2.0 Fatigue Management Technologies Selected for Study

There are currently a growing number of technologies that purport to help drivers manage fatigue.[2] The project was not resourced or designed to study every one of these

2 Krueger, G. *Technologies And Methods For Monitoring Driver Alertness And Detecting Driver Fatigue: A Review Applicable To Long-Haul Truck Driving.* Technical Report for American Transportation Research Institute and Federal Motor Carrier Safety Administration, June 2004.

technologies, or even to study each subset of them. Rather, building on previous work at the U.S. Department of Transportation, the project identified representative technologies in four domains of fatigue management: (1) improving objective information on driver sleep need, (2) improving objective information on driver alertness, (3) improving objective information on driver lane tracking, and (4) lessening of the physical work required of the driver when controlling vehicle stability while driving. These representative technologies were bundled as an FMT package in the study design. Each is described in this report.

2.1 *SleepWatch®* to inform drivers when they need more sleep

Wrist-worn actigraph monitoring of drivers' rest-activity patterns, with feedback regarding estimated sleep need, was judged to be a promising objective way to inform drivers of the development of cumulative sleep debt and the need to obtain more sleep and/or take additional alertness–promoting countermeasures. The technology selected for providing feedback to drivers on their need for sleep was the wrist activity monitor (or actigraph) *SleepWatch®* (Precision Control Design, Inc., FL) shown in Figure 1, combined with an internal algorithm entitled the *"Sleep Management Model"* (developed by Walter Reed Army Institute of Research [WRAIR]). Since 1980, the collaborating investigators at WRAIR (D. Redmond, G. Belenky, T. Balkin et al.) have pioneered both wrist-worn actigraph monitoring for recording of human rest-activity cycles, and algorithm development to detect sleep in actigraph data. See Appendix A-1 for photos of the *SleepWatch®* technology, and Appendix B-1 for instruction in its use provided to drivers.

The *SleepWatch®* used in this study was a commercially available device, the *SleepWatch™ Actigraph*, Model OS2K, manufactured by Precision Control Design, Inc. (Ft. Walton Beach, FL) and marketed by Ambulatory Monitoring, Inc. (Ardsley, NY). It measured 1.5 inches by 1.45 inches by 0.45 inches, and weighed 2 ounces. It was anodized black in color, styled in an octagonal shaped waterproof case, had a 0.8-inch viewing window for the LCD display, and was fitted to the wrist with a standard watchband. Internally, the *SleepWatch®* consisted of a piezo-electric ceramic beam which, with its associated electronics, comprised an accelerometer sensitive to motion in the anterior-posterior axis of the wrist, with a sensitivity of about 0.05 g. Other components included a microprocessor, 2 megabytes of memory, an LCD display driver, and a coin-cell lithium battery. The accelerometric signal was electronically filtered into two separate signal components, one relatively broad-band at 0.1 to 14 Hz, and the other with a tightly filtered pass band of about 1.5 to 3 Hz. The former was used to detect when the device was not being worn, and the latter was further processed for discrimination of sleep and wake states. The filtered signals from the sensor were digitized at a rate of 10 Hz, and at the end of each 1-minute recording epoch of the study, they were converted to three channels of information, consisting of movement counts (zero crossings), movement duration (time above threshold), and summed amplitude (or integral) of movements. In the NO-FEEDBACK study condition, these 3 channels of data were merely stored in memory for later retrieval and analysis. In the FEEDBACK condition, data from the movement-count channel were both stored and processed by the device in real time. First, counts from 7 successive minutes were applied to an approximation of the Cole-Kripke Sleep/Wake algorithm,[3] which is essentially a weighted moving average that assigns a state of sleep (=

3 Cole R, Kripke D, Gruen W, Mullaney D, Gillin JC: Automatic Sleep/Wake Identification from Wrist Actigraphy. *Sleep* 15(5): 461-469, 1992.

1) or wake (=0) to each epoch. Over many days of monitoring the result is a time-history from which "total sleep time" and "sleep per day" were estimated. At each minute, the Sleep/Wake algorithm result was also the input into the Walter Reed Sleep/Performance Model,[4] which used calculated sleep history and adjustment for time-of-day to modulate a Performance Index on a scale of 0 to 100. This Index, initially set to 95, was used in the FEEDBACK condition to inform drivers of relative variation in performance capacity due to sleep or the lack of it.

In both FEEDBACK and NO-FEEDBACK conditions, the LCD display of the *SleepWatch®* showed clock time as would a normal watch face. In addition, in the FEEDBACK condition, a semi-circular reticule display resembling a "fuel gauge" was displayed on a scale from 0% to 100% that varied based on the output of the Performance Index. Thus, during the FEEDBACK condition only, a driver could refer to his/her "performance level" by glancing at the *SleepWatch®*. Also he/she can read the actual numerical value of the current Performance Index by pressing a button on the side of the *SleepWatch®*. The *SleepWatch®* therefore contained a proprietary *Sleep Management Model* algorithm that could provide feedback on an estimated "performance-readiness" (Figure 1 and Appendix A).[5] The feedback aspect of the *SleepWatch®* (i.e., the "performance fuel gauge" and the numeric value of "Performance-Readiness") were suppressed in the control (NO FEEDBACK) condition (see DESIGN) while still collecting objective data on sleep time using the *Sleep Management Model*.

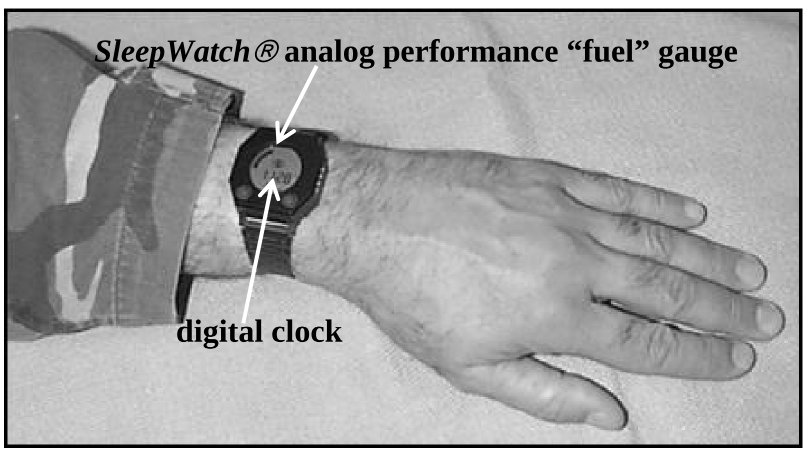

Figure 1. Walter Reed Army Institute of Research (WRAIR) *SleepWatch®*. (See Appendix A-1 for additional photos of *SleepWatch®*.)

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4 Balkin T, Thorne D, Sing H, Thomas M, Redmond D, Wesensten N, Williams J, Hall S, Belenky G: Effects of sleep schedules on commercial motor vehicle driver performance. Washington DC: U.S. Department of Transportation, Federal Motor Carrier Safety Administration; Report No. DOT-MC-00-133, May 2000.

5 As with all fatigue management technologies used in the study, the validity of the proprietary algorithms contained in the specific devices used in the study was not assessed in the study. Therefore the use of a specific technology and algorithm in this study should not be interpreted as evidence for or against the validity of the device or algorithm to measure what it purports to measure. Nor should the use of a technology and algorithm be taken as an endorsement of the technology or algorithm by the study sponsors, investigators, or the participating drivers and companies.

2.2 *Copilot®* monitor of eyelid closures (PERCLOS) to inform drivers of drowsiness

The technology selected for providing feedback to drivers on their alertness while driving was the *Copilot®* (Attention Technologies, Pittsburgh, PA) system for monitoring PERCLOS (percent eyelid closure). U.S. DOT-funded research in the laboratories of W. Wierwille[6] and D. Dinges[7] led to the discovery that slow eyelid closures were a highly reliable measure of lapses of attention due to sleepiness/drowsiness, which led to the development of an infrared-based retinal reflectance monitor for eye closure detection by R. Grace at Carnegie Mellon University, and marketed by Attention Technologies. See Appendix A-1 for photos of the *Copilot®* technology, and Appendix B-1 for instruction in its use provided to drivers.

Real-time detection of in-vehicle driver drowsiness provides drivers with immediate information on their drowsiness levels when driving, which is especially important during driving in the late-night and early morning hours, when drowsiness can be increased. Research has demonstrated that through the delivery of feedback, drivers could avoid driving and/or take appropriate countermeasures when drowsiness is detected via increased eyelid closures.[8] The technology that best addressed this issue was the *Copilot®*. The *Copilot®* uses a structured illumination approach to identifying a driver's eyes. The PERCLOS monitor identifies the driver's eyes using two identical images with different sources of infrared illumination. The monitor utilizes two separate cameras, with both focused on the same point, yet situated at a 90-degree angle to one another. The image is passed through a beam-splitter that transmits or reflects the image onto the lenses of each camera. In order to isolate the correct wavelengths of light, one camera is outfitted with an 850nm filter, and one with a 950nm filter. The 850 nm filter yields a "bright-eye" camera image (i.e., distinct glowing of the driver's pupils or the red-eye effect) as seen in Figure 2A. The 950 nm filter yields a dark-eye (Figure 2B). The difference-image (Figure 2C) eliminates all image features except for the bright pupils.

During the project, the *Copilot®* was mounted on the dashboard of trucks, typically just to the right of the steering wheel (Figure 3 and Appendix A). Feedback from the system was provided on a separate digital display box (see below) and consisted of a *Copilot®* proprietary algorithm score from 0 to 99, where 0 indicated maximum eyelid closure and 99 indicated least eyelid closure (see footnote 5). Eyelid closure feedback information was active during the 2-weeks drivers operated their trucks in the FMT FEEDBACK condition. The numeric feedback from the PERCLOS system was disabled during the NO

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6 Wierwille, W.W.: Historical perspective on slow eyelid closure: Whence PERCLOS? In: Carroll, RJ (Ed.) Technical Proceedings of Ocular Measures of Driver Alertness Conference, Herndon, VA; FHWA Technical report No. MC-99-136). Washington , DC: Federal Highway Administration, Office of Motor Carrier and Highway Safety.

7 Dinges, D.F., Mallis, M., Maislin, G., Powell, J.W.: Evaluation of techniques for ocular measurement as an index of fatigue and the basis for alertness management. U.S. Department of Transportation, National Highway Traffic Safety Administration, Contract No. DTNH22-93-D-07007. pp. 1-113, 1998.

8 Mallis, M., Maislin, G., Konowal, N., Byrne, V., Bierman, D., Davis, R., Grace, R., Dinges, D.F.: Biobehavioral responses to drowsy driving alarms and alerting stimuli. Final report to develop, test and evaluate a drowsy driver detection and warning system for commercial motor vehicle drivers. U.S. Department of Transportation, National Highway Traffic Safety Administration, Contract No. DTNH22-93-D-07007. pp. 1-127, 1999.

FEEDBACK condition, but PERCLOS information was still being recorded for those 2 weeks.

2A: bright-eye image 2B: dark-eye image 2C: difference image

Figure 2: The three images obtained by *The Copilot*. The bright-eye image (2A) and the dark-eye image (2B) are essentially identical except for the glowing pupils in the bright eye image. The difference-image (2C) eliminates all image features except for the bright pupils.

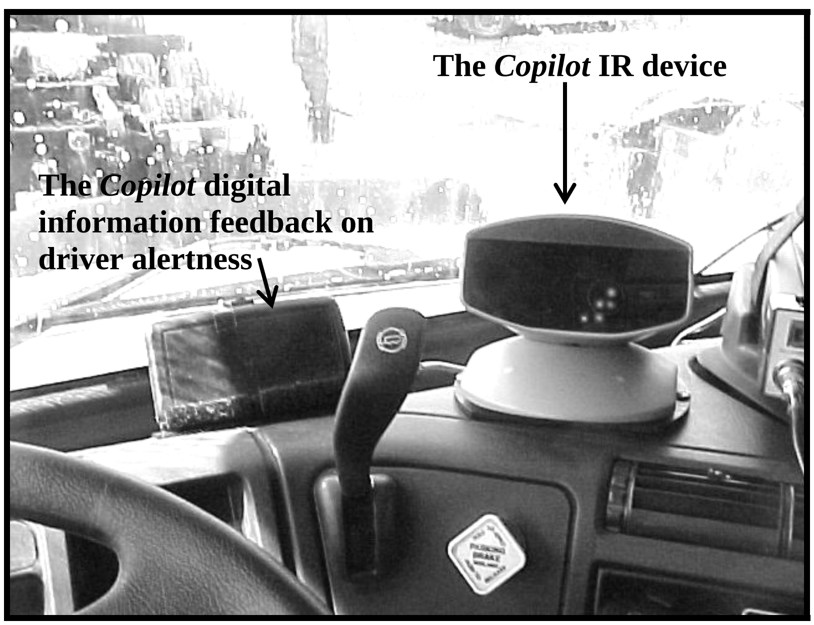

Figure 3. The *Copilot® was* mounted on the truck dash for measurement of slow eyelid closures (PERCLOS) during night driving. (See Appendix A-1 for additional photos of the *Copilot®*, and Appendix B-1 on instructions to drivers regarding *Copilot®*.)

2.3 *SafeTRAC®* technology to inform drivers of lane tracking "alertness"

The technology selected for providing feedback to drivers on their lane tracking was the *SafeTRAC®* (Applied Perception and AssistWare Technology, Inc., Wexford, PA). Lane tracking, which refers to monitoring the position of the vehicle in the driving lane and detection of lane drifting, weaving, or variability in tracking the lane, is a well-established measure of driving performance. Many studies of fatigue-related driving deficits have found variability in lane tracking to be one of the more sensitive measures of drowsiness and fatigue. See Figure 4 and Appendix A-1 for photos of the *SafeTRAC*® technology, and Appendix B-1 for instruction in its use provided to drivers.

Just as *Copilot®* provided an on-line monitor of driver drowsiness (via eyelid closures), *SafeTRAC®* served as an on-line monitor of driver performance. *SafeTRAC®* provided immediate feedback on driving performance in the FEEDBACK condition of the study. *SafeTRAC®* consisted of a video camera mounted on the windshield and coupled to a small computer that continuously analyzed the image of the road, lane markings, and other roadway features. Lane departures, erratic movements and other possible errors were detected. Intentional lane shifts indicated by the turn signal were designed to be ignored by the system. The *SafeTRAC®* feedback monitor was mounted on the dashboard just to the left of the steering wheel. Feedback from the system consisted of a 0 to 99 scale, where 0 indicated most erratic lane tracking, and 99 indicated least erratic lane tracking, according to a proprietary algorithm (see footnote 5). If a driver made an abrupt deviation from the lane without signaling, *SafeTRAC®* also provided an auditory warning signal (a single short beep sound). As with other FMT technologies, feedback information from the SafeTRAC device was active during the 2-weeks drivers operated their trucks in the FMT FEEDBACK condition. The numeric feedback from the system was disabled during the 2-week NO FEEDBACK period (control condition) while still collecting baseline objective data on lane tracking. Figure 4 below shows the *SafeTRAC®* camera. See Appendix A for photos of the *SafeTRAC®* feedback device, which displays a green line centered within two sets of painted lines: A solid vertical lane marker on the right (e.g., road shoulder), and the equal sign (=) on the left (e.g., dashed painted lane marker). The numeric value displayed is the algorithm-based alertness score from 0 (low alertness due to poor lane tracking) to 99 (high alertness due to excellent lane tracking).

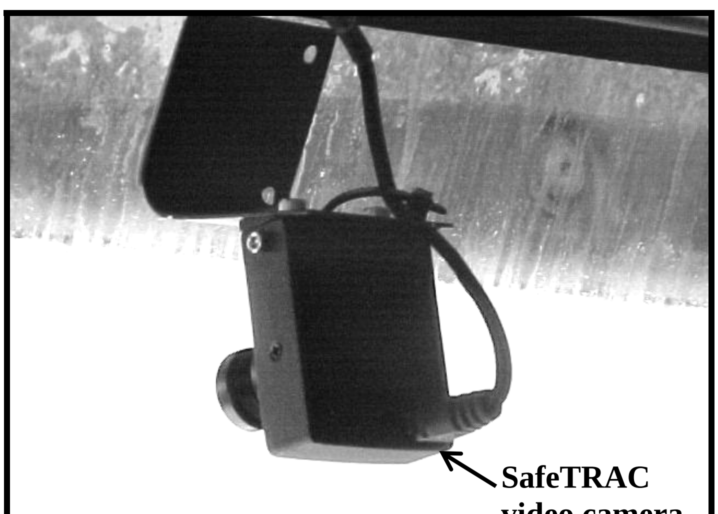

Figure 4. *SafeTRAC®* lane-tracking monitor developed by AssistWare Technology. *SafeTRAC* employs a video camera mounted on the truck windshield (or truck podium) and coupled to a small computer that continuously analyzes the image of the road, lane markings, and other roadway features. (See Appendix A-1 for additional photos of *SafeTRAC®*, and Appendix B-1 on instructions to drivers regarding *SafeTRAC®*.)

2.4 *Howard Power Center Steering®* system to reduce physical fatigue of driving

The technology selected for reducing the physical work of controlling vehicle stability while driving was the *Howard Power Center Steering® (HPCS)* system (River City Products, Inc., San Antonio, TX). Unlike the other FMT technologies that were designed to provide feedback to drivers on their behavioral alertness relative to fatigue based on sleep and circadian biology, the *HPCS* system was designed to lessen physical fatigue associated with drivers “fighting” the steering wheel in cross winds (i.e., driver correction of vehicle instability and control problems). See Appendix A-1 for photos of the *HPCS* technology, and Appendix B-1 for how instruction in its use was provided to drivers.

Heavy vehicle stability and control problems contribute to the “work” of driving a truck, inducing fatigue due to the often continuous amount of driver steering corrections needed to counteract the unstable behavior of the castered truck wheels. The physical workload associated with “fighting” the steering wheel in cross wind is particularly fatiguing to neck and shoulder muscles. There was a need to determine whether a technology that lessened this workload on drivers would result in less fatigue. The technology that best fulfilled this requirement and was tested in the pilot study was the HPCS system (see footnote 5). The HPCS involves a hydraulic device attached to a truck’s tie rod and steering system to reduce the physical demands of driving. The system consisted of two components: the Hydraulic Power Centering Cylinder and the Air Activated Hydraulic Pressure Accumulator (see Appendix A). The normal operation of the system was automatic and required little attention from the driver. The driver controlled the desirable hydraulic pressure on a panel by adjusting air pressure, which increased or decreased effectiveness of the system. The system could be turned off by the driver via a simple switch pressed to release air pressure in the accumulator (Figure 5).

Unlike the *SleepWatch®*, the *Copilot®* drowsiness monitor, and the *SafeTRAC®* lane tracker, the *Howard Power Center Steering®* system did not provide numeric feedback. Rather, this system was turned on in the FMT FEEDBACK condition and it was off in the NO FEEDBACK condition. When on, drivers could feel the steering wheel stability relative to when the system was off. Steering wheel variability was recorded electronically in both the FMT FEEDBACK (HPCS turned on) and NO FEEDBACK (HPSC turned off) conditions. Figure 5 displays HPCS in project trucks.

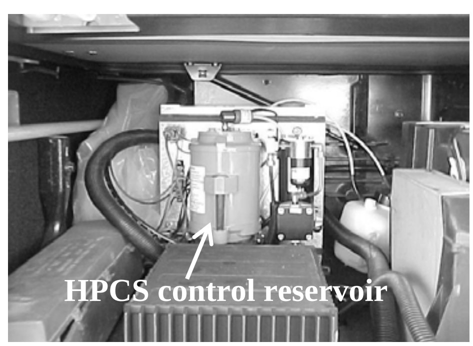

Figure 5. *Howard Power Center Steering®* system. HPCS controls located under a truck dash and the control reservoir tank. (See Appendix A-1 for additional photos of the *HPCS* system, including a schematic of the system.)