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Today and Tomorrow

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TRB

Pilot Test of Fatigue Management Technologies

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Funding Agencies:	FMCSA, US Department of Transportation and Transport Canada, Canadian Ministry of Transportation
FMCSA COTR:	Robert J. Carroll, MS, CPE
Transport Canada:	Sesto Vespa, P. Eng.
Project Manager:	Rebecca Brewster, President, ATRI, ATA
Co-Sponsor:	Graham Cooper, Canadian Trucking Alliance

Investigator Team:

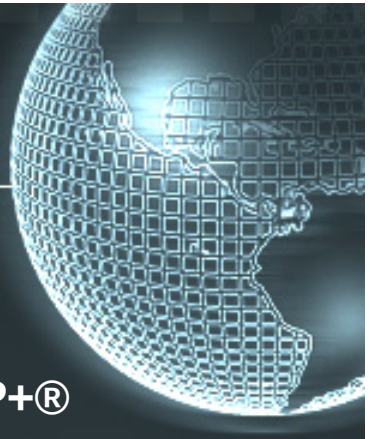
D.F. Dinges, A. Ecker, D. Terry, J.W. Powell, University of Pennsylvania: *Study design; Human Subjects approval; Psychomotor Vigilance Test (PVT); Driver diaries; Data quality control; Interpretation of results; Final Report writing.*

G. Maislin, R. Hachadoorian, Biomedical Statistical Consulting, Inc: *Data quality control; Statistical analyses; Interpretation of results; Final Report writing.*

G.P. Krueger, Krueger Ergonomics Consultants: *Project Operations; Industry Interface; Fatigue Education Module; Human Factors Quest.; Driver diaries.*

D.P. Redmond, G. Lounsberry, T. Balkin, G.L. Belenky, M.D., WRAIR: *Human Subjects approval; Sleep Watch® and Sleep Management Model; Actigraphy measures of sleep duration.*

Pilot Test of Fatigue Management Technologies



Industry Participants:

Accident Prevention Plus, LLC (Palm Beach Gardens, FL) provided ***AP+***® black box recorders.

Applied Perception and AssistWare Technology, Inc. (Wexford, PA) provided ***SafeTRAC***® lane-tracking monitors.

Attention Technologies, Inc. (Pittsburgh, PA) provided ***CoPilot***® monitors to measure PERCLOS.

River City Products, Inc. (San Antonio, TX) provided ***Howard Power Center Steering***® system.

Challenger Motor Fright, Inc. (Cambridge, Ontario, CN) volunteered to have trucks instrumented.

Con-Way Central Express, Inc. (Ann Arbor, Michigan, USA) volunteered to have trucks instrumented.

Pilot Test of Fatigue Management Technologies

Task: Develop an experimental design and instrumentation plan, and conduct a pilot field trial test of commercial truck drivers' reactions to fatigue management technologies under Federally-mandated hours-of-service in both the U.S. and Canada.

Field study evaluated whether Feedback from FMT devices:

1. Improved driver alertness, especially during night driving.
2. Increased sleep time on either work days or non-work days.
3. Were seen as either beneficial or intrusive by drivers.

Procedures and informed consents were reviewed and approved by the Canadian Research Ethics Board and by the Institutional Review Board of Walter Reed Army Research Institute.

Pilot Test of Fatigue Management Technologies

1. Wrist worn ***SleepWatch®*** (Precision Control Design, Inc.) containing 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.

SleepWatch® as worn on the wrist

SleepWatch® analog performance "fuel" gauge

SleepWatch® in clock mode

Button press to view **"Performance-Readiness,"** which is displayed as a percentage (P) from 0-99%; in this example, as "75P" or 75% optimal.

Pilot Test of Fatigue Management Technologies

2. ***CoPilot®*** system (Attention Technologies, Inc.) for infrared monitoring of slow eyelid closures (PERCLOS), a sign of driver drowsiness.

PERCLOS display (left) and infrared detector (right).

Feedback from the system was provided on the digital display box (left) and consisted of a ***CoPilot®*** proprietary algorithm score from 0 to 99, where 0 indicated maximum eyelid closure and 99 indicated least eyelid closure.

Pilot Test of Fatigue Management Technologies

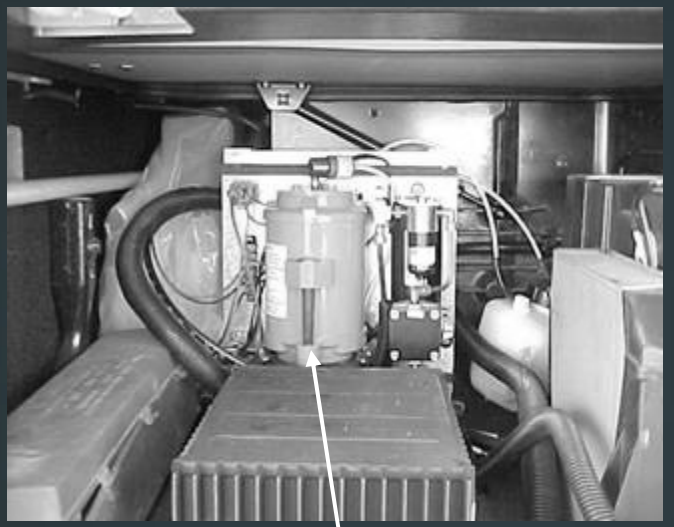
3. ***SafeTRAC®*** lane tracker system (Applied Perception and AssistWare Technology, Inc.) for on-line monitoring of driver lane-tracking performance.

SafeTRAC® mounted in truck. Display indicates **SafeTRAC®** proprietary "alertness" score of 92 out of 99 (maximal "alertness").

Pilot Test of Fatigue Management Technologies

4. ***Howard Power Center Steering®*** system (River City Products, Inc.) for reducing the physical fatigue (neck, arms and shoulders) associated with drivers “fighting” the steering wheel in cross winds.

HPCS control unit accessible to driver

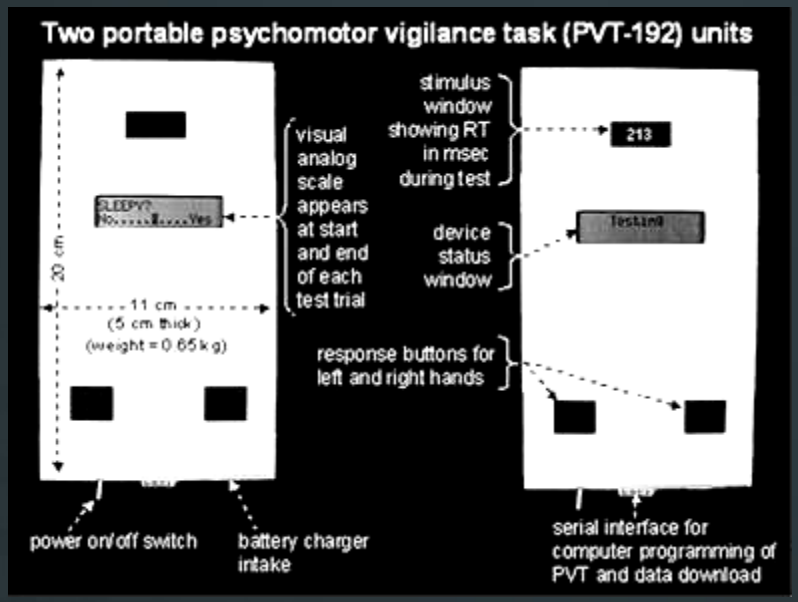


HPCS control reservoir

Pilot Test of FMT: Additional Study Outcomes

5. Trucks were 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 (*CoPilot®* PERCLOS; *SafeTRAC®* lane tracking variability and "alertness;" steering, etc).

6. Driver performance was assessed with the 10-min. ***Psychomotor Vigilance Task (PVT)*** completed twice daily—midway and at the end of each trip—as an independent validation of level of behavioral alertness/sleepiness.



Pilot Test of FMT: Additional Study Outcomes

7. Drivers completed a ***Daily Diary*** on their work-rest activities, which included questions about traffic delays/jams; weather problems; hilly roads; crosswinds; delays by dispatcher/broker; rest breaks; sleep and nap periods (location); number of delivery stops; loading and unloading activities; and impressions of FMT devices.

8. 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.

9. In addition to training in the use of all measures 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.

Motor freight carrier companies that participated in this study

Study Phase 1: Challenger Motor Freight.

- Conducted under Canadian HOS
- Single tractor-trailer units with sleeper berths
- 74% daytime driving
- n = 26 drivers participated (data acquisition 2002)

Study Phase 2: Con-Way Central Express.

- Conducted under US HOS
- Tandem tractor-trailer units without sleeper berths
- 93% nighttime driving
- n = 12 drivers participated (data acquisition 2003)

Photos of FMT monitors and feedback devices in trucks

CoPilot® digital information feedback device. Display indicates proprietary "drowsiness" score.

CoPilot® **IR PERCLOS** monitor

SafeTRAC® video camera monitor oriented out windshield of truck cab.

HPCS driver controls

SafeTRAC® feedback device mounted in truck. Display indicates proprietary "alertness" score.

Study Design

Within-subjects cross-over design

Subjects were their own controls

Informed consent

Education on Alertness and Fatigue Manage-ment

Trucks instru-mented

No-FEEDBACK cond.
2-week driving period

***SleepWatch®* worn; no FB**

SafeTRAK®* on; no FB *(AP+)

CoPilot®* on; no FB *(AP+)

Howard PC Steering®* off *(AP+)

Data dump

HFIQ

FMT FEEDBACK cond.
2-week driving period

***SleepWatch®* "P.R." FB**

SafeTRAK®* on; "Alert" FB *(AP+)

CoPilot®* on; "PERCLOS" FB *(AP+)

Howard PC Steering®* on *(AP+)

Data dump

HFIQ

4-week period of data acquisition

***AP+* black box recorded continuously while truck was running.**

***PVT* performance test was taken midway and end of each trip.**

Diary was completed daily.

Design did not require manipulating or controlling what the drivers did; or their work schedules; or operating practices; or work environment; etc.

Scope of the data acquired

- **1,064 days of data.** N = 38 long-haul truck drivers completed the 28-day study (n = 26 from Study Phase 1 in Canada, and n = 12 from Study Phase 2 in the US). (More than 9,000 hours of driving.)
- **6.7 million *AP+* black box data records.** Data acquired every second (speed, lane tracking, steering, driver "alertness," etc.) resulted in 8.7 million total records among the 38 drivers, which reduced to 6.7 million data records among 29 drivers (n=20 in Canada; n=9 in US) when data analyses were confined to artifact-free records at speeds ≥30 mph (i.e., highway driving).
- **20,000 hours of *SleepWatch®*** actigraphic data.
- **933 *PVT*** 10-minute performance tests (155 hours of testing).
- **3,192** responses and comments to questions from the ***Human Factors Structured Interview Questionnaire***.
- **Final Report** on the "Pilot" study is 420 pages (includes 79 summary tables of results and six appendices containing an additional 144 tables).

Statistical analyses

Redundant statistical approaches were used to test primary hypotheses (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 in subsequent slides relative to the primary hypotheses and to other key findings and recommendations regarding fatigue management in long-haul trucking.

Hypothesis 1: FMT FEEDBACK would improve driver alertness and/or reduce driver drowsiness at night

Combined US and Canadian data.

Composite results from pooling data from the two study phases yielded support for the hypothesis. During night driving, FMT FEEDBACK significantly reduced slow eyelid closures (PERCLOS) as measured by ***CoPilot®*** ($p = 0.004$), increased the ***SafeTRAC®*** estimate of driver "alertness" ($p = 0.002$) and decreased lane tracking variability ($p = 0.007$).

But:

PVT lapses were elevated in each study phase in the FEEDBACK condition, relative to the NO FEEDBACK condition, and the increase occurred during the portion of the 24-hr day in which drivers most often were driving (i.e., daytime for the Canadian drivers, and nighttime for the US drivers). This finding suggests there may be a fatigue-related "cost" to the added effort (in attention and compensatory behaviors) required to respond to the FEEDBACK from the FMT devices.

Hypothesis 2: FMT FEEDBACK would increase driver sleep time

Phase 1: Canadian drivers.

None of the ***SleepWatch®*** actigraphy outcomes demonstrated systematic differences between the NO FEEDBACK and FEEDBACK conditions for all days combined (i.e., work days and non-workdays). There was also no evidence from drivers' **Daily Diaries** to support the hypothesis that FMT FEEDBACK resulted in increased sleep time on workdays relative to NO FEEDBACK.

Phase 2: US drivers.

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 for all days combined (i.e., work days and non-workdays). There was no evidence from drivers' **Daily Diaries** of increased sleep time on workdays when FMT relative to NO FEEDBACK (all days combined).

Hypothesis 2: FMT FEEDBACK would increase driver sleep time

Combined US and Canadian data (workdays vs. non-workdays).

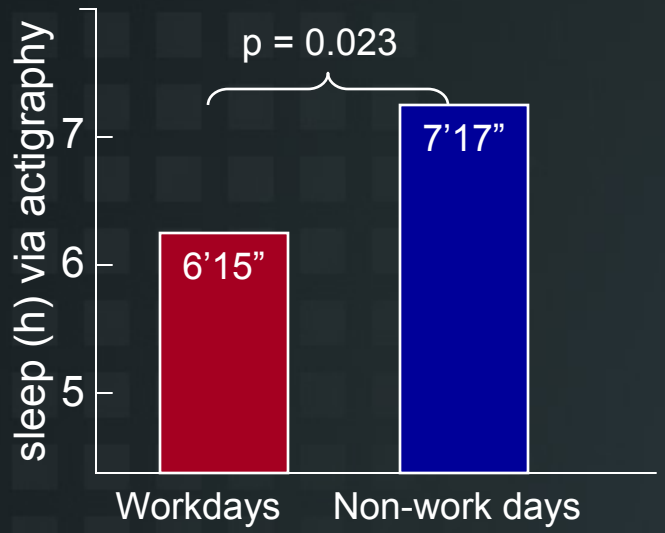
Sleep duration per 24 hours as determined by ***SleepWatch®*** (actigraphy) was analyzed for both study phases, separating workdays and non-workdays. There was clear evidence in support of the hypothesis. In contrast to **workdays**, where FMT FEEDBACK had no effect on sleep time, there was a significant increase in mean sleep duration during **non-workdays** in the FEEDBACK condition relative to the NO FEEDBACK ($p = 0.046$). Drivers increased their non-workday sleep durations by an average of 26 minutes per day over sleep duration on days off in the NO FEEDBACK condition.

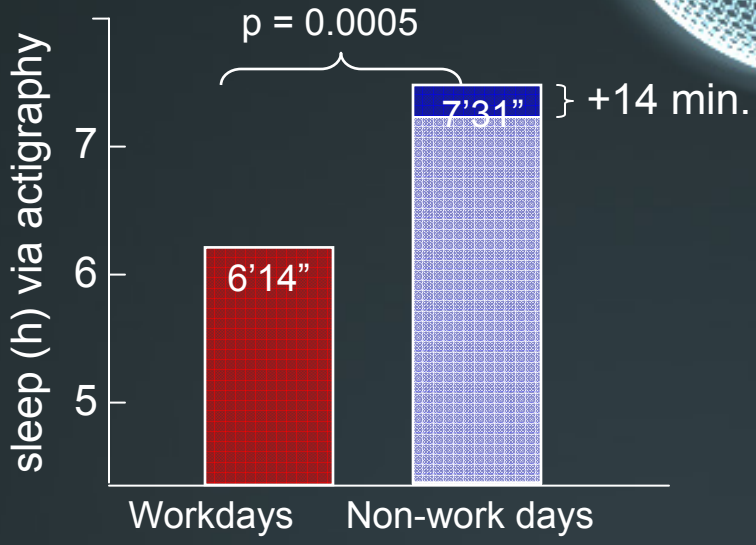
Hypothesis 2: FMT FEEDBACK would increase driver sleep time

NO FEEDBACK condition

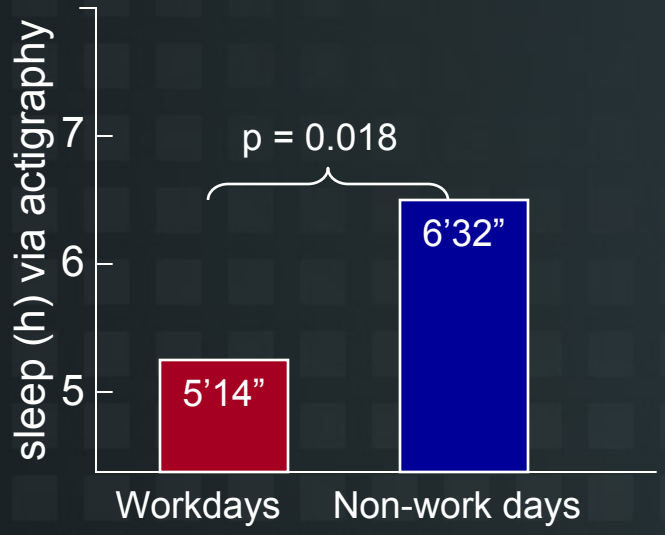
FMT FEEDBACK condition

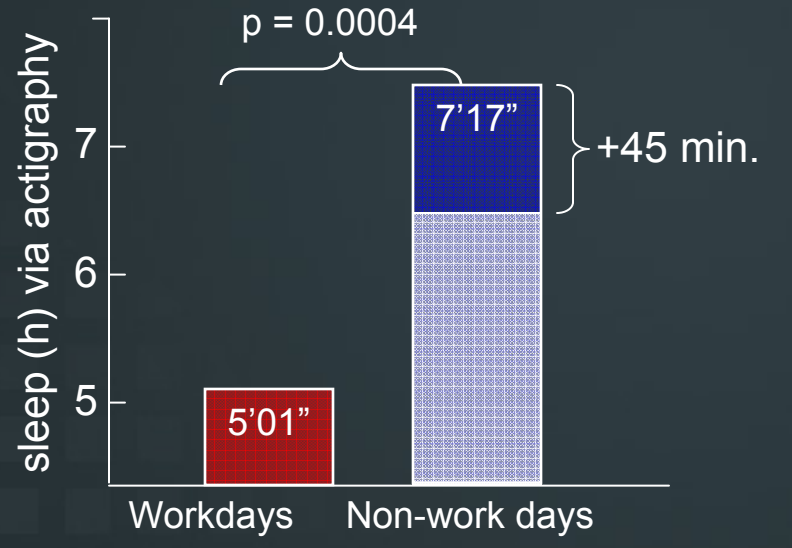
Phase 1. Canadian drivers





Phase 2. US drivers





Drivers' HFSIQ reactions to the FMT technologies

Drivers' responses to ***Human Factors Structured Interview Questionnaire*** after 2-wk NO FEEDBACK period and at end of 2-week FEEDBACK period.

- Both Canadian and US drivers were very positive about the ***Education on Alertness and Fatigue Management*** course.
- 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 FMT technologies drivers were more enthusiastic about the benefits of the ***Howard Power Center Steering®*** system and ***SafeTRAC®***, than they were about ***SleepWatch®*** and ***CoPilot®***.
- ***Howard Power Center Steering®*** and ***SafeTRAC®*** both interface with the vehicle, while ***SleepWatch®*** and ***CoPilot®*** interface with the driver. Drivers may prefer fatigue management be carried out by way of vehicle monitoring more so than driver monitoring.

Drivers' HFSIQ reactions to the FMT technologies

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.

Recommendations for future work outside the scope of the project

- Continue development of fatigue management technologies.
  Both driver monitors and vehicle-based monitors. Drivers appeared to prefer latter mode for fatigue management.
- Provide fatigue management courses.
  Despite differences in country of operation, hours of service, type of trucks, and a host of other factors, US and Canadian drivers want more fatigue management training.
- Develop PVT as a personal aid to identifying fatigue.
  Drivers indicated the **Psychomotor Vigilance Task** could be used as a personal check on fatigue or fitness-for-duty, especially if the PVT could be reduced in duration.

Recommendations for future work outside the scope of the project

- Identify barriers to drivers obtaining adequate sleep.

  Drivers averaged 5-6¼ hours of sleep per day during workdays, despite very different work schedules in Canada and the U.S. Recent scientific work shows that severe sleep debt and deficits in behavioral alertness can develop within a few days at these sleep durations. The fact that project participants markedly increased their sleep durations on non-workdays also supports the view that they were suffering sleep debts. Work is needed to identify factors that determine when and where drivers obtain sleep on workdays and non-workdays; the barriers to obtaining adequate sleep on workdays; and what convinces drivers to get more recovery sleep on non-workdays.

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When time in bed for sleep is chronically ≤ 7h, cumulative deficits in vigilance performance accumulate

Van Dongen et al. (Dinges lab)
SLEEP (2003)
NIH-funded study

14-day condition	PVT lapses
8h TIB per night	no change
6h TIB per night	**increase****
4h TIB per night	**increase****
2h TIB per night	**increase****
0h TIB per night	**increase****

**statistically significant increase

Belenky et al. (WRAIR lab)
J Sleep Res (2003)
DOT-funded study

7-day condition	PVT lapses
9h TIB per night	no change
7h TIB per night	no change*
5h TIB per night	**increase****
3h TIB per night	**increase****

*PVT response speed showed a significant decrease