Fatigue Management for the 21st Century

10TH INTERNATIONAL CONFERENCE ON MANAGING FATIGUE

23 MARCH 2017

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Outline

1. Background
   • Definition of ‘fatigue’
   • Brief history of ‘hours of service” (HOS) rules in the US

2. Sleep and Performance: State of the Relevant Science
   • The interactive effects of Sleep, ‘Time on Task’, and Circadian Rhythm
   • Sleep Banking: Implications for the operational environment
   • Administration of caffeine across multiple days of sleep restriction

3. The Walter Reed Alertness Management System
   • Hardware
   • Software
   • Interventions

4. 2B-Alert Mathematical Performance Prediction Model
   • Recent Improvements
   • Illustration of capabilities (website version)
Fatigue

- **Physical fatigue**
  - Muscle weakness; lack of strength.
  - Some causes: Illness, medication, heavy physical exercise.

- **Mental fatigue**
  - Decreased wakefulness; sleepiness; drowsiness.
  - Decreased state of attention.
  - Some causes: Illness, medication, lack of mental stimulation, lack of adequate sleep (many possible reasons), time of day (Circadian rhythm), physical fatigue.

From FMSCA Presentation by Tom Yager in 2007: “Commercial Motor Vehicle Drivers’ Hours of Service: Background Information”
What is the Purpose of HOS rules?

**Hours of Service (HOS) Rule Purpose**

– Reduce truck and bus crashes by preventing driving of a commercial motor vehicle (CMV) while fatigued. Do so by providing adequate opportunities for sleep by a healthy CMV driver.

From FMSCA Presentation by Tom Yager in 2007: “Commercial Motor Vehicle Drivers' Hours of Service: Background Information”
Fatigue

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Classically, **fatigue** is a hypothetical construct invoked to account for subjective tiredness and associated performance deficits resulting from the application of physical and/or mental effort over time – i.e., “time on task” effects.

**Sleepiness** is a hypothetical construct invoked to account for deficits in alertness and performance resulting from (a) extended wakefulness/sleep loss and/or (b) wakefulness during the descending phase of the circadian rhythm of alertness (from approximately 2300 to 0800 hrs).

In the operational environment, **extended ‘time on task’ often results in extended wakefulness/sleep loss** (stretching into the early morning hours) – and the rate at which operational performance declines during a military operation is function of the **combined** effects of both factors.

**Fatigue = Sleepiness + Time on Task**
80-Year Anniversary of HOS Rules

In 1937, the (now-abolished) Interstate Commerce Commission (ICC) established the first HOS rules for commercial drivers.

These rules limited commercial drivers to 12 hours of work within a 15-hour on-duty period. Work was defined as “loading, unloading, driving (10 hrs limit), handling freight, preparing reports, preparing vehicles for service, or performing any other duty pertaining to the transportation of passengers or property.”

The ICC intended that the 3-hour difference between “on-duty” and “hours of work” would be used for meals and rest breaks. The weekly maximum was limited to 60 hours over 7 days (non-daily drivers), or 70 hours over 8 days (daily drivers). Thus, within the 24-hour day, drivers would be allowed 12 hours of actual work within a 15-hour period (i.e., with three hours of breaks), and would have 9 hours off-duty to sleep and engage in other activities of daily living.
# Hours of Service Over the Years

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Driving</strong></td>
<td>10 hours</td>
<td>10 hours</td>
<td>11 hours</td>
<td>11 hours</td>
</tr>
<tr>
<td><strong>Duty Period</strong></td>
<td>24 consecutive hours from duty start time</td>
<td>15-hour driving window, extendable by breaks</td>
<td>14-hour driving window, not extendable by breaks</td>
<td>14-hour driving window, not extendable by breaks</td>
</tr>
<tr>
<td><strong>Off-duty</strong></td>
<td>8 hours</td>
<td>8 hours</td>
<td>10 hours</td>
<td>10 hours</td>
</tr>
<tr>
<td><strong>7/8 Day Limits</strong></td>
<td>60/70 hours in 7/8 days</td>
<td>60/70 hours in 7/8 days</td>
<td>60/70 hours in 7/8 days</td>
<td>60/70 hours in 7/8 days</td>
</tr>
<tr>
<td><strong>Restart of 60/70 Hr Period</strong></td>
<td>None</td>
<td>None</td>
<td>34-hour restart</td>
<td>34-hour restart</td>
</tr>
<tr>
<td><strong>Sleeper Berth</strong></td>
<td>2 undefined periods totaling 8 hours</td>
<td>2 periods totaling 8 or more hours; each a minimum of 2 hours</td>
<td>2 periods totaling 10 or more hours; each a minimum of 2 hours</td>
<td>2 periods totaling 10 or more hours; one at least 8 consec. Hours; other at least 2 off duty or sleeper</td>
</tr>
<tr>
<td><strong>Time period reference</strong></td>
<td>24 hour period from duty start time</td>
<td>Hours accumulated following 8 hours off duty</td>
<td>Hours accumulated following 10 hours off duty</td>
<td>Hours accumulated following 10 hours off duty</td>
</tr>
</tbody>
</table>

From FMSCA Presentation by Tom Yager in 2007: “Commercial Motor Vehicle Drivers' Hours of Service: Background Information”
# Current Hours of Service Rules

## Property-Carrying Drivers

| **11-Hour Driving Limit** | May drive a maximum of 11 hours after 10 consecutive hours off duty. |
| **14-Hour Limit** | May not drive beyond the 14th consecutive hour after coming on duty, following 10 consecutive hours off duty. Off-duty time does not extend the 14-hour period. |
| **Rest Breaks** | May drive only if 8 hours or less have passed since end of driver’s last off-duty or sleeper berth period of at least 30 minutes. Does not apply to drivers using either of the short-haul exceptions in 395.1(e). [49 CFR 397.5 mandatory “in attendance” time may be included in break if no other duties performed] |
| **60/70-Hour Limit** | May not drive after 60/70 hours on duty in 7/8 consecutive days. A driver may restart a 7/8 consecutive day period after taking 34 or more consecutive hours off duty. |

**Notice:** The [Consolidated and Further Continuing Appropriations Act of 2015](https://www.fmcsa.dot.gov/regulations/hours-service/summary-hours-service-regulations) was enacted on December 16, 2014, suspending enforcement of new requirements for use of the 34-hour restart, pending a study. Based on the findings from the study, the 34-hour restart rule in operational effect on June 30, 2013, is restored to full force and effect. The requirement for two off-duty periods of 1:00 a.m. to 5:00 a.m. in section 395.3(c) of the Agency’s hours-of-service rules will not be enforced, nor will the once-per-week limit on use of the restart in 395.3(d).

**Sleeper Berth Provision:** Drivers using the sleeper berth provision must take at least 8 consecutive hours in the sleeper berth, plus a separate 2 consecutive hours either in the sleeper berth, off duty, or any combination of the two.

## Passenger-Carrying Drivers

| **10-Hour Driving Limit** | May drive a maximum of 10 hours after 8 consecutive hours off duty. |
| **15-Hour Limit** | May not drive after having been on duty for 15 hours, following 8 consecutive hours off duty. Off-duty time is not included in the 15-hour period. |
| **60/70-Hour Limit** | May not drive after 60/70 hours on duty in 7/8 consecutive days. A driver may restart a 7/8 consecutive day period after taking 34 or more consecutive hours off duty. |

**Sleeper Berth Provision:** Drivers using the sleeper berth must take at least 8 hours in the sleeper berth, and may split the sleeper berth time into two periods provided neither is less than 2 hours.

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From FMCSA website: [https://www.fmcsa.dot.gov/regulations/hours-service/summary-hours-service-regulations](https://www.fmcsa.dot.gov/regulations/hours-service/summary-hours-service-regulations)  
Updated: Thursday, March 9, 2017
Can we do better?
The “Big Three” Factors that Interactively Determine Military Operational Performance:

A. Sleep Debt

B. Circadian Rhythm of Alertness

C. Time on Task
Percentages of crashes due to fatigue as a function of hours of driving

Source: Federal Motor Carrier Safety Administration
Circadian Rhythm, Sleep Deprivation, and Time on Task Interactions

Adapted from: Wesensten et al. (2004). Aviation, Space, and Environmental Medicine, 75, 520-525.
Individual Sleep History:

“Sleep Banking”. The more sleep that an individual obtains prior to an operation involving sleep loss (either acute total sleep deprivation or multiple days of sleep restriction) the better the performance.
1. 14-day AT-HOME “sleep schedule assessment”
   a. Reported usual TIB ~7 hrs.
   b. Used to determine “Habitual” sleep schedule

2. In-laboratory Overnights
   Sleep Extension/ Habitual (7 nights)
   10 (h) OR Habitual (h) TIB

3. Full-time In-laboratory
   Baseline (1 night)
   Sleep Restriction (7 nights)
   Recovery (5 nights)

   PVT, SSS: every hr, 0800-1800, 11 test bouts daily,
   MWT: every 2 hrs, 0800-1800, 6 test bouts daily

Actigraphy
Recovery of PVT Lapses

In-lab Day

*Restrict x Group, p = .01
+Recov x Group, p = .03

Estimated means, controlling for age.
The Sleep Reservoir: (what we used to think)

Sleep @ time t?

No

Performance Decrement Algorithm
\[ P_t = P_{t-1} - kw(P_{t-1}', W_t, M_p) \]

Yes

Performance Increment Algorithm
\[ P_t = P_{t-1} + ks(P_{t-1}', S_t, M_p) \]

Initialized: Time, Date, Time Zone

Circadian Rhythm Algorithm
\[ C_t = a \cos \left( \frac{\pi (t - c)}{720} \right) + b \cos \left( \frac{\pi (t - d)}{360} \right) \]

- \( P_t \) = performance potential at time t
- \( kw \) = rate of decline during wake
- \( ks \) = rate of recuperation during sleep
- \( M_p \) = specific measure of performance
- \( C_t \) = circadian influence at time t
- \( a \) and \( b \) = transient time zone shift factors
- \( c \) and \( d \) = acrophase of 24- and 12-hour rhythms
The Sleep Reservoir: (what we now think)

Sleep @ time t?

- **Performance Decrement Algorithm**
  \[ P_t = P_{t-1} - kw(P_{t-1}', W_t, M_p) \]

- **Performance Increment Algorithm**
  \[ P_t = P_{t-1} + ks(P_{t-1}', S_t, M_p) \]

- **Circadian Rhythm Algorithm**
  \[ C_t = a \cos \left( \frac{\pi (t - c)}{720} \right) + b \cos \left( \frac{\pi (t - d)}{360} \right) \]

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*\( C_t \) = circadian influence at time t
\( a \) and \( b \) = transient time zone shift factors
\( c \) and \( d \) = acrophase of 24- and 12-hour rhythms*
Performance Capacity

7 hrs  9 hrs
Recovery of PVT Lapses

*Restrict x Group, \( p = .01 \)

+Recov x Group, \( p = .03 \)

Estimated means, controlling for age.
State of the Relevant Science III

Effects of daily use of caffeine across multiple days of sleep restriction
Effectiveness of Caffeine Across 5 Days of Sleep Restriction and Effects on Subsequent Recovery

![Graph showing sleep latency test results with caffeine and placebo. The graph displays the mean sleep latency test values (min) across 5 days of sleep restriction (SR1 to SR5) and subsequent recovery (R1, R2, R3) with caffeine (*) and placebo (○). The graph indicates a significant difference between caffeine and placebo on days SR2 and SR3.](image)
The WRAIR Alertness Management System

Wrist Actigraphy

- Because that which cannot be measured in the field cannot be managed in the field

Performance Prediction (2B-Alert) Model

- So that operational performance degradation can be anticipated and planned for, and informed decisions regarding dosage and timing of countermeasures can be made.

Armamentarium of Countermeasures

- Stimulants to restore/maintain performance during sustained/continuous operations when there is little or no opportunity to sleep
- Sleep inducers to enhance recuperative sleep when needed
2B-Alert Model: Recent Improvements

1. Smartphone version has the ability to “learn” the individual when he/she intermittently performs a PVT on the smartphone over a 2-week period - including individual differences in (a) sensitivity/resilience to sleep loss and (b) responsiveness to caffeine.

2. Improved prediction of the effects of caffeine during acute sleep loss and chronic sleep restriction – effects on both performance and subsequent recuperation rate during recovery sleep.

3. Next iteration will include a function that provides specific guidance re: timing and dose level of caffeine to optimize performance for any operational scenario.
2B-Alert Web

https://2b-alert-web.bhsai.org/2b-alert-web/login.xhtml

NOTE: Currently, this website only works if accessed with a PC. The website fails to recognize some commands from Apple computers.
2B-Alert Web

Predict the effects of sleep/wake and caffeine on alertness

This software tool predicts alertness of an “average” individual as a function of sleep/wake schedule and caffeine consumption. Specifically, this tool allows users to manually enter a sleep/wake schedule and caffeine dosing and timing, and displays the corresponding predictions for three different psychomotor vigilance task alertness statistics.

This tool can be used to:
1. Assess the effect of different sleep/wake schedules and caffeine consumption
2. Design sleep/wake and caffeine schedules to optimize alertness
3. Generate hypotheses that can be experimentally tested

Disclaimer: The 2B-Alert Web tool is for educational and informational purposes only. It should not be used for or relied upon for predicting the performance of any specific individual or the likelihood of errors or accidents by any specific individual or a group of individuals.

Key References:

Cite 2B-Alert Web as:
Initial 2B-Alert Screen

2B-Alert Web
Predict the effects of sleep/wake and caffeine on alertness

Y-Min: 200.0  Y-Max: 550.0

Show Values: On  Alertness Statistic: Mean Response Time (ms)
Schedules: Sleep Restriction + Caffeine

Sleep Schedule
<table>
<thead>
<tr>
<th>Day</th>
<th>Start Time</th>
<th>Sleep End Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>23:00</td>
<td>07:00</td>
</tr>
<tr>
<td>2</td>
<td>04:00</td>
<td>07:00</td>
</tr>
<tr>
<td>3</td>
<td>04:00</td>
<td>07:00</td>
</tr>
<tr>
<td>3</td>
<td>23:00</td>
<td>07:00</td>
</tr>
<tr>
<td>5</td>
<td>04:00</td>
<td>07:00</td>
</tr>
<tr>
<td>6</td>
<td>04:00</td>
<td>07:00</td>
</tr>
<tr>
<td>6</td>
<td>23:00</td>
<td>07:00</td>
</tr>
<tr>
<td>7</td>
<td>23:00</td>
<td>07:00</td>
</tr>
</tbody>
</table>

Caffeine Schedule
<table>
<thead>
<tr>
<th>Day</th>
<th>Time</th>
<th>Dose (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>08:00</td>
<td>200</td>
</tr>
<tr>
<td>2</td>
<td>13:00</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>08:00</td>
<td>200</td>
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<tr>
<td>3</td>
<td>13:00</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>08:00</td>
<td>200</td>
</tr>
<tr>
<td>5</td>
<td>13:00</td>
<td>100</td>
</tr>
<tr>
<td>6</td>
<td>08:00</td>
<td>200</td>
</tr>
<tr>
<td>6</td>
<td>13:00</td>
<td>100</td>
</tr>
</tbody>
</table>

WRAIR

Initial 2B-Alert screen
Cleared of Data
Schedule: 8, 8, 5, 3.5, 5, 8, 8.75 Hrs of Sleep per Night
Goal: Maintain Performance Above 0.06 BAC Equivalency Level
2nd Dose of Caffeine Added
2nd Dose of Caffeine Added
Add 1 Hour Nap on Morning of Day 5
Long-Lasting Effect

Note the relatively long-lasting beneficial effect of a nap.
Zoom and Cursor Scroll Functions
Demo 2
Schedule: 8, 8, 5, 3.5, 5, 8  Hours of Sleep per Night
Three Strategically Timed 200 mg Doses of Caffeine
...combined with three 30-minute noontime naps
Thank You

This material has been reviewed by the Walter Reed Army Institute of Research, and there is no objection to its presentation. However, the opinions or assertions contained herein are the private views of the author and are not to be construed as official or as reflecting the position of the Department of the Army or the Department of Defense.

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