safety critical device by offering unnecessary or unsafe choices to the user, and not stigmatize or punish the driver for becoming drowsy.

When the experts discussed and speculated on what the drivers would find useful in a warning system they tended to do so in regards to the visual and auditory warnings. The focus was not on appropriateness, annoyance, or giving the drivers undue choices. Rather, the focus was on driver preference and control that is embedded in the system in a way that does not interfere with its functionality, contributes to the effectiveness, nudges the user behaviorally, and supports the overall goal of warning the driver that his or her drowsiness has reached a critical state.

A haptic interface is a challenge. There are issues with safety and effectiveness as well as the fact that it is being explored as the standard warning for lane maintenance and lane departure warning systems.

The inclusion of functional controls, such as volume, is easier to do but something as simple from an engineering perspective as having the ignition power the device raises additional questions. The entire drowsy driver detection and warning system must adhere to user-centered design principles and general human factors guidelines.

Issues that were targeted for exploration with the drivers included:

- how informational the display could be
- what kinds of information would be suitable to display
- if sound customization is desirable
- the categories of sound that are appealing
- their thoughts on haptic feedback
- the controls they would use if they had a choice

DRIVER GROUP

OVERVIEW

It is well known that user focus groups are a sound method to collect qualitative information from focused discussions. User focus groups are typically conducted early in the process and serve as a way to eliminate any concepts that are inherently flawed or ill conceived. It is possible to use techniques such as questionnaires in conjunction with more open-ended activities so that some quantitative information can be collected. Often the quantitative information is not statistically significant unless many focus groups are conducted. Focus groups are more suitable for collecting information about users attitudes, beliefs, and desires (Dumas & Redish, 1999).

The main goal was to collect information from the drivers about their perceptions, preferences, resistance, attitudes, acceptability, and the consequences surrounding the adaptation and use of a drowsy driver detection and warning system. The information can be used to inform the design process and support the design decisions that must be made.

Questionnaire

The purpose of the questionnaire was to collect information about fatigue, individual driver behavior, drowsy driving, and general workplace interactions with people, technology or both.

Action Sequence Model

Because the drowsy driver detection and warning system is a safety critical device for use while driving, it is important to gain a better understanding of driver actions while driving. Though the actions may vary, they occur linearly over time throughout a driving shift. The sequence model method is a way to collect this type of information. Beyer and Holtzblatt (1998) state that sequence models can supply the micro-level information about how work is actually done that is necessary to make detailed design decisions. Their description of a sequence models follows:

> "A sequence model represents the steps by which work is done, the triggers that kick off a set of steps, and the intents that are being accomplished. They are your map to the work that your new system will change." (Beyer & Holtzblatt , 1998)

This method was adapted for the driver focus group. The purpose for doing this was to help the drivers think critically about actions that may have become rote or habitual and prepare their mindset for the next activity. The discussion did not focus on identifying triggers. As a facilitated brainstorming session, it allowed the drivers to say whatever came to mind, relax, engage in the group dynamic, begin considering how they manage fatigue, and agree to a representative series of actions.

Critical Drowsy Driving Incident Interviews

The critical incident technique developed Flanagan (1954) is a way to collect task-based data from interviews by asking the interviewees first to recall a specific critical incident (story of a real situation) then answer a set of prepared questions to reveal more information about the specific incident (as explained in Hackos, 1998). This method, too, was adapted for the driver focus group.

The purpose was to collect anecdotal evidence about each driver's experience with having a drowsy driving incident, whether it was a near miss or an actual crash, in order to detect patterns of behavior. These patterns of behavior, while statistically lacking, are common enough to provide clues to the resistance and/or acceptance of a drowsy driver detection and warning system.

Design Exercise and Group Discussion

The purpose of this activity was to explore user preferences, the context of use, and usability issues within teams of two first and then as a group last. By dividing the drivers into teams of two, they were encouraged to communicate and reach consensus. They could achieve synergy without the problems inherent in larger group dynamics. Each team was assigned a color with the understanding that the four teams final choices would be displayed and referred to by that color. While the teams were not anonymous, the assignment of color provided a way to refer to the teams' choices without singling out the participants in the closing discussion.

It was decided to present the design choices as descriptions rather than visually represented in rough prototypes. There are pros and cons to using visual prototypes and the thought was to keep the discussion and choices as broad based as possible. While visual prototypes provide clarity they can also provide bias in that someone may agree with the idea and disagree with the visual representation thereby eliminating the idea.
A sample choice is whether the drivers wanted to turn on the system manually or have it be powered automatically via the ignition switch. The choices were extracted from the interaction flow models that were presented to the experts and refined by their subsequent comments.

The seat and sounds used in the expert focus group were available to the drivers to experience as part of the exercise and to inform their decisions.

The group discussion was used to discuss the four team's choices and further investigate behavioral issues surrounding the adoption and use of the system. The drivers had a chance to provide any additional comments and ask questions. The goal was to reach agreement that all of the choices were valid rather than push for consensus.

PARTICIPANTS

There were eight drivers in the focus group. All were

- male
- less-than-truckload (LTL) drivers
- contractors for a multinational parcel shipping company
- ending a shift just prior to the focus group

Seven were on shift regularly during nighttime hours. The eighth driver was not driving at night regularly but had extensive experience with nighttime driving. Their ages ranged from 26 to 46. They had been with their current employer 3 to 9.75 years.

Four experimenters were present for the focus group, two women and two men. One woman acted as the main facilitator, with the other experimenters providing assistance as necessary and depending on the activity. All experimenters participated in the one-on-one critical drowsy driving incident interviews and the closing discussion.

MATERIALS

Conference Room Configuration

- Large conference room with table and seating for 12 people (up to 8 participants and 4 experimenters)
- Table in the front
- Table to the side
- Space for the vibrating seat (see below)
- (1) easel
- Electrical outlets
- Power strips and extension cords, if applicable

Interview Spaces

- (4) separate private rooms or spaces

Presentation Equipment

- Projection system
- (1) Apple G4 laptop
- Video cables

Participant Equipment

- (8) pens
- Blank paper for note taking

Data Collection Equipment

- (2) miniDV camcorders with built in microphones (positioned at each end of the main room)
- (4) tripods

- (2) additional camcorders (one Digital8; one Hi8) for use with interviews and the design exercise
- (10) 60-minute tapes

Design Activities Materials

- (8) copies of the IRB forms (Appendix A)
- (8) copies of the payment form
- 7-slide overview briefing in PowerPoint (Appendix B)

- (1) 7' long black foam core board with a piece of white safety tape affixed to it in a horizontal line from end to end, with two 3' long pieces perpendicular to the main piece on each end to represent a timeline; the back of the board had another piece of foam core taped to it to make a stand
- (2) pads of 3 x 5 post it notes
- (2) black markers
- (1) large flip pad for easel

- (4) 24" x 19' black foam core boards, each with a shelf along the bottom and a piece of foam core taped on the back to make a stand
- (20) flat 24" x 19" pieces of black foam core
- (20) black and white printouts (5 each of 5 different masters) affixed to the flat black foam core boards (Text in Appendix J)
- (4) sets in 4 different colors of 3" x 3" preprinted pieces of paper with a soft adhesive on the back (similar is size and affixability to a post it note)

- (4) clipboards with critical drowsy incident interview questions for interviewer to use

PROCEDURE

The drivers participated in four activities and a closing discussion after the informed consent process was completed. The total session lasted a little over four hours and was conducted in one conference room and several breakout spaces within close proximity to the conference room. A description of each activity follows with corresponding diagrams that provide at-a-glance information about the nature of the activity. All activities after the informed consent process were videotaped.

To prepare the team of experimenters, a list of talking points was generated as a read ahead for the focus group. See Appendix F for the list.

Informed Consent Process

The duration was estimated to be 10 minutes.

Upon entering the meeting room, drivers were quickly briefed by a member of the company who reiterated that the session was strictly for non-company research purposes and the raw results would not be seen by anyone outside the room. The company representative then left the room and did not return.

The drivers were given informed consent forms and a high-level briefing that

- emphasized confidentiality/anonymity
- provided clarification
- confirmed understanding
- answered any procedural questions

They were then asked to individually read the forms and provide their signatures. (See Appendix A for a copy of the form)

Questionnaire

The duration was estimated to be 15 minutes.

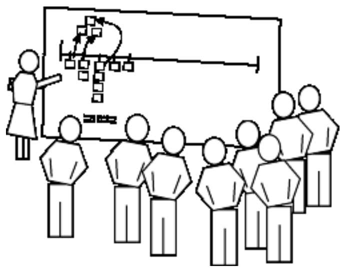
The drivers were given the questionnaire to fill out individually and the facilitator:

- Reiterated that their answers would be confidential
- Explained why this material was needed
- Encouraged honest answers

The surveys were short and the questions included ratings, check box multiple choice and free response. (See Appendix F for a sample questionnaire)

After the surveys were collected the facilitator provided a short overview about drowsy driving. This presentation was similar to the one shown to the expert group but did not include the video clip with the "drowsy" actor. The intent was to prepare the group for the remaining activities.

Action Sequence Model



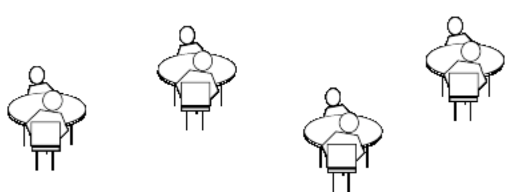
The duration was estimated to be one hour.

The facilitator:

- Explained that this was a real-time, facilitated exercise and provided an example
- Solicited input about the driving activity throughout a shift
- Wrote each comment on a post it (with assistance from another experimenter) and placed them all on a board that was visible to the entire group

The comments were not edited or sorted. They were recorded as stated and when the board was too full to continue, the answers were written on a flip chart. The drivers had an opportunity in real time to correct anything that was erroneously recorded.

Critical Drowsy Driving Incident Interviews



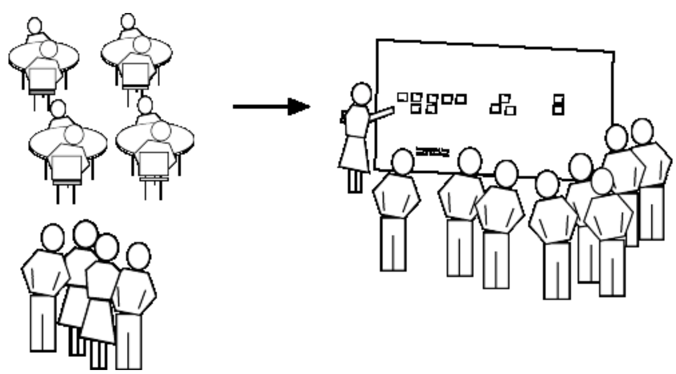
The estimated duration was 15 to 20 minutes for each interview. Given that there were four experimenters and eight drivers, the total for the whole activity was estimated to be no more than 40-45 minutes.

The drivers were given a group overview before being separated. The drivers who were not being interviewed were encouraged to enjoy their break. The experimenters were required to

- Facilitate conversation during the interviews
- Solicit a story or multiple stories about drowsy driving.
- Ask a standardized set of follow up questions (see Appendix F)
- Note any additional information that was provided

Each critical drowsy driving incident interview was conducted in an isolated space in the vicinity of the meeting room. Each experimenter had a clipboard and pen for note taking along with the set of follow up questions.

Design Exercise and Group Discussion



The duration of the activity was estimated to be 45 minutes followed by a group discussion of no more than one hour that would end the day.

The group was:

- Given an overview
- Allowed to split into teams of two of their own choosing
- Presented with kits that consisted of one main worksheet and four sheets that contained choices for different levels of interaction

The team kits (Figure 3) were color coded blue, yellow, green, and tan, so that each teams' choices could be easily referred to during the group discussion. The colors were assigned at random. The experimenters:

- Loosely observed the teams
- Answered any questions and provided clarification as necessary
- Collected the final main worksheets and displayed the four team choices

The eight drivers, with minimal facilitation, then debated and discussed the team choices. Any choices deemed invalid by the group were removed from the main worksheets.

Figure 3. Kit in Use

ANALYSIS

Questionnaire

Descriptive data was reviewed and entered into a spreadsheet. The check box question selections were converted to numbers, averaged, and reconverted to the options provided. Basic statistics were computed for ratings. Answers to open-ended questions were recorded verbatim and in some cases trimmed to key phrases for concise reporting.

Action Sequence Model

Comments were entered into a running list and then sorted according to categories that emerged from the nature of the comments. The sequence was not sorted according to a strict time scale because the linearity of the actions was not straightforward and served more as a loose boundary (begin, break, end) for the discussion.

Critical Drowsy Driving Incident Interviews

The videotapes, transcript, and experimenter notes were reviewed and distilled into general themes and excerpts.

Design Exercise and Group Discussion

Each team's responses were sorted into tables. Videotapes, transcripts, and experimenter notes from the group discussion were reviewed and distilled into general themes and excerpts.

RESULTS

Questionnaire

The minimum length of time that was reported for "How long have you been driving for your current employer?" was 3 years.

Questionnaire results to a set of short answer questions suggested that each driver has developed their own procedure for managing drowsiness. Six out of eight drivers indicated that their current practices include naps. Four of these drivers quoted the exact length of their naps.

The questionnaire also included open-ended questions related to audio-based distractions. CB radios did not appear to be used in a uniform manner. All but two drivers talked with family members via their cell phones. However, during discussion later that day drivers indicated that there was a limited window during which it was acceptable to call family members due to the nature of their shift. Almost all of the drivers listened to music. Four drivers listed non-music formats.

When drivers were asked what they thought the value is of a drowsy driver detection and warning system was, answers were varied yet positive.

See Appendix G for more detailed answers to all of the questionnaire entries.

Sequence Exercise

The drivers all mentioned personal countermeasures that they use to combat drowsiness, as well as general activities that they undertake during the course of a drive. They emphasized the importance of schedule and how delays can have a negative effect on how alert they feel. Weather and traffic play an important role too. An interesting result from this activity was the heavy emphasis on social interaction and human connection, whether it was from the CB, a radio show, cell phone, watching other drivers, during rest breaks, etc., especially when the drivers felt fatigued. See Appendix H for a list of all of the items that were recorded on the post it notes during the brainstorm.

Critical Incident Interviews

Several drivers did not describe specific events, but instead focused on typical drowsiness episodes. Those that had experienced critical incidents were able to recount them in vivid detail, often displaying intense relief that they had survived the episodes. Critical episodes included rumble strips, hallucinations, unrelated police action, and trance-like periods of degraded awareness. Most stories involved interstate driving and highway speeds. Several drivers described pronounced drowsiness from about 3 AM to sunrise. See Appendix I for a summary of some of the topics reported by the drivers.

Design Exercise and Group Discussion

The four teams' choices mostly reflected individual team preferences. The four teams were in agreement that they wanted:

- Brightness adjustment
- Redundant warnings

And reached consensus that the device could be powered by the ignition so long as the driver always had the option to disable it. Three out of four teams also wanted volume control.

Three out or four teams stated they wanted the most aggressive visual and audio warnings, wanted to pick the sound, and wanted the warnings to continue until they were acknowledged. One of the teams firmly believed that if a driver has the ability to diminish the warning he or she would do so.

In regards to the sounds themselves, mostly aggressive ones were selected and the discussion skewed to very aggressive or unsafe sounds such as a blown tire and an ex-wife screaming. Suggestions for sounds included a directive to use only annoying, high-pitched sounds and another directive that, "All we need is a big-ass beep."

Two out of four teams also expressed interest in a haptic interface and picked the most aggressive settings. During the group discussion there was skepticism about the effectiveness and suggestions that drivers would need, "…sudden, jarring, shocking stimulation." and that, "All modes need to be more intense and pulsating than the samples."

Their preferences for the warning display were varied between all of the choices. They expressed concern that the use of an informational display could be used by employers for punitive action or have liability issues until they were reassured that the warning information was not permanently stored. For example, once reassured, they thought that the use of a digital counter would be a “wake up call” and “scare the shit out of you.”

The drivers’ advice for the other components of the interface was somewhat contradictory to the preferences that were selected during the design exercise. The drivers asserted that “no truck driver looks at the owners manual” so it needs to be as simple as possible. Their concerns centered on older drivers who might resist using this device. They said that older drivers “don’t like a lot of knobs” and that they might need to use default settings.

They conceded that the system could be misused to extend hours of service but then concluded that, “You can only doze so much before you crash.” The discussion ended with general consensus that it “comes down to responsibility and human error” but that this could be a valuable aid for responsible drivers.

See Appendix J for all of the choices presented to the teams and the selections each team made during this exercise.

DISCUSSION

In 1998 an American Trucking Association study concluded that technology can be good but is limiting. Hiring that right driver is ultimately better (Kopytoff, 1999). As implied by the drivers themselves, an effective drowsy driver detection and warning system requires both.

The software, hardware, and aesthetic design (look and feel) are relatively straightforward and where they are not, there are many guidelines for making the technology almost error-proof and the design aesthetics comply with sound design and human factors principles. For example, continuing to use the 10 principles of user-centered design mentioned earlier to assess the final interaction flow model and subsequent design.

Introducing functional controls that enhance the usability of the device and afford the drivers a sense of control can only help with the adoption of the system. This is not feature creep but rather an intuitive, concerted effort to give the drivers what they want in combination with what they need in an environment in which they are the masters. Some of the functional controls, such as sensitivity setting, also have an invisible, (to the user) beneficial connection to the warning system. In this case it would be linking PERCLOS thresholds to the sensitivity setting to help diminish the occurrence of false alarms.

When it comes to the warning display and underlying interaction, however, expert experience and understanding of need must take precedence over driver desires. The drivers professed to want aggressive, annoying sounds. Past experience in driving simulators (Mallis et al, 2000) has shown that a simple, subdued tone can be effective and accepted by drivers. . The focus group participants also wanted to be able to select the sound warning. An obvious solution is to allow them to select from a number of sounds, some of which are aggressive, but include other categories of sound and track what sounds are used when. Until they experience it in a real setting, a gap exists between professed want and actual use.

Drivers also expressed that the haptic interface, if included as an option, should be aggressive. There are many issues surrounding the use of vibration, some of which were mentioned in the expert discussion section. The intensity and location(s) of the vibration(s) has to adhere to safe health standards. They cannot be confused with other warnings, such as for lane drift. There also remain questions about the effectiveness and overall safety. While it would be an interesting to see if spot signaling could induce physical movement (a promising short-term countermeasure and one that drivers often employ), there are too many mitigating factors for it to be feasible for this particular study and will therefore be eliminated as a warning option.

It is disturbing that the drivers' tendency at first was to view the device as a snooze alarm, or as one of the experts prophesized during the expert focus group, "A one more mile in you device." It was only after the day's activities and group discussion that the drivers began expressing their beliefs that "driving while fatigued is unsafe – period" and that a load does not equal a life." So while they advocated an aggressive solution that could potentially promote unsafe behavior, their thinking progressed to the point where they were willing to concede that the effectiveness might lay in behavioral change. The challenge to the designer is to build features into the warning system that promote this thought process and help the drivers make the safe decision.

Situation awareness in dynamic environments leads to decision making. There are other factors that have an impact on whether or not good situation awareness leads to successful decision making and performance (Endsley, 1996). Until the external factors and cultural influences can be addressed, what can be done in-cab is to design a warning system that contains the information all drivers need to make a safe, informed decision to stop driving at the beginning of a progressive drowsiness episode or immediately following the sudden onset of drowsiness.

GENERATION TWO INTERFACE

The interaction and interface design incorporates the drivers' desire for a stimulating and alerting response with the researchers desire to encourage safe behavior. Promoting driver acceptance through driver control is a theme throughout the design:

- The driver can adjust the sensitivity of the drowsiness warning.
- The driver can select sounds that range from a robust alerting sound to a gentle advisory tone.
- The driver can adjust the volume to match the ambient sound environment.
- The driver is also given the option to disable the warning system should he/she find it bothersome.

The controls are intuitive and easy to learn how to use. While driver control is only 1 of the 10 principles of user-centered design, all of them were used as a guide to inform the final design decisions.

Driver behavior is primarily addressed by providing the driver with information regarding his/her state of drowsiness and its adverse effect on driving. An informational warning display is provided to make the drivers aware of the immediacy and danger of the situation. The perceptual change needs to be that this is not a system that promotes alertness but rather a fact-based drowsiness information system.

This informational display needs to be easily and readily understood. Neilsen (1994) discusses the concept of learnability, that is, the first experience of a novice user is that of learning to use a system. Remove that obstacle in their first experience or decrease the learning curve and what remains is the potential that drivers will learn to heed the warning rather than have to learn to interpret warnings.

The information display has been designed to provide clear, easily understood measures for the drivers that are potentially unsettling. It is hoped that the unsettling nature of the information will encourage drivers to stop and rest when experiencing drowsiness.

INTERACTION AND INTERFACE

Every action that the user takes or the system initiates has to be accounted for in the interaction. This interaction sometimes results in a visible change to the state of the interface and sometimes it results in an underlying change that is not visible to the user. It is helpful to think of the interface as the means through which a user interacts with the system in a prescribed or semi-prescribed way and that any user action results in feedback from the system.

The interaction flow model that is included was used as the high-level architecture for the design process. The steps following it describe the design in detail assuming that the user has triggered the informational warning display. The wire diagram in Figure 4 is used throughout the section to explain the elements of the design. The accompanying interaction flow is provided on the following page.

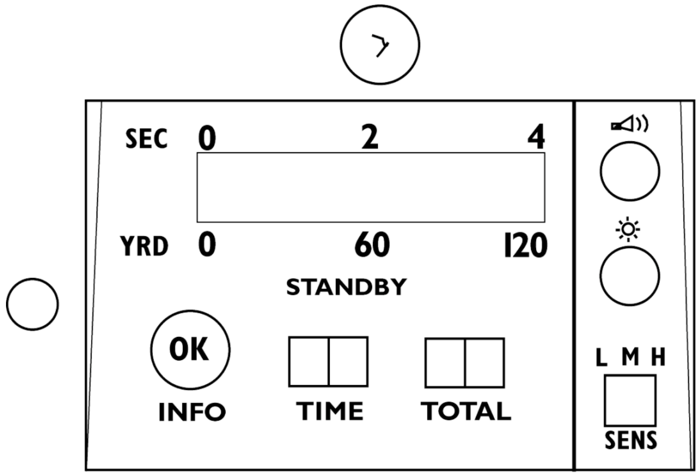


Figure 4. Wire Diagram

The interface that the wire diagram portrays utilizes the front, top, and sides of the housing. The total unit dimensions are:

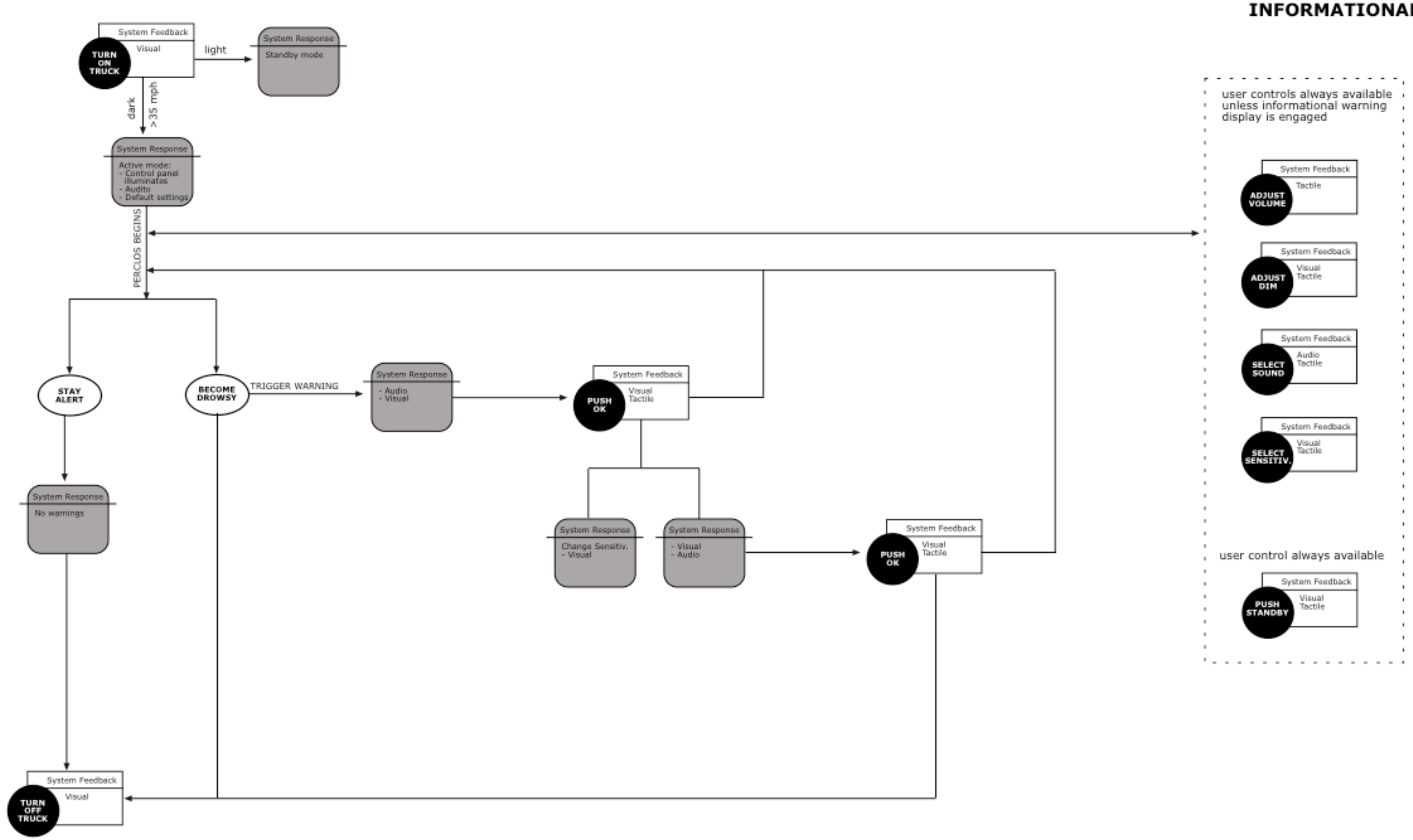
Overall height: 5.43 inches

Overall width: 4.08 inches

Overall depth: 6.12 inches

These dimensions include the camera being mounted on the back of the main housing. The camera arm mount is a ball and socket joint that has adjustable tension to ensure that the unit is stable.

FINAL MODEL
INFORMATIONAL



1. **Power On**

The system is ignition powered but does not begin operating until the light sensor detects that the conditions are dim enough and the truck speed exceeds 35 mph.

User action: start truck

System: standby mode

Interface: standby indicator light is illuminated

Illumination: The standby indicator light is illuminated in dim red. The areas that are grayed out are not illuminated at this time (Figure 5).

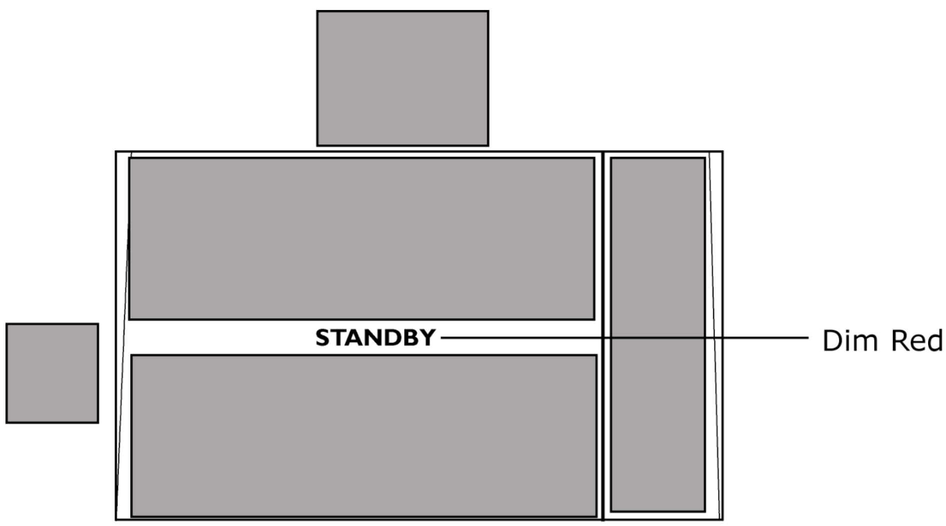


Figure 5. Power On

2. **Activate System**

The system is activated when conditions are dim enough to begin the PERCLOS measurement and the truck speed exceeds 35 mph. All of the functional controls become available to the user and the PERCLOS measurement begins.

User action: not applicable

System: PERCLOS active mode

Interface: standby indicator light dims, an operational notification sound briefly plays, functional controls are accessible

Illumination scheme: All of the functional controls are illuminated in green. The areas that are grayed out are not illuminated at this time (Figure 6).

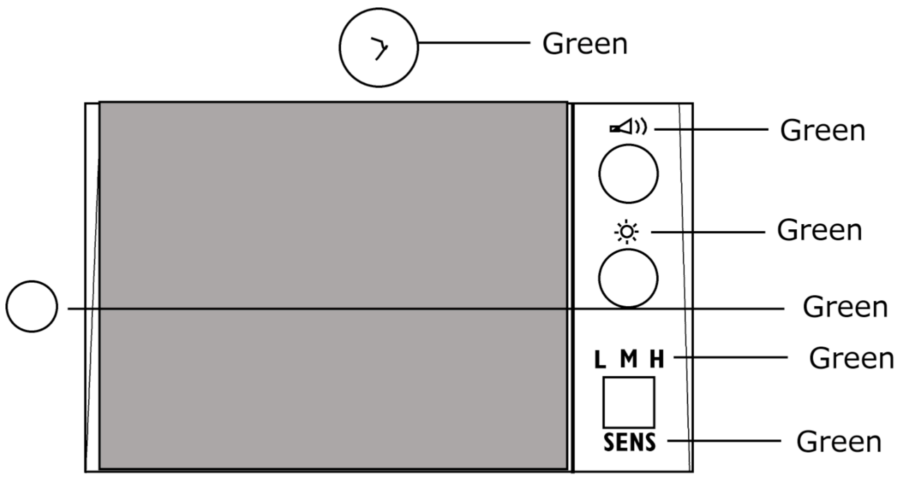


Figure 6. Active

The prototype contains functional controls for volume, brightness/dimness, sensitivity, sound selection, and standby mode with system feedback for the user (Figure 7). All of the functional controls are clustered together in keeping with the Gestalt theory for grouping information. This means that by applying design principles such as proximity, similarity, continuity, size, shape, color, labeling, positioning, etc., like controls are grouped to the extent that the size of the prototype allows.

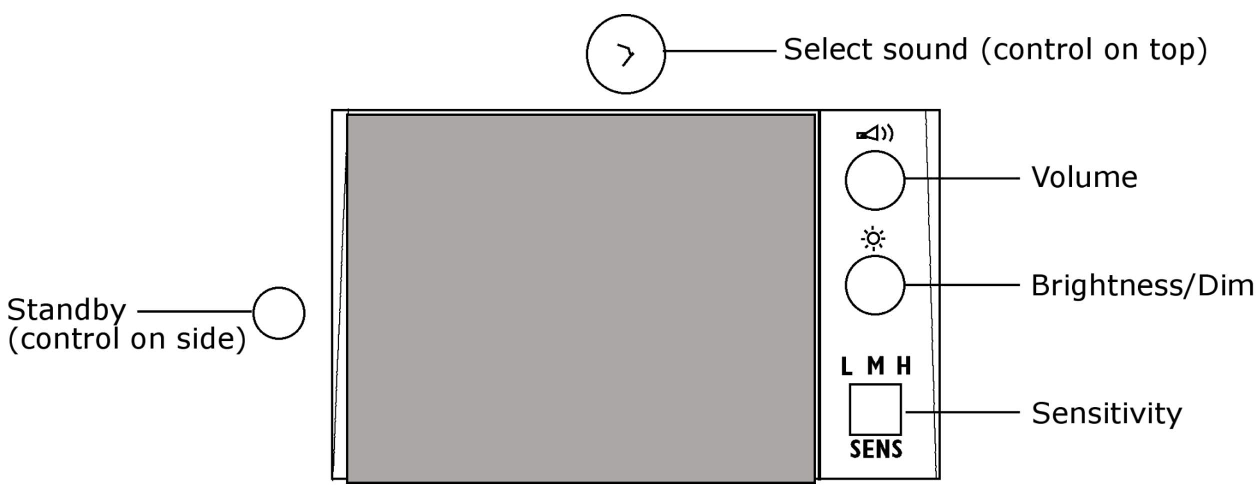


Figure 7. Controls

The control for standby is separate from the other functional controls because it disables the system. By positioning it separately, the chances of the user accidentally disabling the warning system are small.

The Adjust Brightness/Dim control affects the functional controls that are illuminated in green. It does not control the illumination of the warning display.

Each functional control provides the user with feedback (Table 3).

Table 3. Control Feedback

User Control	System Feedback
Adjust Volume	Tactile, Auditory
Adjust Bright/Dim	Tactile, Visual
Select Sound	Tactile, Auditory
Select Sensitivity	Tactile, Visual
Push Standby	Tactile, Visual

3. Trigger Informational Warning Display

The warning system is activated when the user exceeds the threshold for PERCLOS.

User action: drowsiness beyond threshold

System: informational warning mode

Interface: functional controls cannot be adjusted until the primary informational warning is acknowledged. Dropping below 35 mph will not place the system into standby mode until the primary informational warning is acknowledged.

Illumination: The informational warning display and corresponding acknowledgement button are illuminated in bright red. The areas that are grayed out are not illuminated at this time (Figure 8).

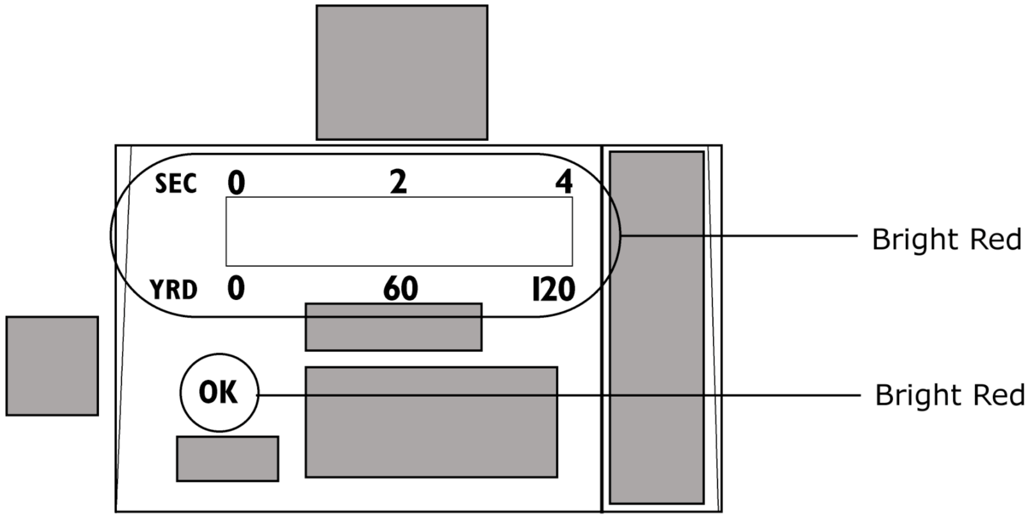


Figure 8. Initial Warning

The warning sound occurs simultaneously with the informational warning display. Eye closure information has been translated into distance traveled and the amount of time the driver's eyes were closed. For the purposes of this display, the longest single eye closure observed during the integration period is displayed. This measure was chosen for display over PERCLOS as being less abstract, more believable, and more relevant to the drivers' experiences.

This information is displayed visually through the use of a single bar graph LED with parallel legends at the top and bottom. The units of measure are up to 4 seconds and 120 yards so that at a glance the driver can see the scale. A speed of 61 mph is assumed to convert the time to distance. Yards were chosen as the unit of distance under the assumption that most drivers are less familiar with meters. Fractions of a mile and feet were determined to be resulting in values that were either not impressive enough or too large to convey an accurate perception of distance traveled. The scale of 120 yards is also fortuitously close in size to an American football field – a dimension many potential users are likely to be familiar with.

The user must push the OK button for the warning sound to cease. This in turn triggers another display that provides secondary information to the driver (Figure 9). The secondary information is accessible only after the first warning and has a time-out of 10 seconds.

The secondary information that the system collects is displayed as the total number of warnings received and the total amount of time that has elapsed since the previos warnings.

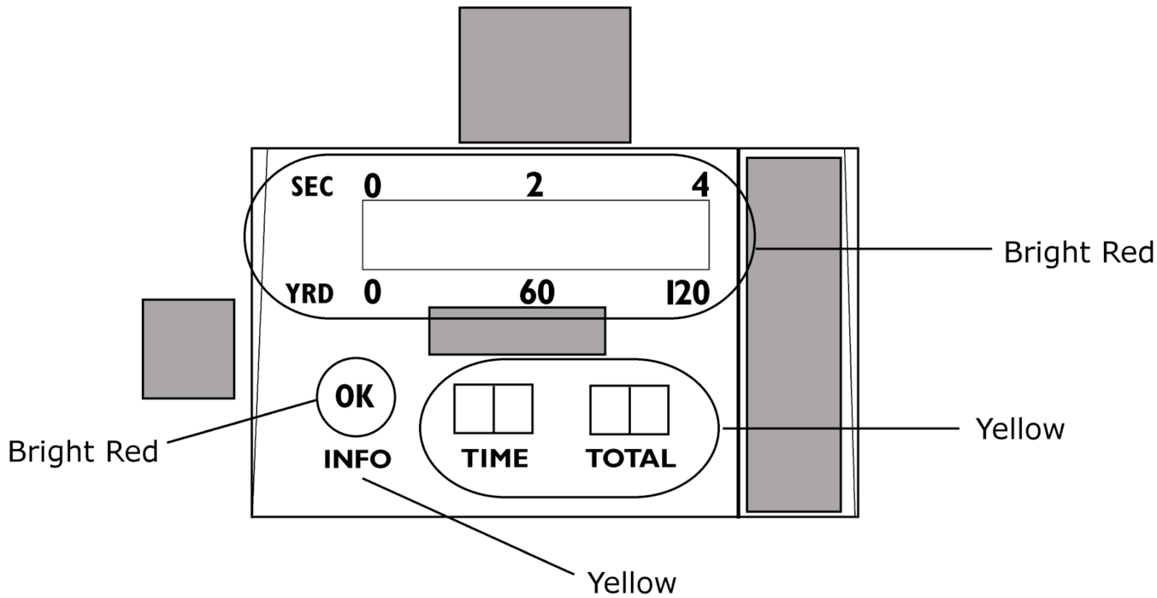


Figure 9. Secondary Information

The user must push the OK button again to clear the display or wait for the display to time out. Once this action is completed, the functional controls will illuminate and be usable again. The sensitivity setting will also automatically reset itself to the next most sensitive setting. The user has the ability to manually override this should they choose to do so.

A quick summary of the OK button functions is given in Table 4 along with the illumination scheme for the informational warning display and secondary information display.

Table 4. OK Button Functionality

Informational Displays	User Control	System Feedback	Color Scheme
Primary Warning	OK	Informational warning display dims and warning sound ceases	Red
		Info label beneath "OK" button illuminates	Yellow
		Secondary information display illuminates	Yellow
Secondary	OK	Secondary information display dims and functional controls illuminate	Green
		Sensitivity setting switches to next higher setting	Green

4. 4. Continue Driving

The driver may choose to continue driving or pull over.

User action: continue driving

System: PERCLOS active mode

Interface: Functional controls can be adjusted and the OK button can be used to view secondary information display

Illumination: The information button remains illuminated in yellow after the first warning was issued and acknowledged. While the OK button does not remain illuminated, its position above the information label suggests to the user to push it to display this information. The areas that are grayed out are not illuminated at this time (Figure 10).

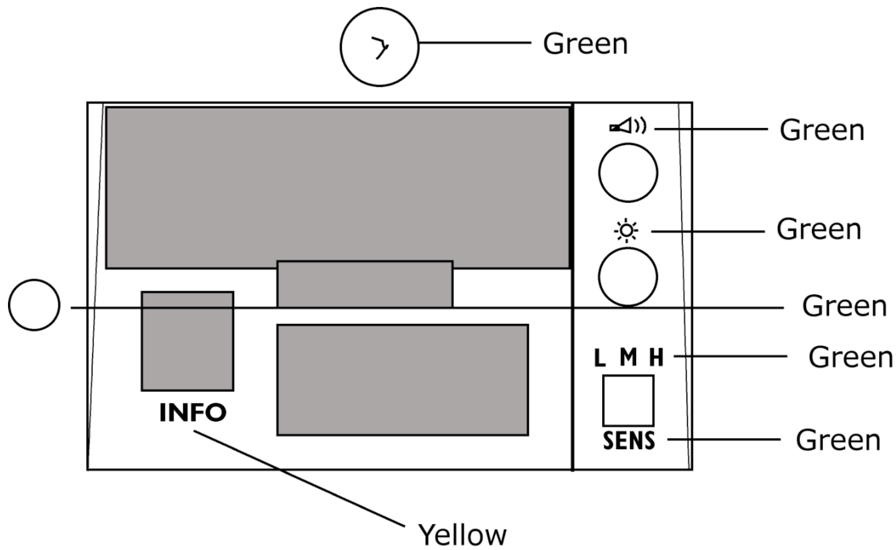


Figure 10. Active with Recent Warning

5. **Stop driving**

The system returns to standby mode when the truck speed goes below 35 mph for more than one consecutive minute. It powers off automatically when the truck is turned off.

WARNING LOGIC

All warnings are triggered based on PERCLOS. Initial warnings are based on PERCLOS crossing a threshold. Historically PERCLOS triggers have been calculated, and validated, over periods ranging from 1-minute to 3-minutes using thresholds ranging from 8% to 12%. Shorter time periods and lower thresholds correspond to higher sensitivity for the detection of drowsiness. For example, by calculating the trigger with P1= 8% a driver will receive a warning if his/her eyes are continuously closed for 4.8 seconds. The time is extended to 21.6 seconds if P3 = 12% is used. Table 5 shows the space of historically used PERCLOS thresholds with three selected values of P1= 8%, P2=10%, and P3= 12% corresponding to high, medium and low sensitivity.

Table 5. Sensitivity Settings

Sensitivity Setting	First Warning Threshold	
PERCLOS	PERCLOS Threshold (%)	Integration Period (min)
Low	12	3
Medium	10	2
High	8	1

Once the initial warning is triggered and responded to there are several ways to consider subsequent warnings. Three subsequent warning models are considered here. The models all use an initial first warning upon crossing a PERCLOS threshold averaged over a specified period ranging from 1-minute to 3-minutes (Table 5). The variation in the models occurs for when to warn drivers when they do not drop back below the first warning threshold. The three considered options are Frequency, Episode, and Reset.

Frequency Model

In this case follow-up warnings are given every X minutes while the driver is above the first threshold. The parameter X can be a constant or can vary with the level of PERCLOS (Mallis et al, 2000). However, within this model warnings are only given when the driver's eyes are closed so that the driver does not rapidly perceive the warning to be a false alarm (Figure 11). If the driver's eyes are open when the period ends, the system waits for the next eye closure to emit a warning.

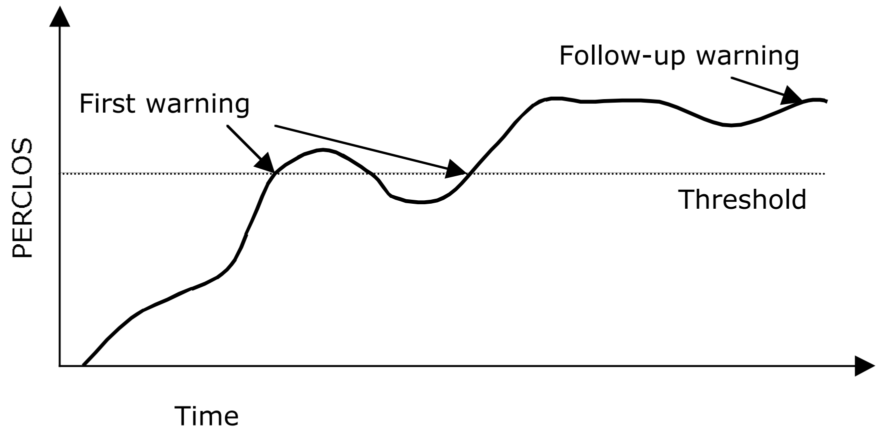


Figure 11. Warning pattern for Frequency or Episode models

Episode Model

After a driver crosses, and stays above, the first threshold the system will monitor eye closure for long episodes. The shortest possible triggering episode is 2 sec – long enough to avoid triggering for a typical mirror or in-vehicle glance. As this method only emits alarms when episodes are occurring, the risk of emitting an alarm when the driver's eyes are open is non-existent.

Reset Model

This model is similar, yet not identical, to model proposed by Wierwille, Lewin, & Fairbanks (1995). After a driver crosses, and stays above, the first threshold the system zeroes the PERCLOS calculations and sets the threshold at the next shortest option until it reaches the lowest level (Figure 12). Again, the risk for emitting an alarm when the driver's eyes are open is minimal, as PERCLOS must cross a threshold in a rising direction.

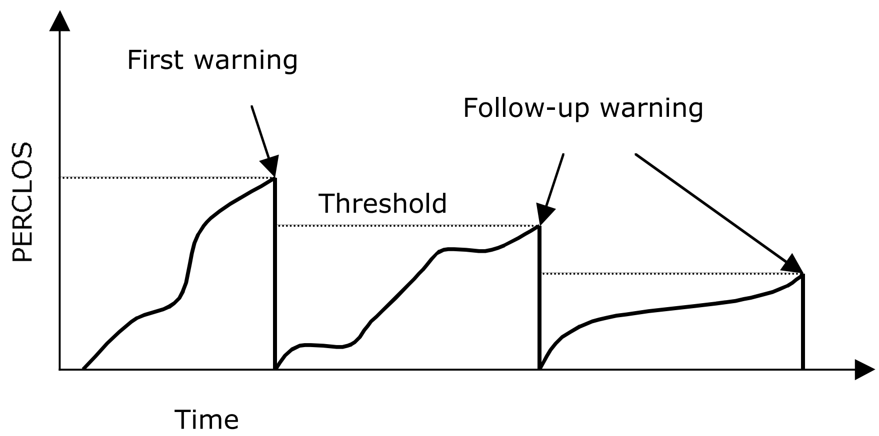


Figure 12. Warning Pattern for the Reset Model

Selected Warning Model

The Reset model was chosen for use in the prototype monitor. The Reset Model simplifies the logic while steadily increasing sensitivity as drowsiness onset occurs. An important feature of the Reset model is that the driver is actively engaged to the extent that he/she can override the automatic increase in sensitivity.

ADDITIONAL SPECIFICATIONS

Volume Settings

Guidelines on in-vehicle displays suggest a wide volume range. For example:

> "It should be possible to hear the auditory output under all driving conditions at a level that will not startle the user. The volume of auditory output should be adjustable over a reasonable range; in most circumstances between 50bB(A) and 90dB(A) is suitable. Higher than 90dB(A) should be avoided.
>
> Sounds containing different frequencies should all be presented at an appropriate volume, usually this can be achieved if the signal exceeds the ambient noise by

> 15dB or more (Sorkin, 1987)[4]. However, to avoid a startle response, the signal should not exceed ambient noise by more than 25dB (Edworthy, 1994)[5]. The signal level is a matter of balancing the listener comfort against message audibility." (Stevens, et al, 2002)

However, these guidelines often fail to account for the relatively high noise levels present in older model trucks. Research specific to truck cab noise levels implies that many drivers are exposed to levels near or at OSHA noise exposure standards (90 dBA over 8 hours or 88.2 dBA for 10 hours):

> "A review of the studies that have examined noise levels in truck cabs under real operating conditions suggests that noise levels in commercial truck cabs exceed 90 db for substantial portions of driving time. Even the most recent U.S. studies, which include newer truck models, reported mean noise levels averaging around 90 db(A) when driving with the windows open and the radios off (Kam 1980, Reif 1980, Hessel 1982)[6]. A study in France (Pachiaudi 1987)[7] reported lower noise levels than the earlier U.S. studies; they found mean levels of 81.2 db(A)

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[4] Sorkin, R. D. (1987). Design of auditory and tactile displays. In *Handbook of Human Factors*. New York: Wiley, pp 549-76.

[5] Edworthy, J. (1994). The design and implementation of non-verbal warnings. *Applied Ergonomics, 25 (4)*, 202-210.

[6] Kam, J. K. (1980). Noise exposure levels among 20 selected truck drivers. *Journal of Environmental Health, 43*(2), 83-85.

Hessel, P. A., Heck, M. M., & McJilton, C. (1982). Noise levels in over-the-road tractors. *American Industrial Hygiene Association Journal, 43*(4), 261-264.

Reif, Z. F., More, T. N., & Stevens, A. E. (1980). *Noise Exposure of Truck Drivers* [SAE Technical Paper Series, Paper No. 800278]. Warrendale, PA: SAE.

[7] Pachiaudi, G. (1987). Noise in the cabs of heavy goods vehicles and effects on the hearing of the drivers. *Rechere-Transports-Sécurité, English Issue, 2*, 41-48.

with radio on and windows open. However, it is not clear whether the interior noise level standards in the two countries are comparable." (Songer, et al, 1993)

> "When measuring truck-cab noise, researchers found that the overall broadband sound pressure level for the 9 trucks evaluated was 89.1 dBA for 8 conditions of highway driving. The sleeper-berth mean dBA was 81.6 dBA, and for engine idle conditions, cab noise was 68.7 dBA. The truck-cab average of 89.1 dBA was very close to the Occupational Safety and Health Administration (OSHA) permissible exposure limit of 90 dBA for an 8-hour day." (Office of Motor Carrier Research and Standards, 1998)[8]

These findings suggest that it is difficult to adequately predict a comfortable range for audible warnings. As with car stereo systems and CB radios, the closest analogous interfaces in the cab, there is an expectation that a very small minority will even attempt to select the loudest volume. Thus, we recommend a high upper end (~100 dBA) and limiting the lowest setting to approximately 85 dBA – about 15 dBA above the lowest reported in-cab value (68.7 dBA , OMCRS, 1998).

Illumination Settings

The reduced levels of luminance in at night (e.g., Steinfeld et al, 1996) can interfere with the legibility of text and icons. Configuring a minimum brightness that was too low setting could easily drop text luminance levels below legible thresholds (Howett, 1983). The provision of a brightness knob should readily permit users to identify the necessary illumination level for their own needs and varying levels of visual acuity. When the system enters a warning state, the brightness of the interface will be fixed to a level well above legible limits.

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[8] Summarized from: Robinson, G.S., Casali, J.G., & Lee, S. E. (1997). *Role of Driver Hearing in Commercial Motor Vehicle Operation: An Evaluation of the FHWA Hearing Requirement* (AUDIO LAB-9/1/97/5-HP, ISE-9703, PB98-114606). Washington, DC: Federal Highway Administration.

Labeling

The labels for the controls and warning display are a combination of commonly understood abbreviations and standardized international icons (Tables 6 and 7).

Table 6. Functional Controls

User Control	Label
Adjust Volume	Icon
Adjust Dim	Icon
Select Sound	Icon
Select Sensitivity	SENS; L, M, H
Push Standby	STNBY
Acknowledge warning	OK

Table 7. Informational Displays

Display	Label
Seconds	SECS
Yards	YDS
Information	INFO
Time	TIME
Total	TOTAL

Typography

The typography for the labels was determined as according to basic typographic principles of legibility. The most legible typefaces are dependent on three qualities: (1) contrast, (2) simplicity, and (3) proportion (Carter, Day, & Meggs, 1993). The way these typefaces are used and the spatial relationships of the letterforms also contribute to legibility. For example, using all capital letters had traditionally interfered with the readability of words and uses a greater amount of space than lowercase letters. But in a darkened cab interior at a distance, using all capital letters may help with readability of labels as they take on more of a display quality. Finally, the size and interletter spacing (kerning), and the weight of the type are critical to legibility and the misapplication of these can have a serious impact on usability.

The typeface being used in the prototype is Gill Sans bold and Gill Sans Condensed bold. Gill Sans is a classic typeface that was inspired by the type used for the London Underground Railroad of 1916 (Meggs & Carter, 1993). It was designed in 1928 and is a highly legible sans serif due to its being based on classic Roman proportions. It is considered to be an informal and friendly looking typeface, which is a subtle perceptual quality that should not be underestimated when used on a device whose use may be initially resisted.

Dashboard Location and Mounting Options

The drowsy driver detection and warning system is designed to mount on the dashboard just to the right of the steering wheel. The camera unit is attached to the warning unit with a ball and socket hinge that allows the user to adjust the camera until he or she can see their reflection in the infrared plastic that covers the camera lens. The field of view is large enough to accommodate significant head movement. At a distance of 30 cm from the camera, a square image measuring 30 cm is obtained. This image size allows approximately 42 cm of head translation while maintaining at least one eye in the field of view.

Dashboard styles vary in their depth and the angle at which they slope back toward the windshield. Because of this, the mounting mechanism must be adaptable while at the same time providing enough stability to avoid excessive vibration. It must also be secure enough that the unit will not separate from the dashboard in the event of a collision or sudden stopping.

GENERAL DISCUSSION & CONCLUSIONS

The drowsy driver interface has been designed through careful interactions with design experts and CMV drivers with guidance from previous research results and the team's expertise. The final design incorporates much of what was learned from the focus groups. The primary focus of the effort has been to produce an interface and interaction that will promote safe behavior. These will be successful if they are shown to induce timely rest breaks while on shift. It is also hoped that they will influence behavioral change outside of the shift, i.e., drivers report trying to get more sleep.

To accomplish this goal the system must first be accepted by the drivers as a loyal servant and trusted advisor, providing the information that they need to make informed decisions. The design has many features that satisfy the basic principles of user-centered design and satisfy the wants and needs explored in the focus group activities. The drivers can control or select many of the functional features of the interface to correspond to their specific driving environment and individual desires. These features include sound selection, volume control, brightness/dimness, and sensitivity selection.

The informational warning displays or "advisor" portion of the interface gives the driver valuable information in terms that emphatically point out the inherent danger in driving while drowsy. Drivers often convince themselves that – "my eyes where closed for just a second" while research shows that eye closures of 3 – 30 seconds have been observed. It is hoped by displaying eye closure times, together with the total distance traveled with eyes closed, the driver will be convinced that he/she is driving in an unsafe condition and make the choice to stop and rest. The secondary warning display of how many warnings have been received and the time elapsed since the last warning reinforces this message.

The drowsy driver interface will likely be most effective if used as part of a fatigue management program that emphasizes education and safety. The goal of any fatigue management program is to minimize driver fatigue (maximize driver alertness) and, hence, maximize driver performance, which in turn maximizes both productivity and safety.

The first step in implementing a fatigue management program is education. Workers, supervisors and managers need to understand basic sleep physiology and learn to speak a common language. A fatigue management-training curriculum can take many forms. For example, the curriculum could be arranged as an overall wellness program including basic information about fatigue, good eating habits, and exercise. The basic curriculum can also be modified to include industry specific issues such as wisely applying hours of service regulations. Whatever its form, certain core information about basic sleep physiology is required. The basic information includes:

1. The basic human drive for sleep
2. How much sleep the average person requires each day
3. Performance degradation as sleep debt accumulates
4. Circadian rhythms and their effects on fatigue and performance
5. Fatigue management strategies – napping strategies, strategic use of caffeine etc.

This basic information will provide the knowledge that a driver needs to best manage his/her sleep – wake cycle, and to understand and internalize the relationship between drowsiness and safety.

REFERENCES

Beyer, H., & Holtzblatt, K. (1998). *Contextual Design: Defining Customer-Centered Systems.* San Francisco, CA: Morgan Kaufmann Publishers.

Bonnet, M.H., & Arand, D.L. (1994a). The impact of naps and caffeine on extended nocturnal performance. *Physiology & Behavior, 56*, 103-109.

Bonnet, M.H., & Arand, D.L. (1994b). The use of prophylactic naps and caffeine to maintain performance during a continuous operation. *Ergonomics, 37*, 1009-1020.

Bravo, E. (1993). The hazards of leaving out the users. In D. Schuler & A. Namioka (Eds.) *Participatory Design Principles and Practices*. Hillsdale: NJ: Lawrence Erlbaum Associates, Inc.

Brown, I.D. (1997). Prospects for technological countermeasures against driver fatigue. *Accident Analysis and Prevention 29*, 525-531.

Carter, R., Day, B., & Meggs, P. (1993). *Typographic Design: Form and Communication* (second edition). New York, NY: John Wiley & Sons, Inc.

Dinges, D. F., Mallis, M., Maislin, G., & Powell, J. W. (1998). *Final Report: Evaluation of Techniques for Ocular Measurement as an Index of Fatigue and as the Basis for Alertness Management* (Report DOT HS 808 762). Washington, D.C.: National Highway Traffic Safety Administration.

Dinges, D. F. (1989). The nature of sleepiness: Causes, contexts and consequences. In A. Stunkard and A. Baum (Eds.), *Perspectives in Behavioral Medicine: Eating, Sleeping and Sex.* Hillsdale, NJ: Erlbaum.

Dumas, J. S., & Redish, J. C. (1999). *A Practical Guide to Usability Testing* (revised edition). Portland, OR: Intellect Books.

Ehn, P. (1993). Work-oriented design of computer artifacts. In D. Schuler & A. Namioka (Eds.) *Participatory Design Principles and Practices*. Hillsdale: NJ: Lawrence Erlbaum Associates, Inc.

Endsley, M. R. (1996). Situational awareness measurement in test and evaluation, In T. G. O'Brien & S. G. Charlton (Eds.) *Handbook of Human Factor Testing and Evaluation*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Federal Highway Administration. (1998). *Crash Problem Size Assessment: Large Truck Crashes Related Primarily to Driver Fatigue.* Washington, D.C.

Flanagan, J. C. (1954). The critical incident technique, *Psychological Bulletin, 51*, 327-358.

Grace, R., Byrne, V. E., Bierman, D. M., Legrand, J. M., Gricourt, D. J., Davis, R. K., Staszewski, J. J., & Carnahan, B. (1999). A machine vision based drowsy driver detection system for heavy vehicles. *Proceedings of the Ocular Measures of Driver Alertness Conference, April 26-27, 1999*, (FHWA-MC-99-136, pp. 75-86). Washington, D.C.: National Highway Traffic Safety Administration.

Grace, R., & Stewart, S. (2001). The Co-Pilot: A Low-Cost Drowsy Driver and Driver Inattention Monitor. In proceedings of *The International Driving Symposium on Human Factors in Driver Assessment, Training And Vehicle Design*, *Aspen, CO, August 14-17, 2001.*

Hackos, J, T., & Redish, J. C. (1998). *User and Task Analysis for Interface Design.* New York, NY: John Wiley & Sons, Inc.

Howett, G.L. (1983). *Size of Letters Required for Visibility as a Function of Viewing Distance and Observer Visual Acuity* (NBS Technical Note 1180), Washington, DC: U.S. Department of Commerce, National Bureau of Standards.

Jordan, P. W. (1998). *An Introduction to Usability*. Bristol, PA: Taylor & Francis LTD.

Knipling, R. R., & Wierwille, W. W. (1994). *Vehicle-based Drowsy Driver Detection: Current Status and Future Prospects*. Paper presented at IVHS America fourth annual meeting, Atlanta, GA April 17-20, 1994.

Kopytoff, V. G. (March 14, 1999). Rolling on: 18 wheels, G.P.S., radar and e-mail, *The New York Times*, [www.nytimes.com/library/tech/99/03/circuits/articles/04rigg.html].

Krueger, R. A. (1994). *Focus Groups: A Practical Guide for Applied Research* (2nd ed.) Thousand Oaks, CA: SAGE Publications.

Lerner, N. D., Dekker, D. K., Steinberg, G. V., & Huey, R. W. (1996). *Inappropriate Alarm Rates and Driver Annoyance*. (Report DOT HS 808 533). Washington, D.C.: National Highway Traffic Safety Administration.

Mallis, M. M., Maislin, G., Konowal, N., Bierman, D. M., Byrne, V. E., Davis, R. K., Grace, R., & Dinges, D. F. (2000). *Biobehavioral Responses to Drowsy Driving Alarms and Alerting Stimuli.* Final report. (DOT Contract No. DTNH22-93-D-07007). Washington, D.C.: U.S. Department of Transportation.

Meggs, P., & Carter, R. (1993). *Typographic Specimens: The Great Typefaces.* New York, NY: John Wiley & Sons, Inc.

Neilsen, J. (1994). *Usability Engineering*. San Francisco, CA: Morgan Kaufmann.

Noy, I., Vincent, A., & Laing, A. (1998). Behavioral adaptation to fatigue warning systems. *Proceedings of the 16th International Technical Conference on the Enhanced Safety of Vehicles (ESV) Windsor, Ontario, Canada May 31-June 4, 1998*.

Office of Motor Carrier Research and Standards (1998). *Role of Driver Hearing in Commercial Motor Vehicle Operation: An Evaluation of the FHWA Hearing Requirement* (FHWA-MCRT-99-001). Washington, DC: Federal Highway Administration.

Rachlin,H. (1970). *Introduction to Modern Behaviorism*. San Francisco, CA: W.H. Freeman and Company.

Rosekind, M. R., Graeber, R, Dinges, D. F., Connell, L. J., Rountree, M. S., & Gillen, K. (1994). *Crew Factors in Flight Operations IX: Effects of Planned Cockpit Rest on Crew Performance and Alertness in Long-Haul Operations.* (NASA Technical Memorandum No. 108839). Moffett Field, CA: NASA Ames Research Center.

Songer, T., LaPorte, R., Palmer, C., Lave, L., Talbott, E., Gibson, J., & Austin, L. (1993). *Hearing Disorders and Commercial Motor Vehicle Drivers* (FHWA-MC-93-004). Washington, DC: Office of Motor Carriers, Federal Highway Administration.

Steinfeld, A., Manes, D., Green, P., & Hunter, D. (1996). *Destination Entry and Retrieval with the Ali-Scout Navigation System* (Technical Report UMTRI-96-30), Ann Arbor, MI: The University of Michigan Transportation Research Institute.

Steinfeld, A., & Tan, H. S. (2000). Development of a driver assist interface for snowplows using iterative design, *Transportation Human Factors*, 2(3), 247-264.

Stevens, A., Quimby, A., Board, A., Kersloot, T., & Burns, P. (2002). *Design Guidelines for Safety of In-Vehicle Information Systems* (Project Report PA3721/01). Crowthorne, UK: Transport research Laboratory.

Wierwille, W.W. (1992). Visual and manual demands of in-car controls and displays. In J.B. Peacock & W. Karwowski (Eds.), *Automotive Ergonomics: Human Factors in the Design and Use of the Automobile*. London: Taylor & Francis.

Wierwille, W.W., Ellsworth, L.A., Wreggit, S.S., Fairbanks, R.J., & Kirn, C.L. (1994). *Research on Vehicle-Based Driver Status/Performance Monitoring: Development, Validation, And Refinement of Algorithms for Detection of Driver Drowsiness.* Final Report. (DOT HS 808 247). Washington, D.C.: National Highway Traffic Safety Administration.

Wierwille, W. W., Lewin, L.G., & Fairbanks, J, R. (1995). *Research on Vehicle-Based Driver Status/Performance Monitoring: Seventh Semi-Annual Report*. (DOT HS 808 299). Washington, D.C.: U.S. Department of Transportation.

Wierwille, W. W., Lewin, M. G., & Fairbanks, R. J. (1996a). *Final report: Research on Vehicle-Based Driver Status/Performance Monitoring: Part I, Specifications for a Driver Drowsiness Detection/Alarm/Countermeasures System, (DDDACS*). (Report No. DOT HS 808 638). Washington, D. C.: National Highway Traffic Safety Administration.

Wierwille, W. W., Lewin, M. G., & Fairbanks, R. J. (1996b). *Final Report: Research on Vehicle-Based Driver Status/Performance Monitoring: Part II, Simulator Test and Evaluation of a Complete Driver Status/Performance Monitoring System*. (Report No. DOT HS 808 639). Washington, D. C.: National Highway Traffic Safety Administration.

Wierwille, W. W., Lewin, M. G., & Fairbanks, R. J. (1996c). *Final Report: Research on Vehicle-Based Driver Status/Performance Monitoring: Part III, Development of Revised Algorithms for Driver Status/Performance Monitoring.* (Report No. DOT HS 808 640). Washington, D. C.: National Highway Traffic Safety Administration.

Wylie, C.D., Shultz, T., Miller, J.C., Mitler, M.M., & Mackie, R.R. (1996). *Commercial Motor Vehicle Driver Fatigue and Alertness Study: Project Report.* (Report No. FHWA-MC-97-002). Washington, D.C.: U.S. Department of Transportation.

ADDITIONAL REFERENCES

Belz, S.M., Winters, J.J., Robinson, G.S., & Casali, J.G. (1997). *Auditory icons: A new class of auditory warning signals for use in intelligent transportation subsystems* (SAE Technical Papers Series 973185, from *Electronics and Electrical Systems for Trucks And Buses*.) Society for Automotive Engineers.

Fairbanks, R. J., Fahey, S. E., & Wierwille, W. W. (1995). *Research on Vehicle-Based Driver Status/Performance Monitoring: Seventh Semi-Annual Research Report* (Report No. DOT-HS-808299). Washington, D.C.: National Highway Traffic Safety Administration.

Hanowski, R.J., Wierwille, W.W., Gellatly, A.G., Early, N., & Dingus, T.A. (1998). *Impact of Local/Short Haul Operations on Driver Fatigue, Task 1: Focus Group Summary and Analysis.* (Report FHWA-MC-98-029 FHA) Washington, D.C.: Federal Highway Administration.

Hurwitz, J.B., & Wheatley, D.J. (2001). Driver choice of headway with auditory warnings. *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting*. Human Factors & Ergonomics Society.

Lave, J., & Wagner, E. (1991). *Situated Learning: Legitimate Peripheral Participation*. Cambridge, UK: Cambridge University Press.

Lerner, N., Kotwal, B., Lyons, R., & Gardner-Bonneau, D. (1996). *Preliminary Human Factors Guidelines for Crash Avoidance Warning Systems*. (Report DOT HS 808 342). Washington, D.C.: National Highway Traffic Safety Administration.

Marshall, D., Lee, J.D., & Austria, P.A. (2001). Annoyance and urgency of auditory alerts for in-vehicle information systems. *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting*, Human Factors & Ergonomics Society.

National Highway Traffic and Safety Administration. (1996). *Preliminary Human Factors Guidelines for Crash Avoidance Warning Devices*. (NHTSA Project No. DTNH22-91-C-07004).

Pomerleau, D., Jochem, T., Thorpe, C., Batavia, P., Pape, D., Hadden, J., McMillan, N., Brown, N., & Everson, J. (1999). *Run-Off-Road Collision Avoidance Using IVHS Countermeasures*. (DOT HS 809 170). Washington, D.C.: National Highway Traffic Safety Administration.

Tan, A.K., & Lerner, N.D. (1995). *Multiple Attribute Evaluation of Auditory Warning Signals for In-Vehicle Crash Avoidance Warning Systems* (Report No. DOT HS 808 535). Washington, D. C.: National Highway Traffic Safety Administration.

Wang, J. S., Knipling, R. R., & Blinco, L. J. (1996). Motor vehicle crash involvements: A multi-dimensional problem size assessment. *Sixth Annual Meeting of the American Intelligent Traffic System, Houston, TX, April 14-18, 1996.* Washington, D.C.: National Highway Traffic Safety Administration.

Wickens, C.D., Gordon, S.E., & Liu, Y. (1998). *An Introduction to Human Factors Engineering*. New York, NY: Addison-Wesley Educational Publishers, Inc.

Wierwille, W.W., Tijerina, L., Kiger, S., Rockwell, T., Lauber, E., & Bittner, A. (1992). *Final Report Supplement: A. Heavy Vehicle Driver Workload Assessment Task 4: Review of Workload and Related Research*. (DOT HS 808 467). Washington, D.C.: National Highway Traffic Safety Administration.

APPENDIX

A IRB FORMS

Informed Consent, Drivers

Informed Consent Form – Design Group

CARNEGIE MELLON UNIVERSITY
CONSENT FORM

Project Title: NHTSA's Drowsy Driver Detection and Interface
Conducted By: Dr. Richard Grace, Carnegie Mellon University

I agree to participate in this study of drowsy driver detection and interface conducted by Dr. Richard Grace and staff under his supervision. I understand that the proposed research has been reviewed by the University's Institutional Review Board and that to the best of their ability they have determined that the observations involve no invasion of my rights of privacy nor do they incorporate any procedure or requirements which may be found morally or ethically objectionable. If, however, at any time I wish to terminate my participation in this study I have the right to do so without penalty.

If I have any questions about this study, I should feel free to ask them now or anytime throughout the study by contacting:

Dr. Richard Grace
National Robotic Engineering Consortium
10 - 40th Street
Pittsburgh, PA 15201
Phone: 412-681-7159

I know that I can report any objections to the study either orally or in writing to:

Dr. Ann Baldwin Taylor, IRB Chair
at0j@andrew.cmu.edu
Carnegie Mellon University
5000 Forbes Avenue, Warner Hall #405
Pittsburgh, PA 15213
Phone: 412-268-4727

Purpose of the Study:

I understand that I will be participating in testing the usability of a drowsiness detection and interface device. I realize that in the experiment I will receive a briefing and then experience the device in a stationary truck cab and a desktop simulated driving environment within the context of a focus group. I understand that I will be encouraged to make comments while experiencing the device and that this session will be videotaped. I understand that the components of the drowsiness detection and interface device may have some or all of the following: 1) Visual gauge 2) Audible tones that are typically 1000 Hz square waves pulsed at 3 Hz 3) Voice commands such as "Drowsiness has been detected. Please take appropriate action" 4) Vibrating seats, steering wheels or other equipment commonly found in a truck 5) Drowsiness countermeasures that typically include exercise, social interaction, fresh air or peppermint scents. I understand that I will participate in an individual debriefing interview following the session and that I will receive a negotiated hourly rate for my participation in this experimental session.

I understand that the following procedure will be used to maintain my anonymity in analysis and publication/presentation of any results. My observations will be assigned a number; names will not be recorded. The researchers will save data and videotape files by number, not by name. Only members of the research group will view that tape. The videotapes and data records will be stored in locked files by researchers assigned by Dr. Grace. No other researchers will have access to these files.

Optional Permission: I understand that the researchers may want to use a short portion of a video for illustrative reasons in presentations of this work in specific meetings or other public outlets (i.e. professional meetings, publications and/or news media releases). I give my permission to do so provided that my name will not be used in the context of such an illustration.

______ YES ______ NO (Please initial here __________)

I understand that in signing this consent form, I give Dr. Grace and his associates permission to present this work in written and oral form without further permission from me.

Name (please print)	Signature
Telephone	Date
Witness	Date
Investigator	Date

Informed Consent, Drivers

Informed Consent Form – Professional Truck Driver Evaluator Group

CARNEGIE MELLON UNIVERSITY
CONSENT FORM

Project Title: NHTSA's Drowsy Driver Detection and Interface
Conducted By: Dr. Richard Grace, Carnegie Mellon University

I agree to participate in this study of drowsy driver detection and interface conducted by Dr. Richard Grace and staff under his supervision. I understand that the proposed research has been reviewed by the University's Institutional Review Board and that to the best of their ability they have determined that the observations involve no invasion of my rights of privacy nor do they incorporate any procedure or requirements which may be found morally or ethically objectionable. If, however, at any time I wish to terminate my participation in this study I have the right to do so without penalty.

If I have any questions about this study, I should feel free to ask them now or anytime throughout the study by contacting:

Dr. Richard Grace
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I know that I can report any objections to the study either orally or in writing to:

Dr. Ann Baldwin Taylor, IRB Chair
at0j@andrew.cmu.edu
Carnegie Mellon University
5000 Forbes Avenue, Warner Hall #405
Pittsburgh, PA 15213
Phone: 412-268-4727

Purpose of the Study:

I understand that I will be participating in testing a drowsiness detection and interface device. I understand that I will receive a briefing and then repeatedly experience the warning system components in a stationary truck cab and a desktop simulated driving environment within the context of a focus group over an eight hour period. I understand that I may verbalize my observations of the DDI. I understand that the components of the drowsiness detection and interface device may have some or all of the following: 1) Visual gauge 2) Audible tones that are typically 1000 Hz square waves pulsed at 3 Hz 3) Voice commands such as "Drowsiness has been detected. Please take appropriate action" 4) Vibrating seats, steering wheels or other equipment commonly found in a truck 5) Drowsiness countermeasures that typically include exercise, social interaction, fresh air or peppermint scents. I understand that this focus group session will also be recorded/videotaped and that I will receive $200 for this experimental session that will last approximately eight hours.

I understand that the following procedure will be used to maintain my anonymity in analysis and publication/presentation of any results. My observations will be assigned a number; names will not be recorded. The researchers will save data and videotape files by number, not by name. Only members of the research group will view that tape. The videotapes and data records will be stored in locked files by researchers assigned by Dr. Grace. No other researchers will have access to these files.

Optional Permission: I understand that the researchers may want to use a short portion of a video for illustrative reasons in presentations of this work in specific meetings or other public outlets (i.e. professional meetings, publications and/or news media releases). I give my permission to do so provided that my name will not be used in the context of such an illustration.

______ YES ______ NO (Please initial here __________)

I understand that in signing this consent form, I give Dr. Grace and his associates permission to present this work in written and oral form without further permission from me.

Name (please print)	Signature
Telephone	Date
Witness	Date
Investigator	Date

B DESIGN GROUP: BRIEFING

Slide 1

DROWSY DRIVER DETECTION AND WARNING SYSTEM FOR COMMERCIAL MOTOR VEHICLE DRIVERS

Typically less than load, overnight, out and back truck drivers, for example, Fed Ex route from here to Harrisburg and back, who are fighting progressive drowsiness

Slide 2

MEASURE EFFECTIVENESS

Against Driver Behavior

DETERMINE PERCLOS LOGIC

Tolerance for false alarms

REDESIGN THE INTERACTION

User centered

Slide 3

PERCLOS: Proportion of time that eyes are closed over a specified period.

CAMERA: Captures whether or not the eyes are open.

Slide 4

PAST RESEARCH

Audio: tone and voice

Visual: usually LEDs

Haptic: seat back, seat pan, directional, steering column

Olfactory: blast a scent

Behavioral: chewing gum, stimulants, cold air, radio, physical movement etc.

Slide 5

PAST RESEARCH

Appropriate/Inappropriate

Annoying/Tolerable

Imminent/Cautionary Warnings

Acceptable/Unacceptable

Benefits/Risks

Integrated/Stand Alone

Slide 6

OUR PROCESS

Literary reviews

Brainstorming

Usability design research

Human factors research

Field work

Concepting

Slide 7

SOCIAL INTERACTION

CHOICE

ENGAGEMENT

INTEGRATION

DRIVER AWARENESS

ASSOCIATION

C DESIGN GROUP: INTERACTION FLOWS

Interaction Flow Response Form

HIGH-LEVEL USER INTERACTION MODELS

We will walkthrough four user interaction models and preliminary visual concepts that support these models, one at a time. You will be asked to evaluate each concept against defined design principles and provide feedback during the discussion. Please remain focused on the possible interactions and do not provide feedback specific to the visuals (e.g., make it big and red) during the discussion. If you cannot resist sharing a specific visual for an interface, please draw or note it on the scrap paper provided to you in your clipboard.

The following 10 user-centered design principles were adapted from Patrick Jordan's book *An Introduction to Usability.* They were submitted as part of our operating hypotheses and have been guiding the design process. Please use this top sheet for easy reference.

User Control
How much power or perceived power does the user have over their interaction with the system?

Consistency
How familiar are the controls? For example, does a volume knob behave the way a user would expect?

Compatibility
How similar is the system to other like systems?

User Resources
Does the interaction require capabilities or skills that are beyond the user's limits, especially while driving?

Feedback
Does the system provide enough feedback in response to user actions?

Errors
Does the model minimize the chances of user errors and allow for easy recovery?

Visual Clarity
Is the interface clear, concise, and easy to see and use?

Prioritization
Do the hierarchy and control clusters make sense? Is the functionality clear?

Explicitness
Are there cues that provide clear direction to the user about how to operate the system?

Tech Transfer
Can the system be easily extended beyond the original user base and functionality?

Model One: Audio Only

Circle your rating choice for *all ten categories*.

Design Principles	Degree to Principle is Addressed									
	Not at all									Very
User Control	1	2	3	4	5	6	7	8	9	10
Consistency	1	2	3	4	5	6	7	8	9	10
Compatibility	1	2	3	4	5	6	7	8	9	10
User Resources	1	2	3	4	5	6	7	8	9	10
Feedback	1	2	3	4	5	6	7	8	9	10
Errors	1	2	3	4	5	6	7	8	9	10
Visual Clarity	1	2	3	4	5	6	7	8	9	10
Prioritization	1	2	3	4	5	6	7	8	9	10
Explicitness	1	2	3	4	5	6	7	8	9	10
Tech Transfer	1	2	3	4	5	6	7	8	9	10

Model Two: Hierarchy
Circle your rating choice for *all ten categories*.

Jordan's Principles	Degree to Principle is Addressed Not at all									Very
User Control	1	2	3	4	5	6	7	8	9	10
Consistency	1	2	3	4	5	6	7	8	9	10
Compatibility	1	2	3	4	5	6	7	8	9	10
User Resources	1	2	3	4	5	6	7	8	9	10
Feedback	1	2	3	4	5	6	7	8	9	10
Errors	1	2	3	4	5	6	7	8	9	10
Visual Clarity	1	2	3	4	5	6	7	8	9	10
Prioritization	1	2	3	4	5	6	7	8	9	10
Explicitness	1	2	3	4	5	6	7	8	9	10
Tech Transfer	1	2	3	4	5	6	7	8	9	10

Model Three: Sensitivity Setting
Circle your rating choice for *all ten categories*.

Jordan's Principles	Degree to Principle is Addressed Not at all									Very
User Control	1	2	3	4	5	6	7	8	9	10
Consistency	1	2	3	4	5	6	7	8	9	10
Compatibility	1	2	3	4	5	6	7	8	9	10
User Resources	1	2	3	4	5	6	7	8	9	10
Feedback	1	2	3	4	5	6	7	8	9	10
Errors	1	2	3	4	5	6	7	8	9	10
Visual Clarity	1	2	3	4	5	6	7	8	9	10
Prioritization	1	2	3	4	5	6	7	8	9	10
Explicitness	1	2	3	4	5	6	7	8	9	10
Tech Transfer	1	2	3	4	5	6	7	8	9	10

Model Four: Modality
Circle your rating choice for *all ten categories*.

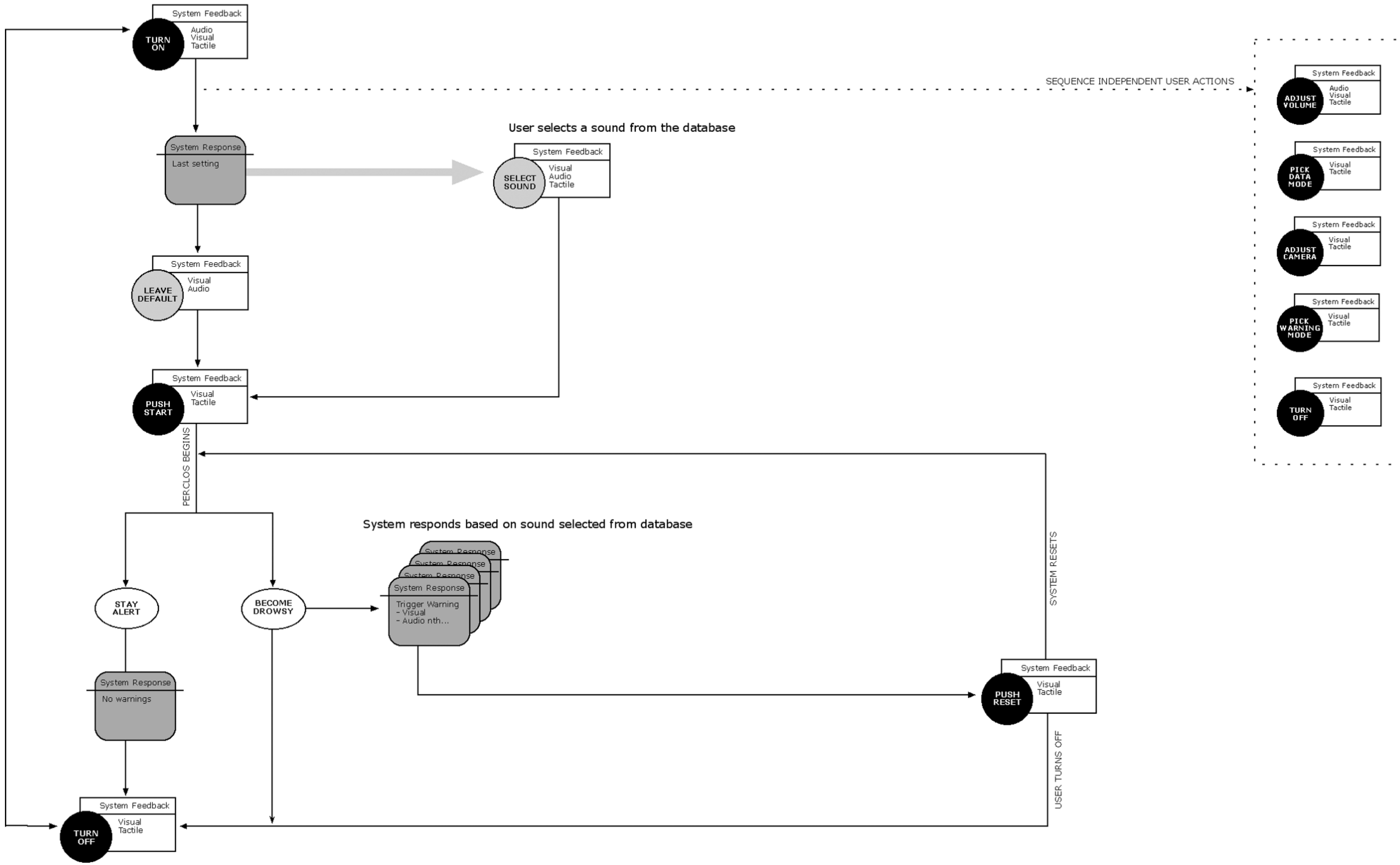
Jordan's Principles	Degree to Principle is Addressed Not at all									Very
User Control	1	2	3	4	5	6	7	8	9	10
Consistency	1	2	3	4	5	6	7	8	9	10
Compatibility	1	2	3	4	5	6	7	8	9	10
User Resources	1	2	3	4	5	6	7	8	9	10
Feedback	1	2	3	4	5	6	7	8	9	10
Errors	1	2	3	4	5	6	7	8	9	10
Visual Clarity	1	2	3	4	5	6	7	8	9	10
Prioritization	1	2	3	4	5	6	7	8	9	10
Explicitness	1	2	3	4	5	6	7	8	9	10
Tech Transfer	1	2	3	4	5	6	7	8	9	10

Model One: Audio Only

Discussion Points

- Do you think that drivers require continuous visual feedback about their drowsiness level separate from the warning system?
- Does the warning system need to be multi modal, i.e., provide a visual warning in conjunction with the audio warning, or is the audio warning enough?
- Can the system induce behavior through association? For example, using suggestive sounds such as coffee percolating as a cue to stop and ingest caffeine.
- How many sounds need to be in the system database? Does it need to be expandable?
- As an added feature, do you think that the drivers would like the ability to record their own sounds?

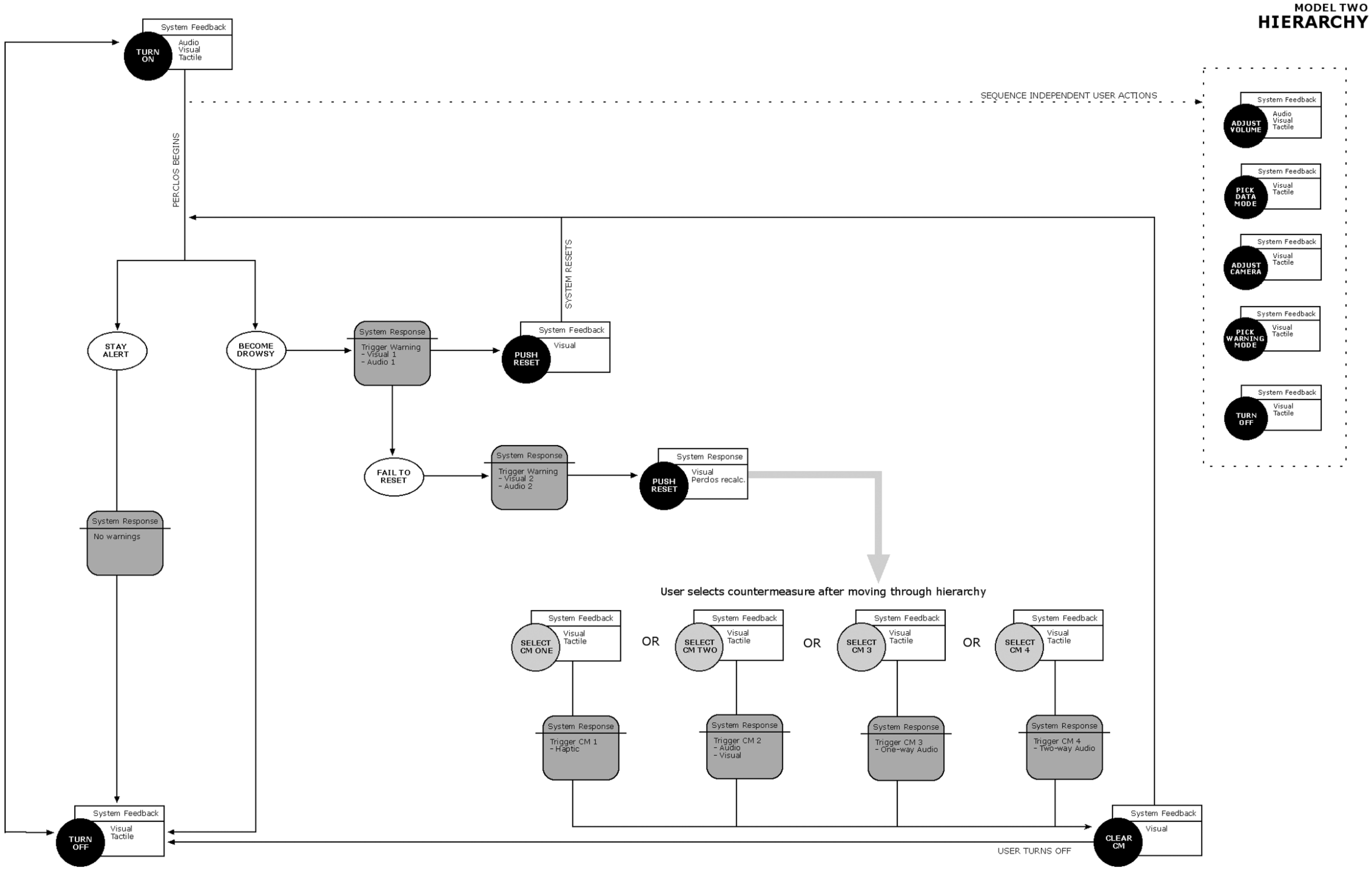
MODEL ONE
AUDIO ONLY



Model Two: Hierarchy

Discussion Points

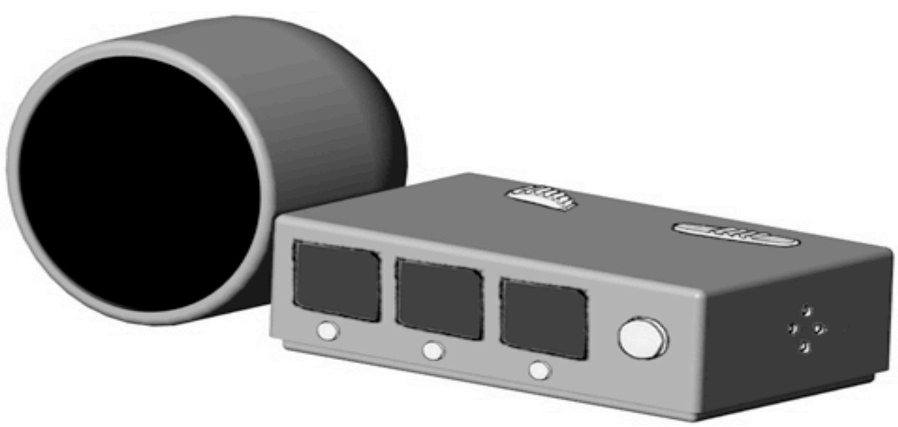
- Is it problematic that the countermeasure functions are inaccessible unless the driver progresses through the warning hierarchy through increased drowsiness?
- When the driver misses the first warning and pushes reset after the second warning, should they be able to opt out of using the countermeasures?
- Countermeasure 2 could take the form of a game, such as a visual and audible simon sez or an alertness game that requires a response. What are the issues surrounding such forms of engagement?
- Countermeasures 3 and 4 propose voice interaction with a remote person that is either driver initiated or system initiated. Is one preferable over the other?


MODEL TWO
HIERARCHY
System Feedback
TURN ON
Audio
Visual
Tactile
SEQUENCE INDEPENDENT USER ACTIONS
PERCLOS BEGINS
SYSTEM RESETS
STAY ALERT
BECOME DROWSY
System Response
Trigger Warning
- Visual 1
- Audio 1
System Feedback
PUSH RESET
Visual
FAIL TO RESET
System Response
Trigger Warning
- Visual 2
- Audio 2
System Response
PUSH RESET
Visual
Perclos recalc.
System Response
No warnings
User selects countermeasure after moving through hierarchy
System Feedback
SELECT CM ONE
Visual
Tactile
OR
System Feedback
SELECT CM TWO
Visual
Tactile
OR
System Feedback
SELECT CM 3
Visual
Tactile
OR
System Feedback
SELECT CM 4
Visual
Tactile
System Response
Trigger CM 1
- Haptic
System Response
Trigger CM 2
- Audio
- Visual
System Response
Trigger CM 3
- One-way Audio
System Response
Trigger CM 4
- Two-way Audio
System Feedback
TURN OFF
Visual
Tactile
System Feedback
CLEAR CM
Visual
USER TURNS OFF
System Feedback
ADJUST VOLUME
Audio
Visual
Tactile
System Feedback
PICK DATA MODE
Visual
Tactile
System Feedback
ADJUST CAMERA
Visual
Tactile
System Feedback
PICK WARNING MODE
Visual
Tactile
System Feedback
TURN OFF
Visual
Tactile

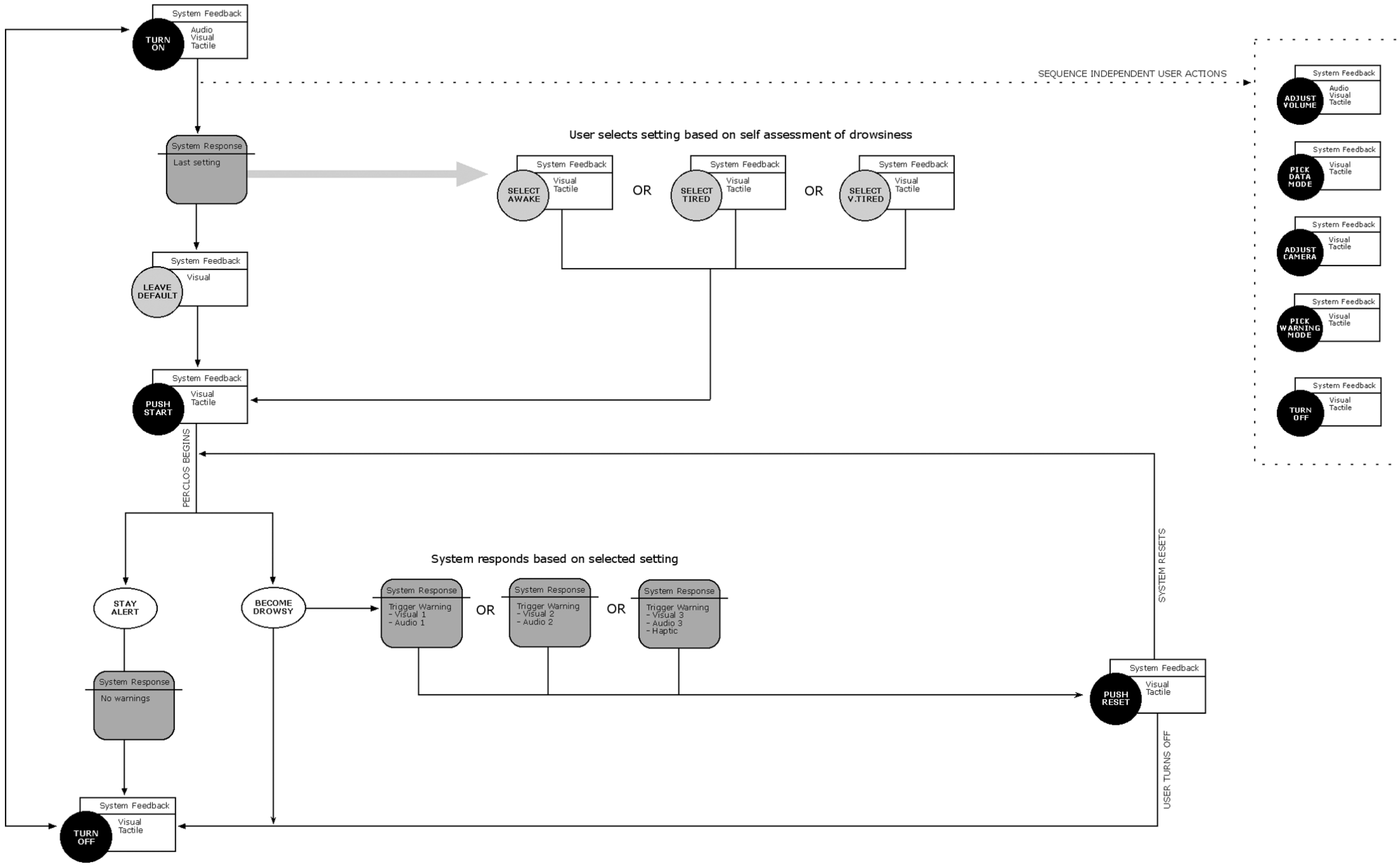
Model Three: Sensitivity Setting

Discussion Points

- How important is it to provide a default setting or display the last used setting when the system is turned on?
- What language best speaks to the drivers for choosing a setting, for example:
  awake, tired, very tired? alert, drowsy, very drowsy? one, two, three?
- Would the use of icons be appropriate? Generally speaking, would they need to be used in conjunction with words?
- Scenario: the system initiates an audio warning for the very tired setting by sending a signal to an outside source and that source contacts the driver, for example, an On-star type system engages the radio and an operator assists the driver in finding a rest area. Would this be too intrusive or startling? Would too much time elapse before the warning?



MODEL THREE
SENSITIVITY SETTING



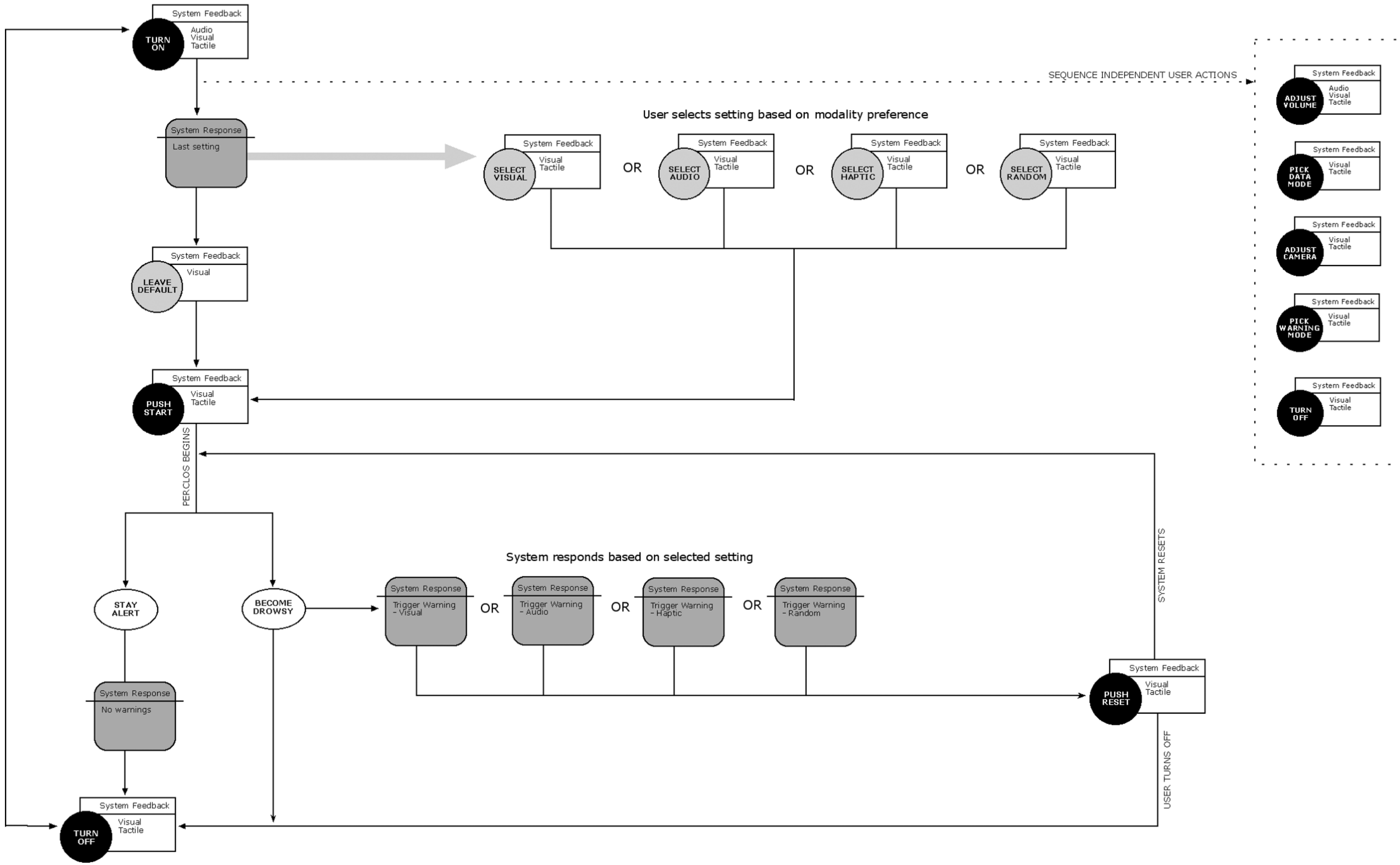
Model Four: Modality

Discussion Points

- What are the pros and cons for allowing the user to select the channel for feedback?
- What language best speaks to the drivers for choosing a setting based on the type of warning they want to receive, for example:

  see, hear, feel? visual, audio, vibro? one, two, three?
- Is it necessary to provide the choice of random warnings, which lets the system choose the type of warning to issue from warning to warning?
- Should the user be allowed to select more than one mode of warning? For example, see and hear?
- Should the system automatically reset after issuing a warning or should the driver be required to respond? Or both, with the reset button as an added feature to halt a warning before the system does?

MODEL FOUR
MODALITY



Expert Written Comments on Interaction Flow Model Forms

These tables are not exact transcripts. They are applicable comments gleaned from the total comments. Each listing includes identification of which expert the comment originated from.

Model One: Audio Only

E1	LCD & LED There's no progression of time with LCD. Self-connecting Beeps—calls for reset
E2	System should only turn on when truck is running so that users can adjust volume appropriately. It should turn off when truck turns off too. Sounds can be loud and friendly (Let's get ready to rumble?) Human voice for sound? Siren for severe warning Puff of air on eyelids?
E3	N/A
E4	Tried to see whole scale throughout. No grade inflation. :) Consistency: does this apply to alarm variability? Random? User Resources: very concerned with user ability to select appropriate alarm Errors: too easy to leave off. What knowledge does the user have to assess alarm types and levels? Ideas: Dynamic feedback on audio Passive functionality with option for manual override Can the user select an ignition triggered start? Can the driver be given feedback at the end of the drive (positive?)? Reset should not cycle the user back to same alarm level. Resets should be counted and alarm severity adjusted accordingly as driver resets more often. Concerned about users being presented with settings.
E5	Would also be visual if LCD comes on at alarm onset. Progressively louder? No. I feel there should be at least two forms of feedback—redundancy. Simplicity is good. LCD may be overkill depending on implementation. May want a lock feature during calibration (hardware or software), physical setup. Driver confidence. Make sure system doesn't move during myriad vibrations. I like customization of sound.
E6	Sound—function of waking, alarm sound—choice Back up to miss?

E7	Working themes addressed: association—alert could be personally meaningful engagement—sound can improve alerting task Feedback bimodal Compatibility: don't know Other ideas: on/off reset button

Model Two: Hierarchy

E1	Feedback: what level of sound is critical? Going thru two levels is not desirable. High level of error what is the prioritization must go thru 2^{nd} alarm to get to options?
E2	Truck should be on before system can start. What is data collection mode and why would users use it?
E3	N/A
E4	Select a countermeasure interesting – should select Need countermeasure of not driving, getting coffee More levels of alarm Game.
E5	Idea of outside person contacting driver is interesting. Turns system from product to service company. Interaction; don't understand why I get <u>pushed</u> into countermeasure if I hit second reset. Form of punishment. Concerning countermeasures: haptic is interesting but adds new issues. User is asked to choose countermeasure (tougher mental task) as they are at the height of tiredness. Make user tasks progressively less taxing as sleep onsets, not more.
E6	Second level of alarm allows control. Alternatives (countermeasures) – opportunities.
E7	Working themes addressed: engagement—but too much? Social interaction—outside caller could be bad Not a pure hierarchy Compatibility: don't know. One-way audio and two-way audio may be unsafe: callers do not know context of driver Other ideas: too much interaction engaging outside callers may be unsafe high potential for drivers to make errors in operation would need a better understanding of user behavior to know if this is desirable

Model Three: Sensitivity Setting

E1	What are the levels? No progression as it stands
E2	Truck should be on before users can start system (volume calibration) Levels of warning should increase as system detects progressive drowsiness
E3	N/A
E4	Errors: last setting is not applicable to this design Explicitness: self selecting possibly over emphasized Presumption in same state How about a: reset false positive (help system make adjustments) reset yes I'm sleepy (tell it to be more aggressive)
E5	I like the sensitivity setting capability. As a user it would probably be as much a less annoying setting/more annoying setting…if it is like a radar detector. However, this would make user more inclined to choose least annoying setting, which may be the opposite of their alertness state. Automate sensitivity. You're collecting all of this rich PERCLOS data. Use it to calibrate system and influence feedback.
E6	Perceived vs Actual
E7	Working themes addressed: choice association Compatibility: don't know. Letting drivers have agency in process may be good. Reset? Tune out? Other ideas: do drivers want to collect data on themselves? Is variable PERCLOS setting useful? Is feedback in terms of numeric data useful? Will system progress by itself or will user select it? Is it bad for users to select?

Model Four: Modality

E1	Why Random? Explicitness: must use Consistent: system response consistent with setting. Don't like random however. User Resources: too many selection buttons Feedback: seems okay. No variable input settings except volume Errors: must turn off to pick system setting. Don't like that. Visual clarity: no visual reference to level of tiredness
E2	Truck should be on Warning levels should be progressive

E3	N/A
E4	Random is a concern Select all system Are you training people not to blink? Are blink rates different for different people? Need to prompt a sleepy rating again on trip
E5	Don't like only one form of feedback. Need redundancy. Don't like random feature; some feedback must be better than others, plus there is no expectation setting. don't know what you're (user) waiting for. Don't think four choices is necessary This isn't like picking out clothes where there needs to be highly individualized options. Don't trade off quality of warning for customization. If there are one or two warnings that are better than others, don't let user choose a less good warning. Like haptic because of its immediacy/intimacy to user. More challenging implementation. Audio can get drowned out.
E6	Performance object/Preference
E7	Compatibility: don't know. Modality appropriateness may be an issue Other issues: could include varying levels within each mode of feedback? Are interruptions in different modes more successful with different tasks?

Additional comments independent of forms:

Indicate a false positive
Have a tell me a story option Social interaction aspect/empathy with other drivers interchangeable disks (can add to their collection) record other drivers' stories and play back try tapping your feet, lift your left arm up, lift your right arm up Jokes, riddles (hey did you hear the one about the one-armed thief) Our estimation of your alert level (like a gas gauge or something)
Perhaps bundle alertness functionality with another business relationship/product like the vibrating chair
Overall goal: drowsy signaling vs. stay awake vs. pull over
Do they (drivers) want to collect information about themselves?
Are some alerts more effective?
Algorithms to select warning and a bypass mode
Progressively less taxing
Assistive product, not stigmatizing
Camera analogy: combination of simple settings and variable automated warnings
Default setting? Why presumption that I am in the same state.
Product semantics, motivation, compliance, monitoring, user vs. customer
What if no on? Engine interconnect
Some positive feedback about end of drive?

What if new turnoff?
Volume control and sound? What criteria does the driver have to assess volume and sound types?
Reflection of face—lean forward to adjust? Is that accurate? How do they know about this reflection positioning thing?
Can the alarm be gradated? Words in screen?
Should the device function differently after a reset?
Day in the life journal—does system accurately detect drowsiness
Other biometric info?
Does it adapt? What are patterns of drowsiness?
Can system learn? Is it consistent per user? Across users?

D DESIGN GROUP: SOUNDS

Sound Response Form

SOUNDS

You will hear a sound presented a single time. Please circle your rating choice for *all four categories* for each sound that you hear.

You will then hear the same sound presented three more ways. *After* hearing all of the presentation methods, select the method that you feel is the most appropriate for the context of this application.

Sound		**Not at all**									**Very**
1	Aggressive	1	2	3	4	5	6	7	8	9	10
	Percussive	1	2	3	4	5	6	7	8	9	10
	Suggestive	1	2	3	4	5	6	7	8	9	10
	Vocal	1	2	3	4	5	6	7	8	9	10
	Presentation	Single		Loop		Bass		Loop + Bass			
2	Aggressive	1	2	3	4	5	6	7	8	9	10
	Percussive	1	2	3	4	5	6	7	8	9	10
	Suggestive	1	2	3	4	5	6	7	8	9	10
	Vocal	1	2	3	4	5	6	7	8	9	10
	Presentation	Single		Loop		Bass		Loop + Bass			
3	Aggressive	1	2	3	4	5	6	7	8	9	10
	Percussive	1	2	3	4	5	6	7	8	9	10
	Suggestive	1	2	3	4	5	6	7	8	9	10
	Vocal	1	2	3	4	5	6	7	8	9	10
	Presentation	Single		Loop		Bass		Loop + Bass			
4	Aggressive	1	2	3	4	5	6	7	8	9	10
	Percussive	1	2	3	4	5	6	7	8	9	10
	Suggestive	1	2	3	4	5	6	7	8	9	10
	Vocal	1	2	3	4	5	6	7	8	9	10
	Presentation	Single		Loop		Bass		Loop + Bass			
5	Aggressive	1	2	3	4	5	6	7	8	9	10
	Percussive	1	2	3	4	5	6	7	8	9	10
	Suggestive	1	2	3	4	5	6	7	8	9	10
	Vocal	1	2	3	4	5	6	7	8	9	10
	Presentation	Single		Loop		Bass		Loop + Bass			

Sound		Not at all									Very
6	Aggressive	1	2	3	4	5	6	7	8	9	10
	Percussive	1	2	3	4	5	6	7	8	9	10
	Suggestive	1	2	3	4	5	6	7	8	9	10
	Vocal	1	2	3	4	5	6	7	8	9	10
	Presentation	Single		Loop		Bass		Loop + Bass			
7	Aggressive	1	2	3	4	5	6	7	8	9	10
	Percussive	1	2	3	4	5	6	7	8	9	10
	Suggestive	1	2	3	4	5	6	7	8	9	10
	Vocal	1	2	3	4	5	6	7	8	9	10
	Presentation	Single		Loop		Bass		Loop + Bass			
8	Aggressive	1	2	3	4	5	6	7	8	9	10
	Percussive	1	2	3	4	5	6	7	8	9	10
	Suggestive	1	2	3	4	5	6	7	8	9	10
	Vocal	1	2	3	4	5	6	7	8	9	10
	Presentation	Single		Loop		Bass		Loop + Bass			
9	Aggressive	1	2	3	4	5	6	7	8	9	10
	Percussive	1	2	3	4	5	6	7	8	9	10
	Suggestive	1	2	3	4	5	6	7	8	9	10
	Vocal	1	2	3	4	5	6	7	8	9	10
	Presentation	Single		Loop		Bass		Loop + Bass			
10	Aggressive	1	2	3	4	5	6	7	8	9	10
	Percussive	1	2	3	4	5	6	7	8	9	10
	Suggestive	1	2	3	4	5	6	7	8	9	10
	Vocal	1	2	3	4	5	6	7	8	9	10
	Presentation	Single		Loop		Bass		Loop + Bass			
11	Aggressive	1	2	3	4	5	6	7	8	9	10
	Percussive	1	2	3	4	5	6	7	8	9	10
	Suggestive	1	2	3	4	5	6	7	8	9	10
	Vocal	1	2	3	4	5	6	7	8	9	10
	Presentation	Single		Loop		Bass		Loop + Bass			

Sound		Not at all									Very
12	Aggressive	1	2	3	4	5	6	7	8	9	10
	Percussive	1	2	3	4	5	6	7	8	9	10
	Suggestive	1	2	3	4	5	6	7	8	9	10
	Vocal	1	2	3	4	5	6	7	8	9	10
	Presentation	Single		Loop		Bass		Loop + Bass			
13	Aggressive	1	2	3	4	5	6	7	8	9	10
	Percussive	1	2	3	4	5	6	7	8	9	10
	Suggestive	1	2	3	4	5	6	7	8	9	10
	Vocal	1	2	3	4	5	6	7	8	9	10
	Presentation	Single		Loop		Bass		Loop + Bass			
14	Aggressive	1	2	3	4	5	6	7	8	9	10
	Percussive	1	2	3	4	5	6	7	8	9	10
	Suggestive	1	2	3	4	5	6	7	8	9	10
	Vocal	1	2	3	4	5	6	7	8	9	10
	Presentation	Single		Loop		Bass		Loop + Bass			
15	Aggressive	1	2	3	4	5	6	7	8	9	10
	Percussive	1	2	3	4	5	6	7	8	9	10
	Suggestive	1	2	3	4	5	6	7	8	9	10
	Vocal	1	2	3	4	5	6	7	8	9	10
	Presentation	Single		Loop		Bass		Loop + Bass			
16	Aggressive	1	2	3	4	5	6	7	8	9	10
	Percussive	1	2	3	4	5	6	7	8	9	10
	Suggestive	1	2	3	4	5	6	7	8	9	10
	Vocal	1	2	3	4	5	6	7	8	9	10
	Presentation	Single		Loop		Bass		Loop + Bass			
17	Aggressive	1	2	3	4	5	6	7	8	9	10
	Percussive	1	2	3	4	5	6	7	8	9	10
	Suggestive	1	2	3	4	5	6	7	8	9	10
	Vocal	1	2	3	4	5	6	7	8	9	10
	Presentation	Single		Loop		Bass		Loop + Bass			

Sound		Not at all									Very
18	Aggressive	1	2	3	4	5	6	7	8	9	10
	Percussive	1	2	3	4	5	6	7	8	9	10
	Suggestive	1	2	3	4	5	6	7	8	9	10
	Vocal	1	2	3	4	5	6	7	8	9	10
	Presentation	Single		Loop		Bass		Loop + Bass			
19	Aggressive	1	2	3	4	5	6	7	8	9	10
	Percussive	1	2	3	4	5	6	7	8	9	10
	Suggestive	1	2	3	4	5	6	7	8	9	10
	Vocal	1	2	3	4	5	6	7	8	9	10
	Presentation	Single		Loop		Bass		Loop + Bass			
20	Aggressive	1	2	3	4	5	6	7	8	9	10
	Percussive	1	2	3	4	5	6	7	8	9	10
	Suggestive	1	2	3	4	5	6	7	8	9	10
	Vocal	1	2	3	4	5	6	7	8	9	10
	Presentation	Single		Loop		Bass		Loop + Bass			

Suggest more or different categories:

Suggest more or different sounds:

Extended Discussion of Sound Categorization and Ratings

Presentation type was quantified (Single = 1, Loop = 2, Bass = 3, Loop+Bass = 4) and included with the ratings in a correlation analysis. Significance was computed using a *Fisher's r to z* (111 observations, 1 missing value).

As seen in Table 2.1, there appeared to be only moderate correlations between rating categories or Presentation type (Single = 1, Loop = 2, Bass = 3, Loop+Bass = 4). Sounds with high Suggestive ratings also seemed to be rated highly for Aggressive and Vocal, although Vocal and Aggressive were not linked. The sounds with high Vocal ratings were rated low for Percussive.

Table 2.1. Ratings and presentation choice correlations

	Aggressive	Percussive	Suggestive	Vocal	Presentation
Aggressive	1.00	.15	**.28**	.11	-.12
Percussive		1.00	.04	**-.35**	.14
Suggestive			1.00	**.21**	-.15
Vocal				1.00	**-.33**
Presentation					1.00

$p < .05$

The only significant correlation with Presentation occurred with the Vocal rating. Presentation type trended towards Single for high Vocal ratings. This suggests that the more intrusive forms of presentation are less desirable for the sounds with more vocal natures.

There was concern that the early sounds would be rated higher in the Aggressive category due to unfamiliarity with the context and test method. Examination of the results suggests that the Practice sounds seem to have been effective in eliminating any potential bias towards early rating of sounds as being overly aggressive. Aggressive ratings in the Test portion appeared to be appropriately variable. The other ratings also seemed to have no obvious presentation order trend.

Two of the top three aggressive sounds, buzzthruloud and googler, were not surprising in that they were explicitly chosen for their grating, annoying nature. The other sound was the robot from *Lost in Space* saying “Warning! Warning! Warning!” (Figure D.1). The two least aggressive sounds were an electronic chime (notify) and a single beat musical chime (temple). The other chime presented to the experts, a grandfather clock chime (chimes), also had a low aggressive rating.

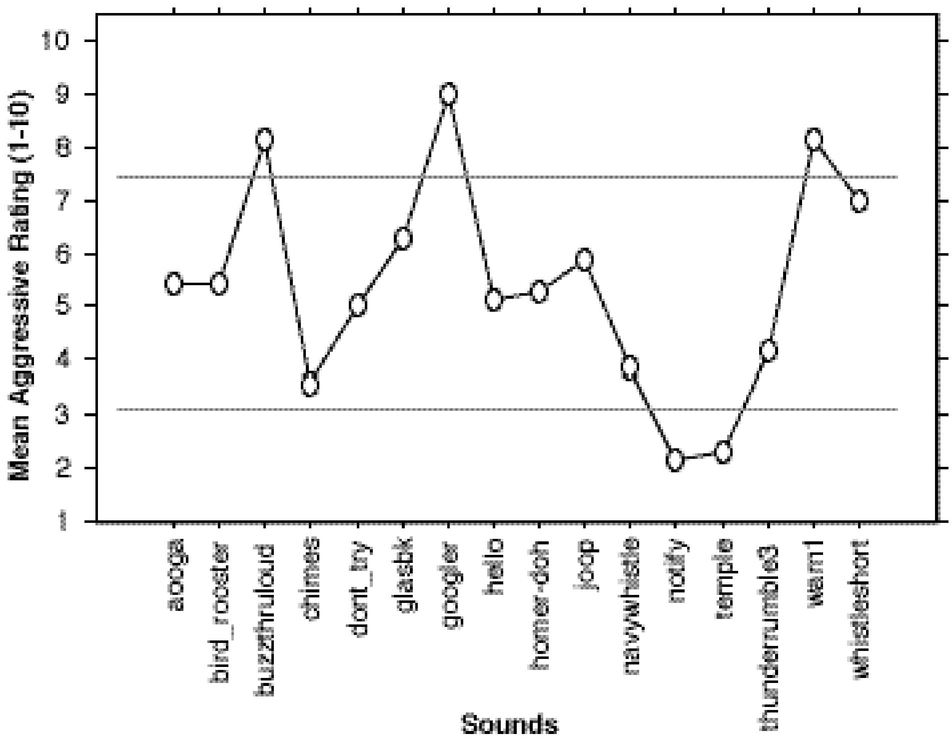


Figure D.1. Mean aggressive ratings for each sound

The percussive ratings tended to be uniformly low, with only two sounds in the upper half of the possible range (Figure D.2). Furthermore, four sounds were marked as being in the first unit of the scale (1-2) implying almost no percussive quality. The top two sounds were an electronic beat with a reverb effect (joop) and an electronic chime (notify).

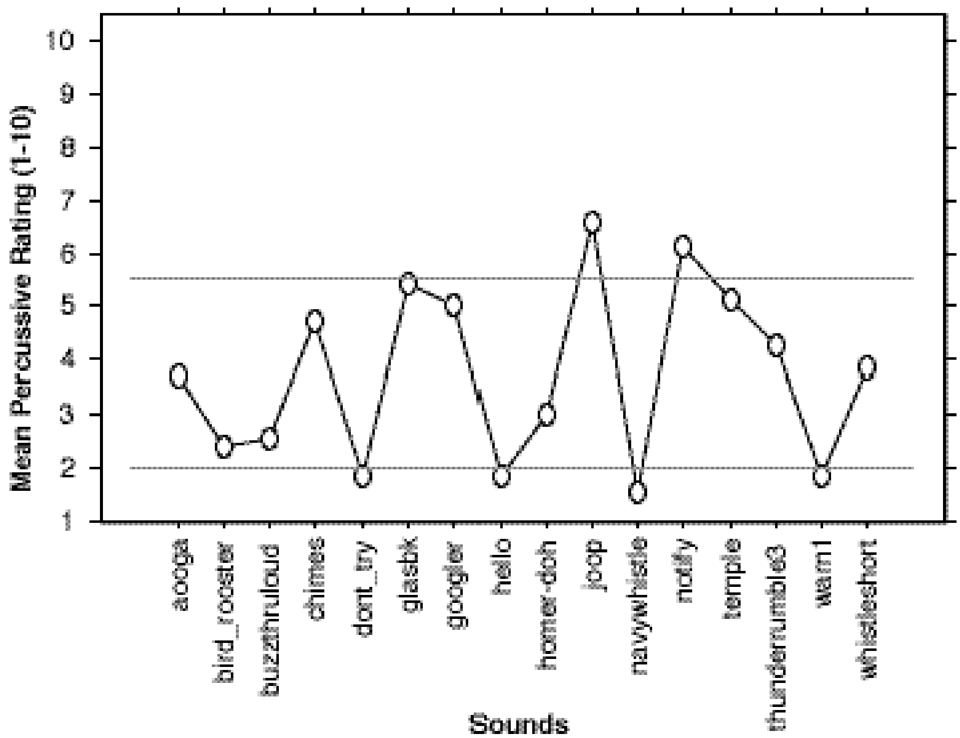


Figure D.2. Mean percussive ratings for each sound

The top three sounds for Suggestive ratings were a rooster crowing, a glass breaking, and the previously mentioned robot from *Lost in Space* (Figure D.3). The next three were Homer Simpson saying “Doh!”, a short whistle, and thunder rumbling. For all these sounds there is a distinct connotation of a freshly discovered problem or event that needs to be urgently addressed. This implication may be what influenced the positive correlation between Suggestive and Aggressive ratings.

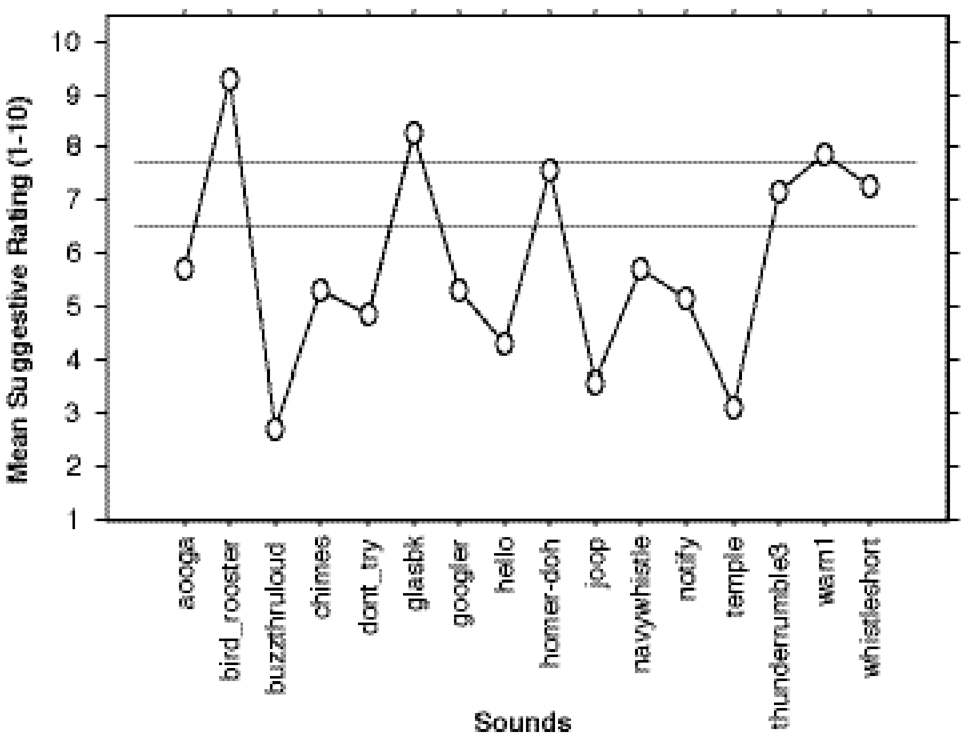


Figure D.3. Mean suggestive ratings for each sound

The experts clearly made full use of the vocal scale as the mean vocal ratings for the sounds were spread across the full range (Figure D.4). Two sounds, a glass breaking and a single beat musical chime (temple) received a mean rating of 1 which had a questionnaire anchor of "Not at all." There was also an obvious separation between the top four rated sounds and the rest of the set. These sounds were all people speaking. These were Homer Simpson's "Doh!" the robot from *Lost in Space*, Grandpa Simpson shouting "Hello!" and Eric Idle saying "Don't try that." A rooster crowing was the sole sound in between these highly rated vocal sounds and the remainder of the sound set.

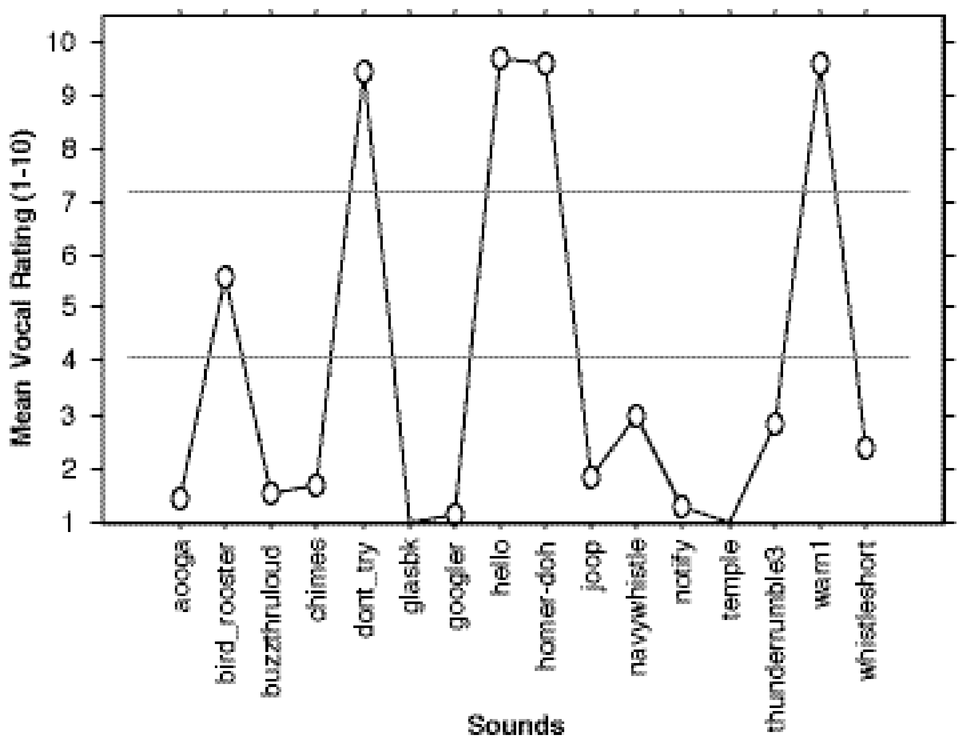


Figure D.4. Mean vocal ratings for each sound

E DESIGN GROUP: SPOT VIBRATION

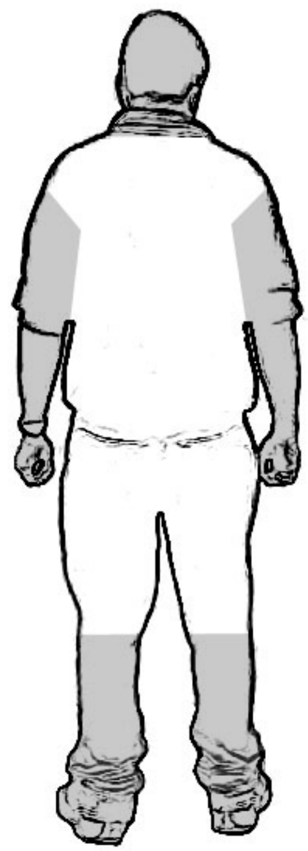
Spot Signaling Response Form

RANDOM SPOT SIGNALING VIA VIBRATION

You will have the opportunity to sit in a chair that has four examples of spot signaling: two rougher vibrations and two gentler vibrations in varying locations.

On the image below, please put a number where you think spot vibration would be effective and acceptable to the user. You can mark as many locations as you wish. Indicate your recommended vibration (rough or gentle) for each location or suggest something new. Do not select locations in the shaded areas.

Location	VIBRATION
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	



(circle one please)

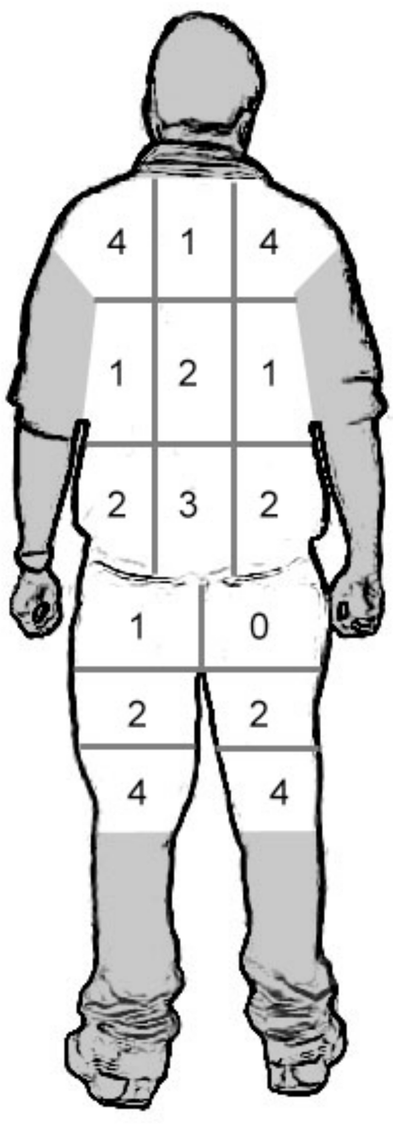
Do you think that spot signaling alone is enough to induce physical movement? Yes No

Do you think that adding audio cues would enhance usability? Yes No

Do you think that adding visual cues would enhance usability? Yes No

Random Spot Signaling Exploration Vibration Location Sums

The raw expert choices for suitable locations of spot vibration were classified into 15 regions (9 on the back and 6 on the legs). Locations that were marked on the questionnaire were scored as a 1 while unmarked locations were scored as a 0. Regions where experts voluntarily indicated that spot vibrations should not be used (e.g., "Not on the butt!") were scored as -1. An overall sum was computed for each region.



Written Expert Comments on Random Spot Signaling Exploration

Explore ramping, pulsing, etc.
[The low-back through buttocks area] should be avoided because of bowel functions, etc.
This was surprisingly effective
Not on the butt!
Maybe step the actions. Not both Immediately. [With respect to adding audio cues to the vibrations]
I would base this selection [of central mid-back, low-back, and mid-thigh] on: 1) centrality, 2) sensitivity of area (this is a combination of fatty and muscle mass analysis), 3) ability to hit the area or diverse population ranges and, 4) get good contact against this area
The tactile is actually quite audible [With respect to adding audio cues to the vibrations]
Alternate [left and right mid-back]
Probably useful to give this cue on one side [leg] only
People have different levels of body sensitivity
Not sure adding modes would be effective here, especially if sleepy, might confuse vibrations with something else [With respect to adding audio or visual cues to the vibrations]

F DRIVER GROUP: PROCEDURE DETAILS

Talking Points

These are some general items to keep in mind when talking with the drivers:

Process

[Do not judge driver actions or imply they may have done something wrong.]

Management will only see results that are anonymous and stripped of identifying remarks.

System Functionality

The system tracks eyelid closures only – it does not record pictures.

The system only works at night.

There will always be a visual warning.

There will always be a way to shut the system off.

Preventing all false alarms is not possible.

False alarms may occur when the driver rubs their eyes or looks away from the forward scene.

Cattleprods are not an option.

Drowsy Driving

The only remedy for drowsiness is sleep.

Shifting around in the seat has been seen to lessen drowsiness for short periods of time.

Caffeine has limited impact on drowsiness.

Briefing

Slide 1

DROWSY DRIVER MONITOR AND WARNING SYSTEM TO HELP WITH PROGRESSIVE DROWSINESS

Slide 2

PERCLOS: Proportion of time that eyes are closed over a specified period.

INFARED: Captures whether or not the eyes are open.

Slide 3

DROWSINESS CAUSES UP TO 35% OF ANNUAL TRUCK DRIVER DEATHS

Slide 4

IN ONE TEST, SOME DRIVERS DROVE FOR 3-30 SECONDS WITH THEIR EYES CLOSED.

WE HAVE ALL DONE THIS…

Slide 5

…BUT YOU DRIVE FOR A LIVING

• Interrupted Circadian rhythms

• Monotony and Darkness

• Low mental workload

• Schedules and deadlines

Slide 6

YOU ARE HERE TO HELP US DESIGN THE BEST SYSTEM POSSIBLE TO TEST ON THE ROAD, KNOWING THAT ONLY LONG-TERM SOLUTION IS SLEEP.

Slide 7

WHAT'S GOING ON TODAY

Fill in a questionnaire

Participate in a group discussion

Be interviewed

Work in teams

Participate in a closing group discussion

Questionnaire

Initials: ________ Age: __________ Estimated Annual Mileage: ______________________

Question		Strongly Disagree										Strongly Agree
1	I feel tired when I'm on the job	0	1	2	3	4	5	6	7	8	9	10
2	My job involves too little physical exertion	0	1	2	3	4	5	6	7	8	9	10
3	My job involves too little mental exertion	0	1	2	3	4	5	6	7	8	9	10
4	My schedule has enough time for adequate rest	0	1	2	3	4	5	6	7	8	9	10
5	I use my CB a lot while driving	0	1	2	3	4	5	6	7	8	9	10
6	I use my cell phone a lot while driving	0	1	2	3	4	5	6	7	8	9	10
7	I listen to the radio a lot while driving	0	1	2	3	4	5	6	7	8	9	10
8	I use an in-cab message center a lot while driving	0	1	2	3	4	5	6	7	8	9	10
9	I am often bored while driving	0	1	2	3	4	5	6	7	8	9	10

For the following questions, please write a brief response in the blanks provided.

(1) How many total hours of sleep do you get per day? ______________________

(2) Of this total, how long are your naps while working? ______________________

(3) What is your typical shift? *(Example: 8pm – 6am)* ______________________

(4) During what time of the work day are you most tired? *(Example: 6am)* ______________________

(5) What is the first thing you usually do when you start to feel tired while driving? ______________________

____

If that is not enough, what do you do next? ______________________

____

If that is not enough, what do you do next? ______________________

____

(6) Is there anything you could add to your truck that would help relieve drowsiness? ______________________

____

____

(7) What do you usually do when you feel tired for a long period of time while driving? ________________

____

____

(8) I nod off momentarily while driving: *(check one)*

Each shift	Several times a week	Several times a month	Several times a year	Never
[ ]	[ ]	[ ]	[ ]	[ ]

(9) The time it takes me to commute home from work is: *(check one)*

Less than 15 minutes	15-30 minutes	31-45 minutes	46 minutes to an hour	More than an hour
[ ]	[ ]	[ ]	[ ]	[ ]

If more than an hour, please enter amount here: ________________________________

(10) Have you ever taken a break from professional driving? If so, for how long?

____

(11) How long have you been driving for your current employer?

____

(12) Do you use a radar detector?

Never	Rarely	Often	All the time, highway only	All the time, highway & city
[ ]	[ ]	[ ]	[ ]	[ ]

If yes, do you change the sensitivity settings at lease once a shift? ____________________

(13) If you use a CB while working, who do you usually speak with? ______________________

____

(14) If you use a cell phone while working, who do you usually speak with? __________________

____

(15) If you use a radio while working, what do you usually listen to? *(Example: Music, books on tape)*

____

(16) What do you think the value is of a drowsy driver detection and warning system? Please explain.

____

____

____

(17) What type of truck do you drive most often? Make? Model? Year?

____

(18) Does it have any of the following systems on board? If yes, how often do you use them?

GPS tracking ______________________________

A message system (aka Qualcomm) ________________________

Collision warning ______________________________

Adaptive Cruise Control (aka SmartCruise) ____________________

Other (describe) ______________________________

____

(19) Are any of these mandated by your employer? If yes, please list which ones.

____

____

Critical Incident Experimenter Sheet

CRITICAL INCIDENT INTERVIEWS

Ask the driver to recall a specific critical incident of driving while drowsy. It need not be the worst case. If that is what they start with, let them describe the incident, ask our questions, then ask them to describe another specific incident of driving while drowsy that is more typical. There is nothing wrong with collecting information about more than one incident.

The drivers may answer most of these in the course of telling their story.

- ❑ What speed were you going?
- ❑ What time of the day or night was it?
- ❑ At what point during your drive did this happen?
- ❑ Where were you going?
- ❑ How long was the route?
- ❑ Is this your usual route? If not, how was it different?
- ❑ Was this an LTL run?
- ❑ Were you driving with someone?
- ❑ How much sleep did you get before this drive?
- ❑ What were the road conditions?
- ❑ What were the traffic conditions?
- ❑ What type of road was it? eg., curvy, straight, two-lane, etc.
- ❑ Were you tired when you started?
- ❑ How long did you keep driving?
- ❑ What did you do to try to become more alert?
- ❑ What else would have helped you become more alert?
- ❑ After the incident, were you more alert? How long did this "adrenaline effect" last?
- ❑ Were you more tired once the adrenaline wore off?
- ❑ When you stopped driving was it because you were drowsy or another reason?
- ❑ Did you nap at all when you stopped?
- ❑ Do you think that you drove at all with your eyes closed? If so, for how long?
- ❑ Were you drowsy at the end of your drive?

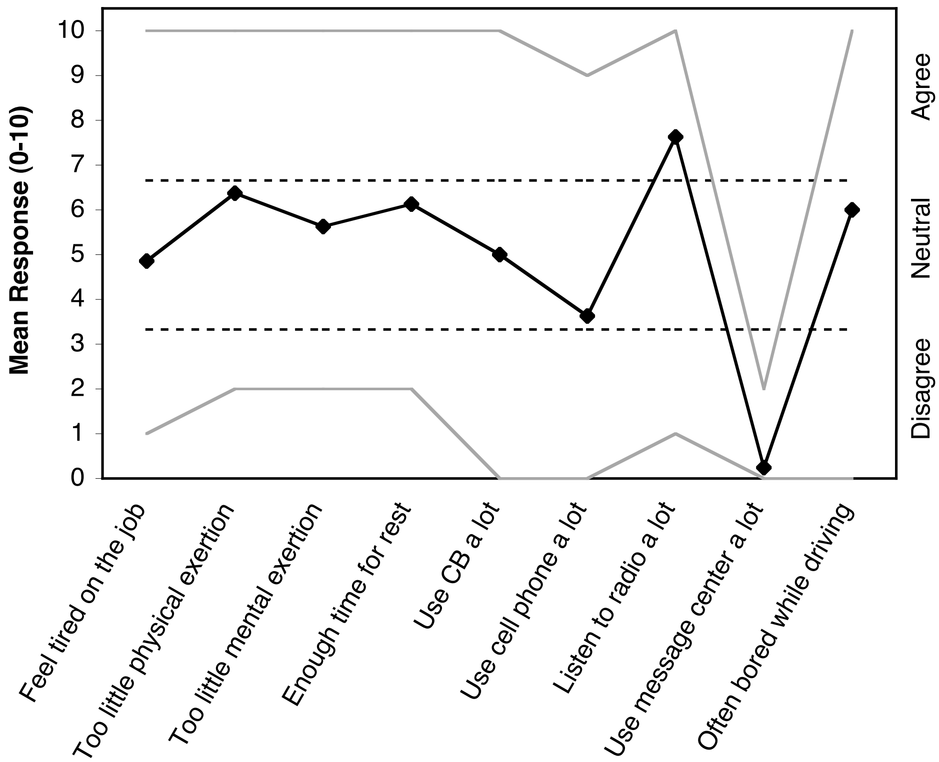
G DRIVER GROUP SURVEY ANSWERS

The survey included a series of rating questions (0-10, 10 being Strongly Agree). Of these, only two questions had a mean rating outside the "neutral" range – the interior third of the overall range (Figure 3.1). Drivers reported that they listed to the radio often while driving and that they rarely used a message center while driving (one driver provided a rating of 2, all other marked 0). It is important to note that the range labels used here were not present in the survey.

Driver descriptive data

Value Questions	**Mean**	**sd**
Total sleep (hrs)	6.5	0.8
Naps while working (hrs)	0.3	0.5
When most tired*	5:45	2:05
With current employer (y)	6	3
Age (y)	42	11
Est Annual Mileage (1,00mi)	107	30
Checkbox Questions	**"Mean" Response**	
Nod off momentarily	Several times a year	
Commute time, from work	31-45 minutes	
Use radar detector	Rarely	
Other findings		
One driver took a break for 2 years		
One driver has ACC in his truck (2001 model)		
Schedules: 5 night, 2 swing, 1 day		

* Daytime driver and "at dawn" omitted



Mean, maximum, and minimum driver responses to rating questions

Driver actions when tired

Self directed countermeasures [sequence]
[1] Open window [2] 20 min nap [3] walk around truck
[1] Talk on CB, run fingers through hair, listen to loud radio, open window [2] sleep for an hour
[1] Rest, not sleep, for approximately one hour
[1] More coffee or tea, cigarette [2] put head out window [3] take a walk
[1] Chew gum [2] stop for 20 oz coffee [3] 20 min nap
[1] Chew gum [2] get in bunk if near end of run and have empty load
[1] Pour more coffee [2] 30 min nap [3] rest or eat breakfast [4] sleep longer
[1] Fight it [2] coffee [3] walk around truck, short nap

In-vehicle distractions

CB: who do you speak with?	Frequency
Anyone	3
Company drivers	3
Don't use	2
Sometimes anyone	1
Cell phone: who do you speak with?	Frequency
Family	6
Work related	2
Friends	1
Radio: what do you listen to?	Frequency
Music	7
NPR	2
Talk	2
News	1

Driver responses to perceived value of a drowsy driver system

Expected value of drowsy driver detection and warning system
It would be good for all drivers
At this point I don't know
Personally, none - for others who can't manage sleep it would certainly save lives & property damage
Its value would be incalculable; I saw too many single truck accidents on straight roads & good conditions where the driver has to have fallen asleep
It could save lives
Well, when you get drowsy and nod off you are warned before you make contact with a fixed object
If it helps then I'm all for it
Very good idea, if you make it this would save a lot of lives

H DRIVER GROUP: ACTION SEQUENCE

Comments that were transcribed from the post its that were used during the brainstorming activity.

Pre-drive

Review written instructions and maps (worthless)
Orientation to prepare for new terminal
Physical exercise (moving equipment etc.)
Hook up loads
Turn on laptop (some hooked in with cell)
Check out with guard

Turn on red light (helps you stay awake; some radios ignition powered)
Turn both radios on
Seat belt goes on (mixed)
Get:water, juice, caffeine, green tea

Destination

You know where you are going; locations are pre set
First 6-8 highways been there before; pin down in 10 minutes
Same destinations always (mixed)
Go around roadblocks, accidents, traffic (take a break)
CB radio is invaluable for information

Sample schedules

out by 8-10:00 pm
break 1:00 or 2:00 am
back by 6:00 am

Line haulers are driving mostly at night
Allowed to stop whenever desired
Break route in half if possible
Take a break whenever you want
3.5 hours leg
Do the whole drive at once (no stopping)

Driving

Five hour blocks of driving

Drive 4-5 hours non-stop

Set cruise control (sooner and better, save on gas)

Activities

Think

Radio (stays on the whole time, music mostly, NPR, talk shows, oldies music)

CB Convo (engaging, keep going, time flies)

Cell phone (handheld or hands free)

Tapes (custom)

Talk with "partner" (another truck driver in a separate truck, go the whole way)

Drinking

Eating

Smoking

Shewing (gum, tobacco)

Peppermints (do everything you can't do☐ on a regular job)

Talk to the same 6 people in 10 hours during a long run

Mini-convoys (keep head on straight, safety in numbers)

Entertainment watching female drivers (they will put on a show)

Other drivers' actions are entertaining

Keep on going until show is done

Breaks monotony

Sex (thinking about, talking about)

Fatigue

Is usually not an issue in first phase

Hour before dawn is the hardest time to drive (most drivers)

Drivers know best as an individual about own circumstances

Know your limits

Will take extra break and be late if necessary

Pull over or you are kidding yourself (freight does not equal life)

Middle of the night is extremely hard to stop truck and rest
Last few minutes of drive are stimulating

Fresher air is brought in
Keep cab very cold or constantly adjusting it to be comfortable
Older drivers = warmer
Tired = colder to the point of uncomfortable (some shiver)

Eat to cause discomfort
Chew ice (sometimes all through leg)
Take shoes off and drive in socks
Take off shoes to rest
Seated exercises to stay awake
Prop foot on dog box, door

Breaks
Drop, hook and log
Paperwork is done during a break

Going to a know place, predictable
Safe havens (know where to stop)
Pacing to make it to safe stops (10-15-20 minute increments)

Walk around at stop
Check tires and walk around
Get a coffee, food, fruit, pastry
Safety check walk around truck

Sleep 1-1.5 hours at halfway point

Less activity: (Other drivers) park close to door, don't want to walk
Intentionally stop farther away to force exercise

Same amount of activity as the first

Use it for lunch break, to sup, big long break, sleep, socialize
Could be waiting for next truckload
Waiting for more than an hour can throw off whole schedule
must keep moving or must rest

Constantly moving along route (stretching, flexing)
Turn off cruise control when tired (about half do)
Make self look around periphery
Keeping an eye on other traffic and threats (bad drivers, deer)
Close calls (10 minute rush)
Look in the mirrors, look around to avoid tunnel vision
Tunnel vision (peripheral gone)
Crazy drivers stop on exit ramps, curves etc.
Rumble strips help tremendously (have saved many lives; wake up driver and partner in sleeping berth)

It can be hard to wake up after a long nap; hard to crawl out of bunk
20 minutes is the <u>best</u> nap; set alarm for 30 minutes to allow 5-10 sleep adjustment
Always feel good after the <u>correct</u> nap: ready to go

Always pull over with empties—no restrictions to keep you from stopping
(48mile/hr estimate) Company X is an easy job for truck drivers, almost too easy
Mindless work but Company X has support systems that are excellent
Other trucking work is considered awful

Cruise control used almost constantly
More traffic on road
Running with someone, "companion" truck driver will keep you going—lifesaver
Voice will keep you awake—all imaginable subject matter

- "If we could only tape some of the conversations we'd make a million"
- People's lows and highs, "nutty" people, same "entertaining intros" every night, CB fights, lot lizards, singing, "smalltown news across the nation"

If too irritating <u>shut off the CB</u>

Conditions

Fog is very taxing, snow too

Traffic can affect you positively or negatively

Traffic causes fatigue

No place to park might mean a ticket

Nation's infrastructure hasn't kept up with amount of trucks

Humidity, switching terminals will weigh you down

Last Leg of Route:

Stretching, twisting moving in last leg of the route (50-20 miles from end of route)

Mentally prepare for arrival; plan for rest of day or to rest

Many many many thoughts go through your head at times

Minimal phone activity during route

- up to 5-6 times for some
- depends on phone set up, “family plan”
- some only business, some mix of business and personal

Drop trailer and head for home

Weigh stations are not a problem in the evening

Police are kind and considerate to Company X drivers; Company X is favorite of police

Time goes by quickly:

- driving the truck
- mental conversations
- good music
- good conversation
- drive to a particular radio station
- naked women
- heavy thoughts
- talk on CB/phone

I DRIVER GROUP: DROWSY CRITICAL INCIDENT

Summary of topics

Topics	Related comments
Tunnel vision, stupor, trance	3-4 AM, empty roads
	"Did I just drive 5 miles in 3 seconds?"
	Ringing phone can trigger awareness of drowsiness level
	One driver: more due to mental activity than drowsiness
Speeding ticket	Very drowsy on straight road, going a bit over the speed limit
	"It was good because it may have saved my life"
	Officer did not appear to realize how tired driver was
Hallucinations	Boulders rolling down a hill or a person walking on the shoulder
	Stomped on brakes, realized nothing was there, and continued on
Rumble strips	Around 4 AM, straight roads, good weather
	Waking up from rumble strips, "no shortage of times"
Planned breaks	One driver: always takes a break at sunrise, knows he has trouble driving during this period
	"I stop driving to prevent getting drowsy"
Other truck drivers	Especially dangerous when passing a tired driver who is having trouble staying in their lane
	"I see, constantly, trucks that have left the road for no reason"
Eye closure periods	Usually reported as being near 3 seconds
	"Scary" was frequently used
Post episode adrenaline effects	Reported as lasting from 10 minutes to the rest of the shift
	"Never as long as I would have thought it would be or as long as I would have hoped for"
Rough roads and bad weather	Several drivers indicated these reduced drowsiness

J DRIVER GROUP: DESIGN EXERCISE

Results for Each Selection by Driver Team

Table J.1. Driver Choices for Power On

TEAMS	BLUE	YELLOW	GRAY	GREEN
1 POWER ON				
Manually, so you:				
Turn it on yourself at dusk				
Turn it on yourself only when you become drowsy	•			
Automatically, so the monitor:				
Powers on when you start your truck and begins working when it is dark enough		•	•	•
Powers on at highway speed and begins working when it is dark enough				
Here is my suggestion:				
Suggestion	•			

Table J.2. Driver Choices for Settings

TEAMS	BLUE	YELLOW	GRAY	GREEN
2 SETTINGS				
Basic Controls:				
Brightness adjustment	•	•	•	•
Volume adjustment	•	•	•	•
Sensitivity adjustment	•	•		•
Warning Settings:				
Turn the sound off and receive a visual warning only	•			
More frequent warnings				
Add another type of warning, like vibration in the seat	•	•	•	
Turn the sound off and receive a vibrating warning only				
No settings, but I want it to track my drowsiness and self-adjust				
the warnings when necessary				
Tell the system how tired you are and it will adjust the warning based on your input				
Here are my suggestions:				
Suggestions		•	•	•

Table J.3. Driver Choices for Warning Characteristics

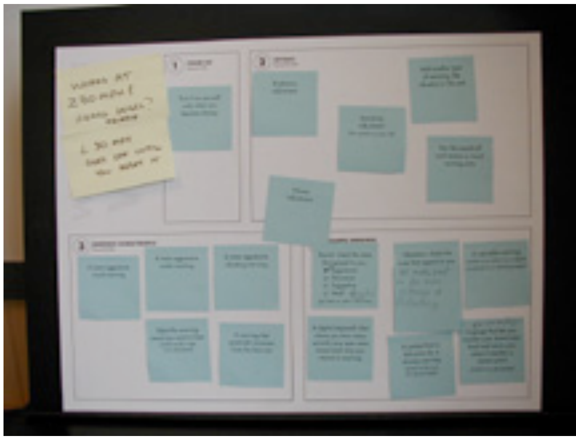
TEAMS	BLUE	YELLOW	GRAY	GREEN
3 WARNING CHARACTERISTICS				
I want:				
A more aggressive visual warning	•	•	•	
A more aggressive audio warning	•	•	•	
A more aggressive vibrating warning	•	•		
A continuous warning that doesn't stop until I respond		•	•	•
A warning that gradually increases from the first one	•			•
The same type of warning as the first one; no changes				
Select the warning sound you want to hear	•	•		•
A completely different warning each time. Surprise me.		•		
A different type of warning than the first one, that I pick.				
Here are my suggestions:				
Suggestions			•	•

Table J.4. Driver Choices for Example Warnings

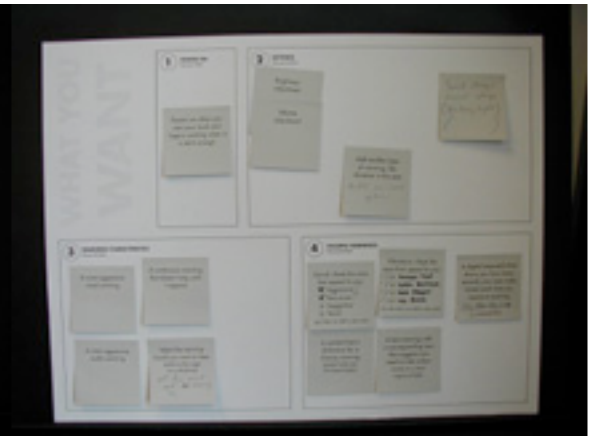
TEAMS	BLUE	YELLOW	GRAY	GREEN
4 EXAMPLE WARNINGS				
I want to try:				
Sound				
- Aggressive	•	•	•	•
- Percussive			•	
- Suggestive				
- Vocal	•			
Vibrations:				
- Top	•		•	
- Bottom	•		•	
- Front	•		•	
- Back	•		•	
A text warning with a corresponding icon that suggests you need to take action			•	
A gauge that lets you monitor your drowsiness level and warns you when it reaches a certain point	•			
A symbol that is distinctive for a drowsy warning	•		•	
A digital stopwatch that shows you how many seconds your eyes were closed each time you receive a warning	•		•	
A warning that suggests short-term actions such as using caffeine or moving around in your seat				
An external prompt, eg., via the radio that involves personal interaction		•		
A wearable warning	•			
Here are my suggestions:				
Suggestions	•	•	•	

Results for Each Selection by Driver Team on Original Boards

Blue



Gray



Green

Yellow