EXECUTIVE SUMMARY

This project developed an experimental design and instrumentation plan, and conducted a pilot field trial test of commercial truck drivers' reactions to fatigue management technologies (FMT) under current federally-mandated, hours-of-service in both Canada (phase 1) and the United States (phase 2). The project sought to experimentally determine how drivers engaged in over-the-road trucking operations reacted to a number of promising fatigue management technologies, and whether the technologies would improve the alertness and fatigue awareness of commercial truck drivers and increase their sleep time, by providing them information feedback about changes in sleep need, in drowsiness and in driving performance. It was hypothesized that the use of FMT would result in more sleep and improved driver alertness and performance while driving. This Executive Summary combines the findings from both the Canada phase and U.S. phase of the study.

A Canadian trucking company and an American trucking company agreed to allow their trucks to be instrumented with the fatigue management technologies. Their drivers were solicited for participation after the protocol, procedures and informed consents were reviewed and approved by the Canadian Research Ethics Board and by the Institutional Review Board of The Walter Reed Army Institute of Research.

The combination FMT intervention consisted of four technologies, each of which was judged to represent a promising fatigue management technology approach from one of four domains.

1. Wrist worn *SleepWatch®* (Precision Control Design, Inc.) contains a *Sleep Management Model* software algorithm (Walter Reed Army Institute of Research) for monitoring and providing feedback to drivers on sleep need and performance readiness. Wrist-worn actigraphic 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.

2. *Copilot®* system (Attention Technologies, Inc.) for infrared monitoring of driver drowsiness uses PERCLOS (a proprietary algorithm based on percentage of slow eyelid closures). On-line detection and feedback of 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. DOT research has demonstrated that tracking slow eyelid closures (PERCLOS) reliably predicts lapses of attention associated with sleepiness.

3. *SafeTRAC®* lane tracker system (Applied Perception and AssistWare Technology, Inc.) provides on-line monitoring of driver performance and alertness. 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. In addition to lane tracking having excellent face validity in driving safety, 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.

4. *Howard Power Center Steering® (HPCS)* system (River City Products, Inc.) reduces the physical work drivers must continually undertake to control vehicle stability while driving. Unlike the other FMT technologies that were designed to provide feedback to drivers on their behavioral alertness relative to fatigue based in sleep and circadian biology, the *HPCS* system was designed to lessen physical fatigue (in neck, shoulders and arms) associated with drivers "fighting" the steering wheel in crosswinds.

The trucks of volunteer drivers were also instrumented with the *Accident Prevention Plus* (*AP+*) on-board recording device (black box) to continuously record a range of truck motion variables (speed, lateral acceleration, etc.) as well as information from the FMT devices (PERCLOS, lane tracking variability, steering, etc.). Volunteer drivers also completed a *daily diary* on their work-rest activities, and performed the *Psychomotor Vigilance Task* (PVT) twice daily, midway and at the end of each trip, as an independent validation of their level of behavioral alertness. In addition to training in the use of all technologies listed above, drivers also received *Education on Alertness and Fatigue Management* before they drove with the instrumented trucks. The education module encouraged drivers to be responsible for their alertness levels at all times throughout the study. Following completion of the study drivers were debriefed and completed the *Human Factors Structured Interview Questionnaire* in which they reported their reactions to all interventions, measures and technologies used in the study.

A within-subjects cross-over design (i.e., using subjects as their own controls) was the most efficient way to compare the effects of combined FMT providing feedback on sleep need, alertness/drowsiness, and performance (i.e., FEEDBACK condition) with the effects of the NO FEEDBACK control (baseline) condition in which technologies were recording but no feedback of alertness/drowsiness, performance and sleep need was provided. The design did not include manipulating or controlling what the participating companies and drivers did, what schedules the drivers adhered to, or what operating practices they actually followed. Rather, the FMT intervention and data collection were applied to existing routine trucking operations. Drivers first drove for 2 weeks in the NO FEEDBACK baseline condition, in which data were recorded, but no feedback on alertness/sleepiness, performance or sleep need was provided to drivers. In the subsequent 2 weeks drivers operated with information FEEDBACK from the *SleepWatch®,* the *CoPilot®* system for monitoring PERCLOS, and the *SafeTRAC®* lane tracker. The *Howard Power Center Steering®* system was also available to use during these 2 weeks of FEEDBACK.

Since it was neither cost-effective nor practical to conduct a separate study of each individual technology, the selected representative four FMT technologies were combined and tested as a set within a single field trial that had two phases. Study Phase 1 (data collection in 2002) took place under Canadian hours-of-service regulations, and involved a Canadian trucking company in which volunteer drivers operated single tractor-trailer units with sleeper berths, and approximately 74% of their driving was conducted during daytime hours. Study Phase 2 (data collection in 2003) took place under U.S. hours-of-service regulations, and involved a U.S. trucking company in which volunteer drivers operated tandem tractor-trailer units without sleeper berths, and approximately 93% of their driving was conducted during nighttime hours. The differences between Canadian and U.S. trucking companies were in part a function of which companies agreed to be part of the study, as well as our goal to expressly study companies in which night driving was both a minority (Phase 1) and a majority (Phase 2) of trucking operations.

A grand total of 38 experienced long-haul truck drivers (n = 32 men; n = 6 women) volunteered for the study and completed both the NO FEEDBACK and FEEDBACK conditions (n = 26 from the Canadian phase, and n = 12 from the U.S. phase). Data from the FMT devices and other driving performance variables were gathered on the AP+ black box recorder every second the trucks were operating for the 28 days each driver was in the study. This resulted in 8,737,705 total records among the 38 drivers in the combined study phases, which reduced to 6,683,855 useable data records among 29 drivers (Canada n = 20 and U.S. n = 9), when confining data analyses to artifact-free records in which speed was at least 30 mph (i.e., highway driving). The equipment failure resulted in a loss of approximately 25% of the data. Even with this attrition, the data set and remaining sample sizes were adequate for hypothesis testing. While rough road conditions in the operating trucks caused some data loss, the final AP+ black box recorded dataset was the most extensive objective data of truck driver alertness and truck performance ever recorded. In addition, data acquired from the drivers' Daily Diaries; their 933 PVT performance tests; their 1.2 million minutes of SleepWatch actigraphic data; and their extensive responses and comments to the Human Factors Structured Interview Questionnaire, resulted in millions of additional data records. Many of the latter variables could be analyzed using all 38 drivers who completed the study. The massive scope of the dataset acquired in this "Pilot" study is the reason the main report contains 79 summary Figures of data analysis results, and is followed by six appendices containing hundreds of additional Figures.

Redundant statistical approaches were used to test the primary hypothesis (e.g., both unweighted analyses and mixed model [doubly weighted] analyses of changes in mean values and standard deviations, as well as changes in median values and interquartile ranges). The sum of total hours during the NO FEEDBACK and FEEDBACK conditions was used as a weighting factor in the mixed models. Key findings are summarized briefly below relative to the primary hypotheses and to other key findings and recommendations relevant fatigue management in long-haul trucking.

Hypothesis: FMT FEEDBACK will improve driver alertness and/or reduce driver drowsiness.

- **Phase 1: Canadian Drivers.** There was evidence in support of the hypothesis. Driver drowsiness as measured by the *CoPilot®* index of PERCLOS (i.e., slow eyelid closures) during night hours was reduced under the FEEDBACK condition compared to the NO FEEDBACK condition. This was further confirmed by drivers' subjective sleepiness ratings taken before and after PVT performance tests at night. However, the *SafeTRAC®* index of driver alertness and drivers' PVT reaction times showed slight reductions in alertness during the daytime in the FEEDBACK condition.
- **Phase 2: U.S. Drivers.** There was evidence in support of the hypothesis. This phase focused more extensively on drivers who primarily drove at night, when sleepiness would be expected to be more of a problem. The *SafeTRAC®* index of driver alertness and the *CoPilot®* index of PERCLOS both provided evidence of greater alertness in the FEEDBACK condition than in the NO FEEDBACK condition. Although only a statistical trend, lane tracking variability also improved with FEEDBACK during night driving in the U.S. study phase.
- **Combined Canada and U.S. data.** Composite results from pooling data from the two study phases yielded strong support for the hypothesis. During night driving, FEEDBACK from FMT significantly reduced slow eyelid closures (PERCLOS) as

measured by *CoPilot®*, increased the *SafeTRAC®* estimate of driver alertness, and decreased lane tracking variability.

Hypothesis: FMT FEEDBACK will increase driver sleep time.

- **Phase 1: Canadian Drivers.** Within the Canadian study phase, none of the S*leepWatch®* actigraphy outcomes demonstrated systematic differences between the NO FEEDBACK and FEEDBACK conditions. There was also no evidence from drivers' Daily Diaries to support the hypothesis that FMT FEEDBACK resulted in increased sleep time relative to NO FEEDBACK.
- **Phase 2: U.S. Drivers.** Within the U.S. study phase, there was a significant increase in the number of *SleepWatch®* actigraphically identified sleep episodes but not sleep duration in the FEEDBACK condition relative to the NO FEEDBACK. There was also no evidence from drivers' Daily Diaries of increased sleep time.
- **Combined Canada and U.S. data.** When the *SleepWatch®* actigraph-identified sleep duration per 24 hours was analyzed for both study phases, separating workdays and non-workdays, there was clear evidence in support of the hypothesis. In contrast to workdays, where FMT FEEDBACK had no effect on sleep time, there was a significant increase in mean sleep duration during non-workdays in the FEEDBACK condition relative to the NO FEEDBACK. Drivers in both study phases increased their non-workday sleep durations by an average of 45 minutes per day over sleep duration on non-workday days in the NO FEEDBACK condition.

Other Key Findings

- **Is there a "cost" to being more alert with FMT FEEDBACK?** As summarized above, during FMT FEEDBACK, alertness improved significantly during driving in the U.S. study phase, which involved predominantly night driving. However, there was also consistent evidence that PVT performance worsened and subjective sleepiness ratings increased during the FEEDBACK period of the U.S. study relative to the NO FEEDBACK period. This suggests the possibility that FMT FEEDBACK in drivers who operate primarily at night, may have alertness-promoting benefits during driving, but such feedback may also create a modest "cost" to the added effort (in attention and compensatory behaviors) required to respond to the information from the devices, and that "cost" may manifest itself as slightly worse performance and greater subjective sleepiness when performing a demanding vigilance-based reaction time task such as the PVT (while not driving).
- **Do drivers prefer vehicle-based measures of alertness?** Descriptive analyses of drivers' responses to the *Human Factors Structured Interview Questionnaire* at the end of the 2-week NO FEEDBACK period, and again at the end of the 2-week FEEDBACK condition period, revealed clear preferences of both Canadian and U.S. drivers for fatigue management training and certain fatigue management technologies. Drivers were uniformly positive about the *Education on Alertness and Fatigue Management* course given at the beginning of each study phase. Among technologies designed to detect alertness or drowsiness, drivers gave higher ratings to *SafeTRAC®*, medium ratings to the *SleepWatch®*, and low ratings to the *CoPilot®*. Among all fatigue management technologies deployed however, drivers were significantly more enthusiastic about the

benefits of the *Howard Power Center Steering®* system and *SafeTRAC®*, than they were about *SleepWatch®* and *CoPilot®*. It is noteworthy that *Howard Power Center Steering®* and *SafeTRAC®* both interface with the vehicle, while *SleepWatch®* and *CoPilot®* interface with the driver. It may be that truck drivers prefer fatigue management be carried out by way of vehicle monitoring more so than driver monitoring.

- **A future for FMT technologies?** Overall, participant drivers were positive toward the FMT approach in general and felt that if such technologies could be further improved, they would be of benefit in helping manage fatigue and alertness.

Project recommendations pointing toward future work outside the scope of this project

- **Continue development fatigue management technologies.** There is enough evidence to support the case for continued development of FMT technologies. But these should not solely be in the area of driver monitors. Vehicle-based monitoring should also get increased attention, as truck drivers appear to have some preference for this mode of fatigue management.

- **Drivers need and want Alertness and Fatigue Management Courses.** Despite differences in country of operation, hours-of-service, type of trucks, and a host of other factors, U.S. and Canadian drivers had surprisingly similar views toward the FMT project. They enthusiastically endorsed the *Alertness and Fatigue Management Training Course* provided in the study. Drivers indicted they benefited from the course and wanted more of this type of didactic to help teach them how to manage their fatigue. This is impressive given that these were largely seasoned long-haul drivers, who appeared not to be inhibited about reporting that they can still learn about fatigue and ways to manage it. These positive views towards fatigue management training suggest that some segments of the trucking industry are likely to welcome fatigue management programs.

- **PVT should be developed as a Fitness-for-Duty test.** Although the Psychomotor Vigilance Task was not discussed with drivers as either an fatigue management technology or a "fitness for duty" test, a majority of drivers in both countries indicated when asked that the PVT could be used as a personal checking system on driver fitness-for-duty system, if it could be reduced in duration. Drivers' generally positive view of the PVT as a potential fitness- for-duty device, suggests that efforts should be made to attempt to validate the sensitivity, and positive and negative predictability of a shorter-duration PVT test (e.g., 3-5 minutes) relative to truck driver fatigue.

- **Barriers to drivers obtaining adequate sleep during workdays need to be identified.** One of the more striking outcomes of the project was the finding that drivers in both countries were routinely averaging between 5 hours and 6¼ hours of sleep per day during workdays, despite very different work schedules. Recent scientific work on volunteer truck drivers (some of it sponsored by the U.S. Department of Transportation), shows that severe sleep debt and deficits in behavioral alertness can develop within a few days at

these sleep durations.[1] The fact that project participants markedly increased their sleep durations on non-workdays also supports the view that they were suffering sleep debts. Much more needs to be understood about the factors that determine when and where drivers obtain sleep on workdays and non-workdays; the barriers to obtaining adequate sleep on workdays; and the factors that convince them to get more recovery sleep on non-workdays.

1 Dinges DF, Pack F, Williams K, et al. Cumulative sleepiness, mood disturbance, and psychomotor vigilance performance decrements during a week of sleep restricted to 4-5 hours per night. *Sleep* 20:267-277, 1997. Van Dongen HPA, Maislin G, Mullington JM, et al. The cumulative cost of additional wakefulness: Dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. *Sleep* 26:117-126, 2003. Belenky G, Wesensten NJ, Thorne DR, et al. Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: a sleep-dose response study. *Journal of Sleep Research* 12:1-12, 2003.