# Control Room Management of Fatigue Effects

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**DISCLAIMER**

**The views and recommendations presented here do not necessarily represent the policies of the PHMSA or the DOT**

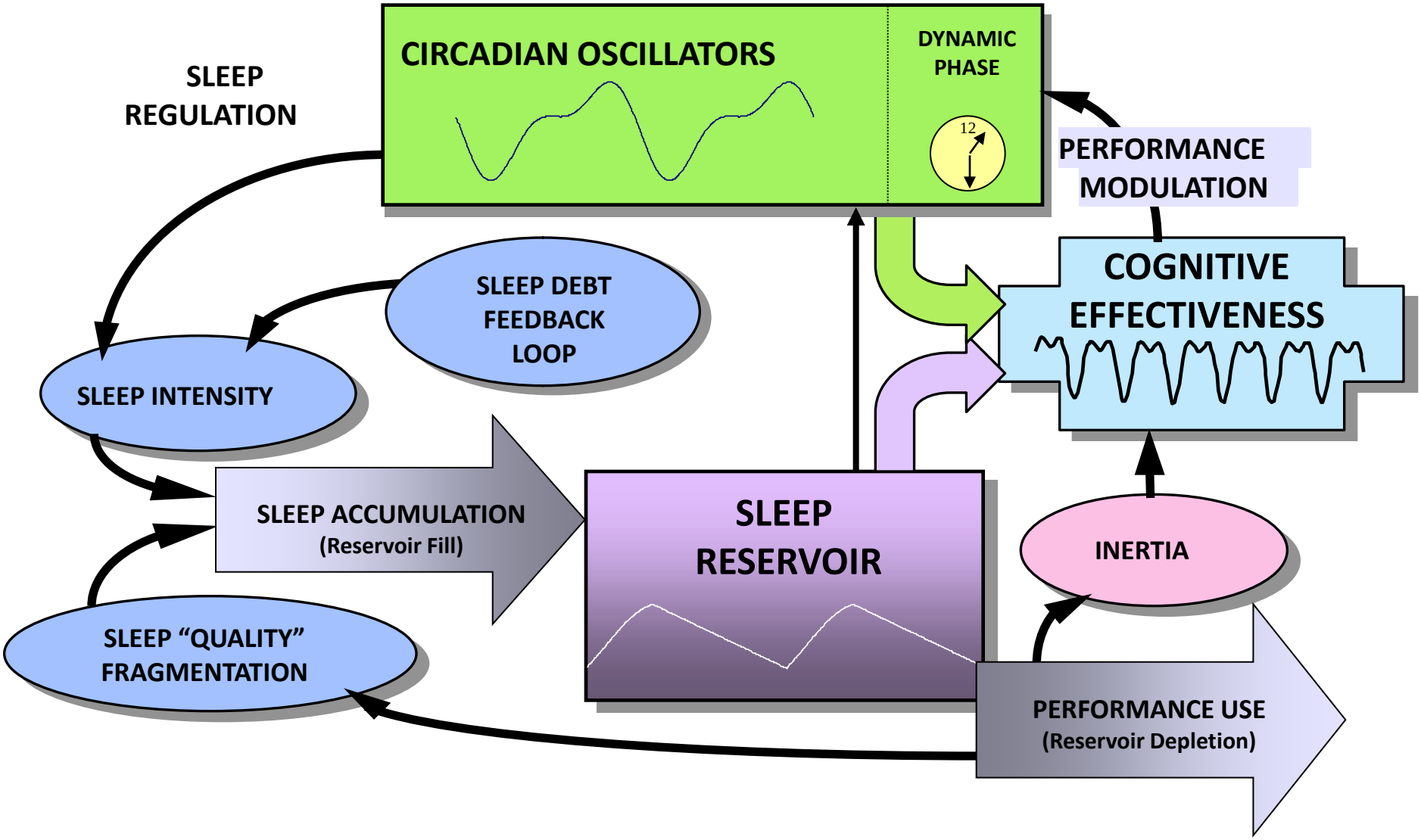
# Myths

**Myths about sleep and shiftwork:**

- **Sleep is a passive, vegetative state -- false**
- **“I can sleep when I die” -- completely inappropriate in safety-sensitive jobs**
- **24/7 shiftwork scheduling is an art, and not quantitative -- false**
- **Other-industry shiftwork guidelines do not apply to my industry -- true only if your employees are not human**
- **Fatigue can’t be measured -- sleep has been quantified for 50 years, and fatigue for 15 years**

# Schematic of SAFTE™ Simulation Model

*Sleep, Activity, Fatigue and Task Effectiveness Model*



# What is Shiftwork?

**"[S]hift work refers to any nonstandard work schedule. It includes evening or night work; a rotating shift, in which hours change regularly (e.g., from day to evening to night); a split shift, in which a period of work is followed by a break and then a return to work; and extended duty hours, consisting of long periods of work (usually over 12 hours)"**

Office of Technology Assessment, 1991

# Shiftwork Types

**Define the types of shiftwork properly and identify their presence in your operations:**

- **Systems without night or weekend work (the “9-to-5” weekday job)**
- **Systems with night work but without weekend work**
- **Systems with both night and weekend work, or "continuous shiftwork." These systems are also called “24/7” systems.**
  - **Regular, fixed**
  - **Irregular; varying numbers of crews and shift lengths; for example, the 5-day irregular work week of Federal Aviation Administration air traffic controllers**
  - **Regular, rotating; for example, four crews and rotating 8-h shifts**

P Knauth, J Rutenfranz (1976), *International Archives of Occupational and Environmental Health*, v. 37, pp. 125-137.

# Fatigue Risk Management

**What are some of the important components of a fatigue risk management program?**

1. **Define the types of shiftwork properly and identify their presence in your operations**
2. **Quantify approximately the specific consequences and risks of fatigue-related incidents and accidents for your operations**
3. **Implement fatigue risk management planning, execution and feedback loops from the top down in your management structure**
4. **Apply shift scheduling principles in planning shift schedules**
5. **Use at least four crews in 24/7 schedules**
6. **For 24/7 8-hour shifts, use shift system 3nW:1nF with n greater than 1; for 12-hour shifts, use shift system 2nW:2nF**

# Fatigue Risk Management

7. (Make specific plans to counter expected fatigue effects in the pre-dawn hours, the last 4 hours of a 12-hour shift and during successive night shifts)
8. (Use NIOSH and Sleep Foundation materials in educational programs for shift and night workers)
9. Teach workers about sleep hygiene, napping and tactical caffeine use
10. (Implement workplace napping)
11. Encourage the use of prescription aids for individuals, if needed
12. Implement the use of semi-quantitative fatigue factors when analyzing the causes of incidents/accidents

# Fatigue Effects

| | |
|---|---|
| **1. Individual Differences**<br>**2. Basic Cognitive Functions**<br>2a. Working memory impairment<br>2b. Anterograde amnesia<br>2c. Retrograde amnesia<br>2d. Cognitive impairment<br>2e. Slowed response time (RT) and reduced response accuracy<br>2f. Impaired manual control<br>2g. Vigilance impairment<br>2h. Narrowed attention<br>2i. Hypnagogic hallucinations | **3. Complex Cognitive Functions**<br>3a. Willingness to accept greater risk<br>3b. Loss of situation awareness<br>**4. Mood & Motivation Impairment** |

JC Miller, DR Eddy (2009). *Operational Risk Management of Fatigue Effects II*. Technical report 2009-0030, Air Force Research Laboratory, Brooks City-Base, TX (ADA501985)

# Fatigue Effects

| | |
|---|---|
| **5. Physiological**<br>5a. General malaise<br>5b. Reduced aerobic capacity<br>5c. Drowsiness<br>5d. Sleep debt and need for recovery sleep<br>5e. Falling asleep on the job<br>5f. Dizziness<br>5g. Decreased altitude tolerance<br>5h. Decreased thermal tolerance<br>5i. Decreased acceleration tolerance<br>5j. Cardiovascular health effects<br>5k. Gastrointestinal health effects | **6. Physiological Interactions**<br>6a. Worsening of alcohol effects<br>6b. Modulation of drug effects<br>**7. Interpersonal/Team Interactions**<br>7a. Reduced interpersonal communications<br>7b. Impairment of shared situation awareness |

**Look at dictionary definitions of the word "stupid."**

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# Consequences

**Operational Risk Management (ORM)**

1. **What are the specific <u>consequences</u> of fatigue-related incidents or accidents from your operations?**
   - **Degrees of consequence should be characterized at least semi-quantitatively**
   - **Risks to the public**
   - **Risks to your employees**

**You are the best judge**

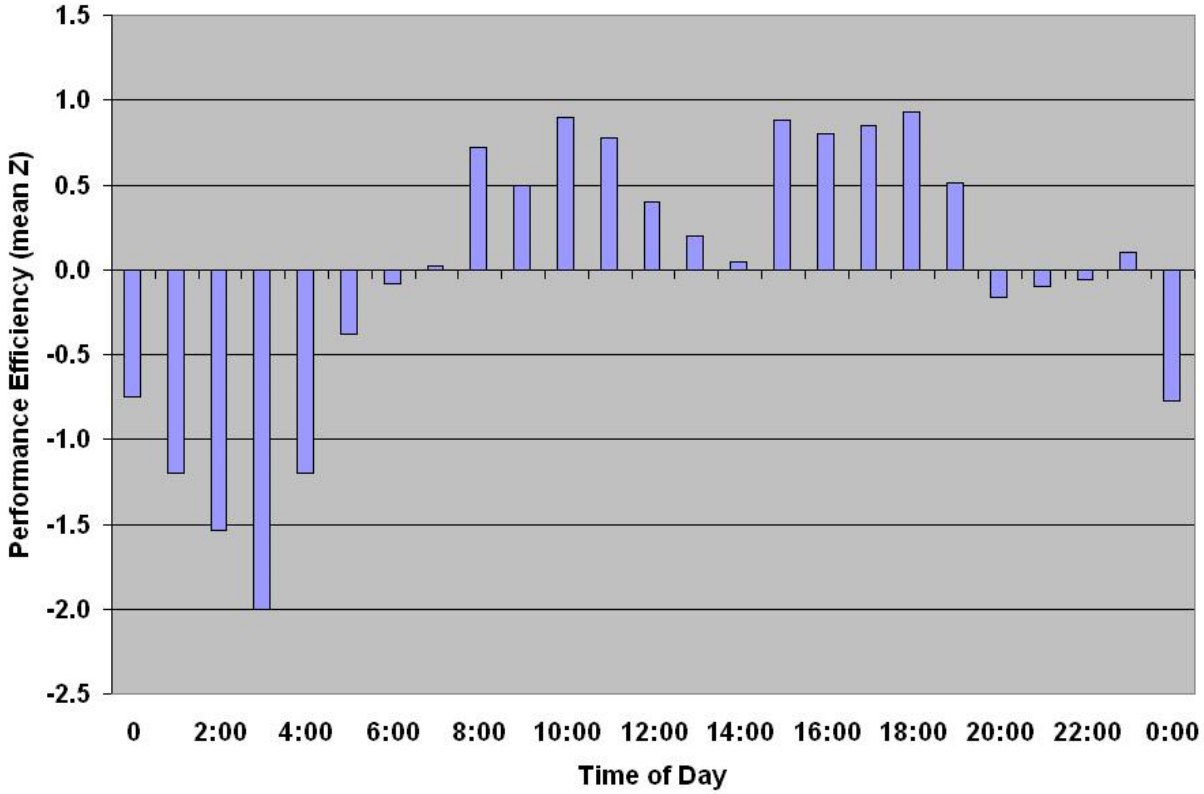
# Likelihood

**Operational Risk Management (ORM)**

2. **What are the relative risks of fatigue-related incidents or accidents within your operations?**
   - **Degrees of risk should be characterized at least semi-quantitatively**
   - **Circadian rhythm effects**
   - **Shift length effects**
   - **Multi-day effects**

# Circadian Rhythm Effects

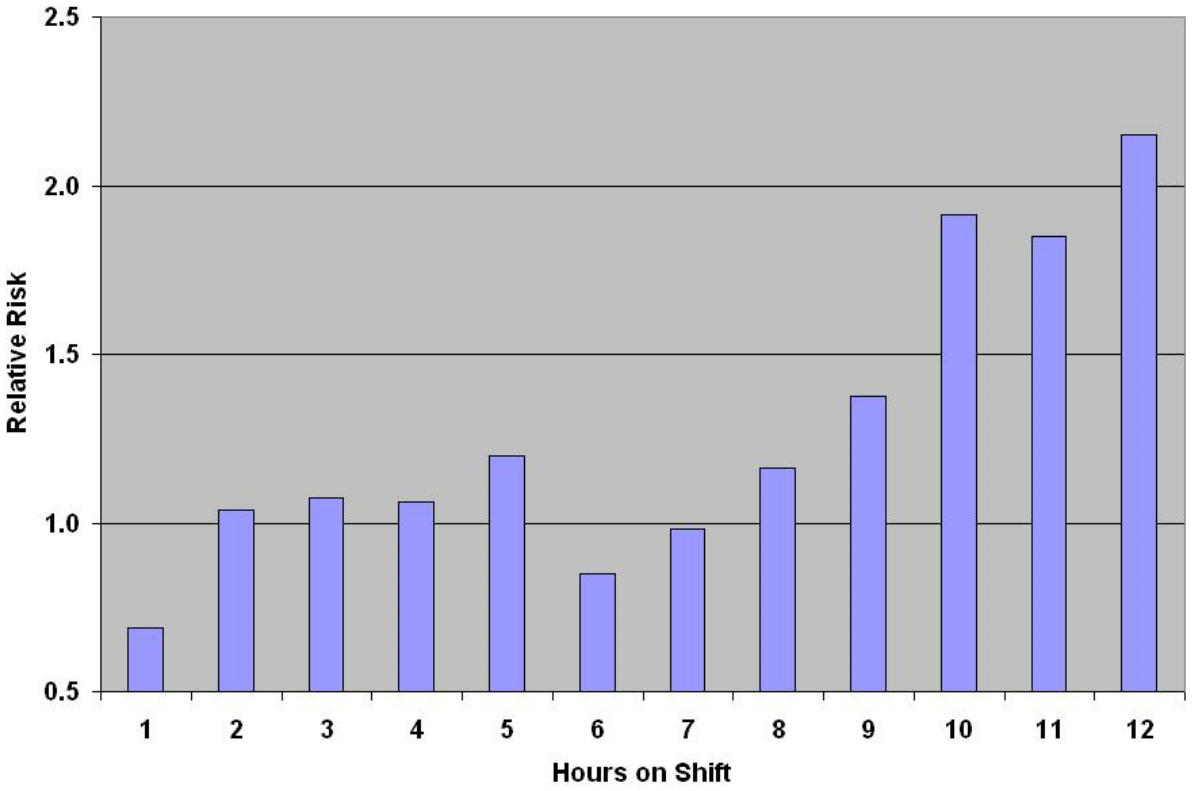
**"…'real-job' speed and accuracy measures are only above average between 07:00 h and 19: h, at all other times efficiency is likely to be relatively impaired, especially so during the early hours of the morning." (Folkard & Tucker, 2003, three studies)**




Folkard S, Tucker P. Shift work, safety and productivity. *Occupational Medicine*, v. 53, no. 2, pp. 95-101, 2003. From the Body Rhythms and Shiftwork Centre, University of Wales, Swansea.

# 12-Hour Shift Length Effects

**"…risk increased in an approximately exponential fashion with time on shift such that in the twelfth hour it was more than double that during the first 8 h." (Folkard & Tucker, 2003, four studies)**

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# 12-Hour Shift Length Effects

***Acute*** **cognitive fatigue acts within a shift:**

- **Diminished mental capability due to normal wakefulness**
- **Occurs between two major sleep periods and degrades task performance**
- **Performance decrement should be eliminated after one good-quality, nocturnal, 8-hour sleep period**

# 12-Hour Shift Length Effects

***Time-on-task*** **fatigue acts within a shift:**

- **Repeated, demanding work causes fatigue and the need for recovery**
- **May be or include habituation and/or boredom**
- **May be additive with acute fatigue**
- **If the individual cannot change tasks, then the effects of task-specific fatigue cannot be avoided**
- ***Technostress*****: Work that is assisted by automation generally requires specific, fine-motor and visual functions, vigilance, and repetitive operations**
  - **This work produces task-specific fine-motor fatigue, visual fatigue, vigilance failures, monotony, and repetitive-stress injuries**

# 12-Hour Shift Length Effects

**Bottom line about 12-hour shifts:**

- **12-hour shifts, compared to 8-hour shifts, have both advantages and disadvantages**

**Advantages:**

- **Greater job satisfaction, fewer recruiting difficulties, improved morale, and reduced absenteeism and attrition**
- **Work compression, allowing more consecutive days off, more family and leisure time, and less personal time taken from work**
- **Fewer shift changes per day, allowing reduced number of communication errors, improved continuity of operations, and reduced commute time and cost**

# 12-Hour Shift Length Effects

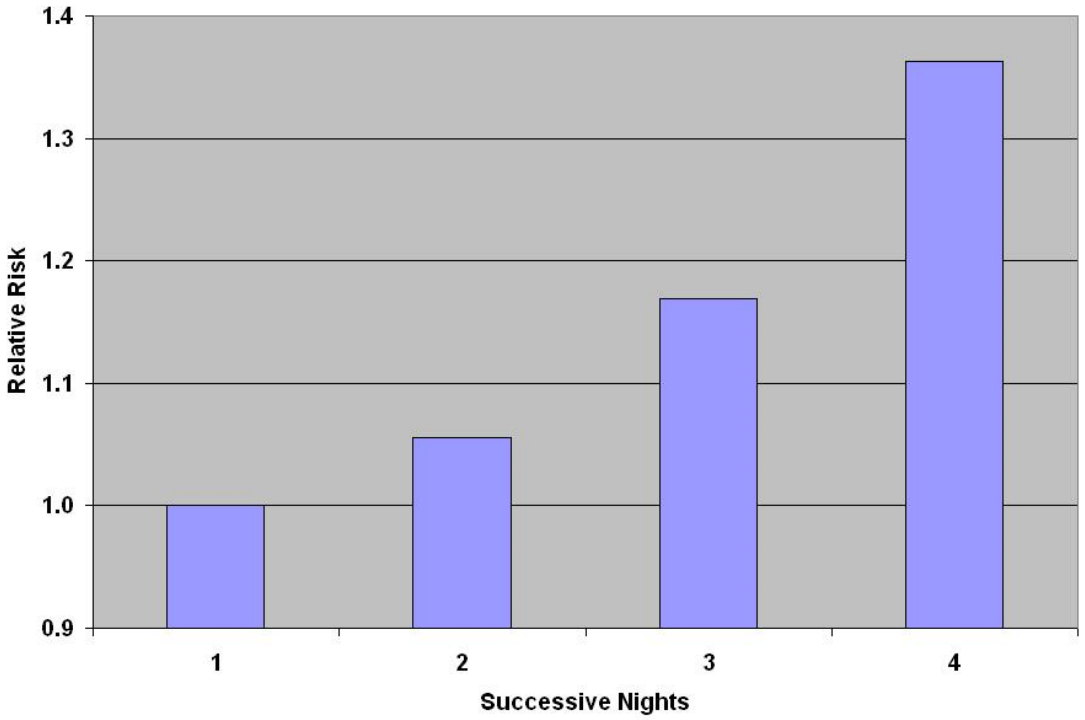
**Disadvantages:**

- **Due to more consecutive days off, workers lose touch with operations and may engage in moonlighting, long-distance travel, or exhausting recreation, and return to work fatigued**
- **Because 12 hours of work per day is more fatiguing than 8 hours, alertness and safety decline, workers may work at a slower pace, 12-hour night shifts are more difficult than 8-hour night shifts, and 12-hour shifts may be difficult for older workers**

**Use the advantages wisely and protect the system from the effects of the disadvantages**

# Multi-Day Effects

**"…risk was ~6% higher on the second night, 17% higher on the third night and 36% higher on the fourth night." (Folkard & Tucker, 2003)**




Folkard S, Tucker P. Shift work, safety and productivity. *Occupational Medicine*, v. 53, no. 2, pp. 95-101, 2003. From the Body Rhythms and Shiftwork Centre, University of Wales, Swansea.

# Multi-Day Effects

***Cumulative*** **fatigue acts across shifts:**

- **Builds up across major waking and work periods when there is inadequate recovery, due to inadequate sleep, between the duty periods**
  - **Sleep debt is cause by getting less than (average) 8 hours of sleep per night**
- **Recovery cannot be accomplished in only one good-quality, nocturnal sleep period**
  - **Recovery sleep requires several nights of sleep longer than (average) 8 hours**

# Multi-Day Effects

***Chronic*** **fatigue may be a result of too much cumulative fatigue:**

- **May set in after several weeks or months of cumulative fatigue**
- **Symptoms may include desire to sleep; apathy; substantial impairment in short-term memory or concentration; muscle pain; multi-joint pain without swelling or redness; headaches of a new type, pattern or severity; unrefreshing sleep; post-exertional malaise lasting more than 24 hours**
- **Long-term presence of chronic fatigue in an individual may contribute to the illnesses associated with long-term shiftwork**
- **Probably relieved only by removal of work demand and extensive recovery sleep**

# Management

**Implement fatigue risk management planning, execution and feedback loops from the top down in your management structure**

- **Need an integrated program addressing the requirements of all stakeholders in the operation**
- **Mature and established fatigue management programs have introduced fatigue countermeasures from a foundation of commitment, cooperation, knowledge, assessment, and program refinement at all levels of the organization**

M McCallum, T Sanquist, M Mitler, and G Krueger. *Commercial Transportation Operator Fatigue Management Reference*, U.S. Department of Transportation Research and Special Programs Administration, 2003.

# Management

- Allocate resources sufficient for establishing and sustaining a fatigue management program
- Involve the highest level of management in supporting, monitoring, and refining the program
- Establish program policy through a joint effort by all stakeholders
- The policy might include:
  - Statement of goals and objectives
  - Specific responsibilities and authority for managing fatigue and alertness
  - Documentation of the support and expertise available to the program
  - Policies regarding employee alertness and fatigue
  - Objectives and methods for program evaluation and refinement

# Scheduling Principles

**Hildebrandt's Principles of Chronohygiene:**

1. **An emphasis on a shift length of no more than 8 hours, with the exception of using a 12-hour shift length for jobs with low physical and emotional work stresses**
2. **Minimum number of consecutive night shifts; preferably, only [three] night shifts in the shift plan**
3. **Each [set of] night shifts followed by [equal set of days] off**
4. **Maximum number of free days on weekends**
5. **At least 104 days off (equal to 52 weekends) per year**

Adapted from G Hildebrandt (1976), *Chronobiologia*, v. 3, no. 2, pp. 113-126

# Scheduling Principles

**Worker-satisfaction principles:**

1. **<u>Good</u> quality of time off: long, continuous periods of time (at least three days)**
2. **<u>Equity</u>: all workers have equal demands for long duty days, night work and weekend work, and equal access to good quality time off and weekends off**
3. **<u>Predictability</u>: the schedule is so easy to understand that workers may apply simple arithmetic to predict their actual work and free days well into the future**

**<u>Circadian stability</u>: the body clock never drifts more than three hours before reversing**

JC Miller (2006). *Fundamentals of Shiftwork Scheduling*. Technical report 2006-0011, Air Force Research Laboratory, Brooks City-Base, TX.

# Schedule Components

**A regular, rotating shiftwork schedule is made up of a number of interacting components:**

- **People**
  - **Number of crews, the optimal number being four**
  - **Employment ratio, to take into account holidays, annual leave, sick leave, training time, etc.**
- **Basic Structure**
  - **Shift system, the ratio of workdays to free days**
  - **Shift plan (*rota*), the sequence of workdays (W) and days off (F) within a shift system**

# Schedule Components

- **Time**
  - **Shift type**
  - **Shift length, usually 8-hour or 12-hour shifts**
  - **Shift overlap (hand-off)**
  - **Shift differentials in terms of different hourly pay rates or different shift lengths across day, swing and night shifts**
  - **Alignment of workdays and days off with weekends**
  - **Shift change times, especially when to begin the morning shift to allow as many shiftworkers as possible to sleep well at night**

# Number of Crews

**The number of hours worked per crew per year depends <u>solely</u> upon the number of crews used in the plan:**

| | Hours Worked | | |
|---|---|---|---|
| **Crews** | **Per Year** | **Per Week** | **Per Day*** |
| 2 | 4368 | 84 | 12 |
| 3 | 2912 | 56 | 8 |
| 4 | 2184 | 42 | 6 |
| Weekday Workers | 2080 | 40 | 5.7 |
| 5 | 1747.2 | 33.6 | 4.8 |
| 6 | 1456 | 28 | 4 |
| 7 | 1248 | 24 | 3.4 |

*364 days per year

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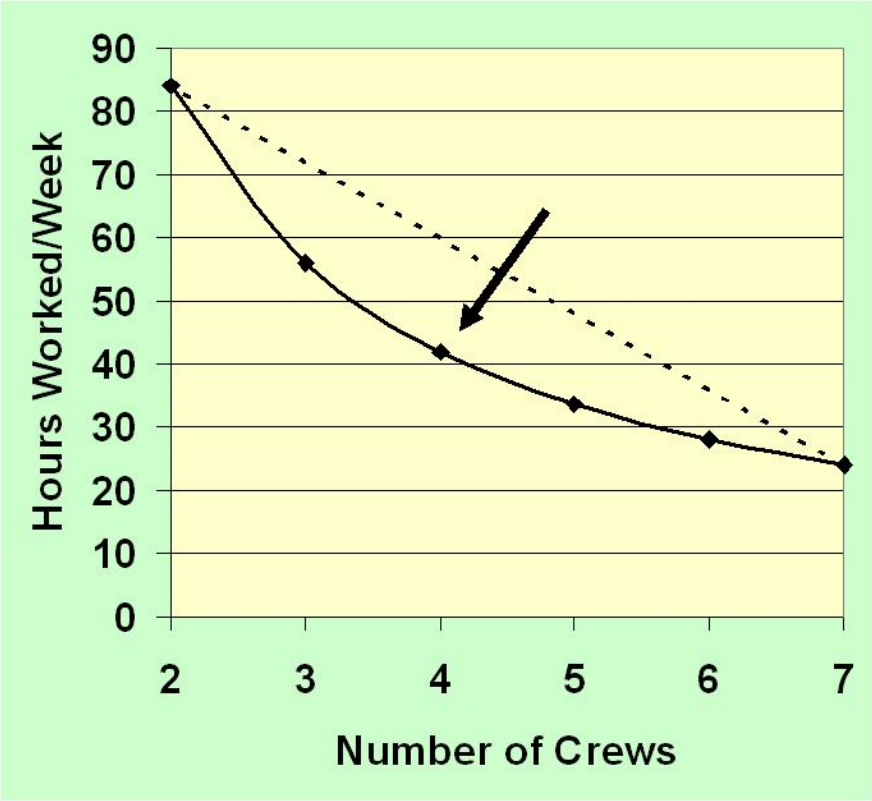
# Number of Crews

**The relationship between the number of crews used and the number of hours worked is a curvilinear function, with the greatest efficiency achieved with four crews:**

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# Shift Systems

**Understand the concept of shift system design for 24/7 operations:**

- **Logical, quantitative usefulness of the 42-hour (average) work week in 4-crew shift work scheduling**
- **Two useful measures for determining the acceptability of a shift system:**
  - **Average number of hours worked per day (or work load)**
  - **Number of days free per year**
- **The *shift system* sets the relative numbers of work (W) and free periods (F; days off), excluding holidays and other days away from shiftwork**

P Knauth, J Rutenfranz (1976), *International Archives of Occupational and Environmental Health*, v. 37, pp. 125-137

P Knauth et al. (1979), *Applied Ergonomics*, v. 10, pp. 9-15

# Shift Systems

**Use a useful shift system for the 42-hour (average) work week for 4-crew schedules:**

**For 8-hour shifts**

**3nW:1nF with n greater than 1**

**For 12-hour shifts**

**2nW:2nF**

**The value of n depends upon factors such as desired work compression and desired speed of rotation in a shift plan…**

P Knauth, J Rutenfranz (1976), *International Archives of Occupational and Environmental Health*, v. 37, pp. 125-137

P Knauth et al. (1979), *Applied Ergonomics*, v. 10, pp. 9-15

# Shift Plans

**How is a shift system used in 24/7 operations?**

- **The shift plan (*rota*) determines the sequence of work (W) and free (F) periods within a shift system**
- **The notation used includes D, S, and N for the work periods, day, swing and night, respectively, and O for free periods (days with no shift start)**
- **One shift system may contain many possible plans**
- **The Continental *rota*, or 2-2-3 plan, is a rapid-rotation plan in the 4-crew, 8-hour, 3nW:1nF, n = 7 (21W:7F) shift system with a 28-day cycle:**

  **DDSSNNNOO DDSSSNNOO DDDSSNNOOO**

- **The Metropolitan *rota*, or 2-2-2 plan, is a rapid-rotation plan in the same system with n = 3 (6W:2F) with an 8-day cycle: DDSSNNOO**

# Shift Plans

- The every-other-weekend-off (EOWO) or Panama plan is a slow-rotation plan in the 4-crew, 12-hour, 1nW:1nF, n = 7 (7W:7F) shift system, quadrupled to a 56-day cycle: WWOOWWWOOWWOOO
  - W = day shifts (D) for 28 days, then night shifts (N) for 28 days; aligned to give weekends off
- A simple, effective, rapid-rotation plan in the 4-crew, 12-hour, 2nW:2nF system uses n = 2 and an 8-day cycle: DDNNOOOO
- The duPont plan is a rapid-rotation, work-compression plan in the 4-crew, 12-hour, 2nW:2nF system with n = 7 (14W:14F), with a 28-day cycle: NNNNOOO DDDONNN OOODDDD OOOOOOO
  - If this plan starts on a Monday, then there are two weekends off in each 28-day month
  - The weakness of the duPont plan is the string of four continuous night shifts. The third and fourth nights of three- and four-night series should be the focus of extraordinary fatigue countermeasures

# Sleep Hygiene

**Sleep, the first line of defense:**

- **The most effective countermeasure for fatigue is to do as much as possible to prevent it from occurring in the first place**
- **The primary culprit for feeling fatigued is sleep loss**
- **Thus, whatever can be done to encourage regular sleep and prevent sleep loss (cumulative fatigue, sleep debt) should be high on your list of fatigue countermeasures**
- **The principal advantage of getting enough sleep is that it will reduce on-the-job fatigue, thereby reducing the need for other fatigue countermeasures**
- **Good-quality, nocturnal sleep is a particularly effective control for the three hazards: length of prior wakefulness, amount of prior sleep, and physical exertion**

# Sleep Hygiene

**Shift Work Sleep Disorder (SWSD):**

- **International Classification of Sleep Disorders (ICSD), American Academy of Sleep Medicine (AASM; www.aasmnet.org), Code 307.45-1, a circadian sleep disorder**
- **Essential features: "symptoms of insomnia or excessive sleepiness that occur as transient phenomena in relation to work schedules"**

# Sleep Hygiene

**How much sleep do we need?**

- **Eight (8) hours per 24 hours is the average sleep need** National Sleep Foundation
- **Thus, half of any given group will need more than 8 hours to prevent cumulative fatigue due to sleep debt**

**No matter what a worker's sleep need is (95% = 7 to 9 hours), each worker should manage his or her personal sleep debt such that it never exceeds about five hours.**

# Napping

**How may napping be used as a countermeasure?**

- **Taking a nap can reduce fatigue effects and increase alertness during both work and non-work periods**
- **A nap can be very effective as a short-term countermeasure against fatigue effects, and to compensate during a period when personnel will need to remain awake for a long time (more than 17 hours)**
- **Some other situations where napping would be appropriate are:**
  - **Less than 8 hours sleep during the main sleep period**
  - **Awake for 30 minutes or longer two or more times during the main sleep period**
  - **During a long and/or nighttime work period**

# Napping

- The polysomnographic structure of naps is dependent upon:
  - The length of prior wakefulness for non-REM sleep
  - 24-, 12- and 4-hour rhythms for REM sleep
- Because we cannot predict reliably what sleep stage will occur in any given nap, and because all sleep stages appear to be important for well-being, we do not prescribe limits on nap lengths
- Instead, we just advise operators with limited sleep opportunities that “any sleep is good”

# Napping

**Napping at work:**

- **Naps at work should be limited to a time, place and duration that will not interfere with system operations**
- **It is important to recognize that when naps are needed because of reduced sleep opportunities, personnel are at risk of being critically fatigued**
- **Allow up to about 30’ for sleep inertia to clear**

# Tactical Caffeine Use

**How may caffeine be used best as a countermeasure?**

- **When natural fatigue countermeasures are impossible, caffeine is a very effective alternative.**
- **Studies have shown that caffeine significantly improves both alertness (measured by MWTs) and performance (measured by the PVT, etc.).**
- **Doses ranging from 200-600 mg are particularly effective in people who do not normally use caffeine.**
- **OTC doses (J. Caldwell, L. Caldwell, c2005):**

| Source | Dose | Source | Dose |
|---|---|---|---|
| 1 cup Maxwell House | 100 mg | 1 Coke | 50 mg |
| 1 cup tea | 50 mg | 1 Mountain Dew | 55 mg |
| Starbucks Tall | 250 mg | 2 Anacin | 65 mg |
| Starbucks Grande | 375 mg | 2 Excedrin Xtra | 130 mg |
| Starbucks Vente | 550 mg | 1 Max NoDoze | 200 mg |

# Tactical Caffeine Use

- **Caffeine must be used judiciously. Habituation occurs when we take in more than about 250 mg/day (one Starbucks Tall)**
- **The best tactical approach to caffeine use is to:**
  - **Avoid habitual use or reduce it to 250 mg/day**
  - **Use a 250+ mg about a half-hour before the period in which you need it**

Also, see Committee on Military Nutrition Research, Food and Nutrition Board (2001). *Caffeine for the Sustainment of Mental Task Performance: Formulations for Military Operations*. The National Academies Press, Washington DC

# Modafinil

**A legal, useful, prescription alertness aid:**

- **Modafinil (ProVigil®): a prescription *alertness aid* which, if used before decreased alertness occurs, greatly increases alertness during a period of expected impairment** (Caldwell & Caldwell, 2005; Caldwell, Caldwell, & R. A. Schmidt, 2008; Caldwell et al., 2009)
- **Modafinil is approved by the Federal Drug Administration for use by shiftworkers and may be prescribed by any physician for any shiftworker**
- **It has no known side effects that lead to abuse or judgment problems**

# Alertness Aids

**There are various other techniques available to keep shiftworkers alert during the pre-dawn performance trough, including:**

- **Increased physical activity**
- **Bright overhead lights with a solar-like frequency spectrum** (Smith & Eastman, 2008)
- **“Signal injection" for boring, repetitive tasks with strong quality control demands**

# Sleep Aids

**Legal, useful sleep aids:**

- **There are now safe, non-habit-forming, prescription sleep aids (Ambien®, Sonata®, Lunesta®) and the hormone, melatonin, that may be used to promote sleep when operations preclude normal, nocturnal, recuperative sleep**
- **Prescription sleep aids and melatonin are applicable to a number of situations such as shift changes, night work, jet lag, and stress-related short-term insomnia**
- **Sleep aids can help to alleviate these short-term problems and may be discontinued at will**

# Automation

**Does automation help reduce concerns about fatigue risk?**

- **Positive: replaces poorly-performed human physical and/or mental functions with electro-mechanical and/or software-based alternatives**
- **Negative: usually forces the human operator into the role of a system monitor, a function handled poorly in most cases by the human brain, setting up perfect conditions for lapses in attention**

Parasuraman, R., Sheridan, T. B., & Wickens, C. D. (2000). A Model for Types and Levels of Human Interaction with Automation. *IEEE Transactions on Systems, Man, and Cybernetics—Part A: Systems and Humans*, 30(3), 286-297.

# Incident Analysis

**How may I determine semi-quantitatively whether fatigue was likely to have been a contributing factor in an incident or accident?**

**If one or more of the following fatigue limits was exceeded, then fatigue may have been a contributing factor:**

A. **Length of prior wakefulness > 17 hrs**
B. **Amount of prior sleep for the preceding 24 hrs < 8 hrs**
C. **Time of day 2 a.m. to 6 a.m. (body clock)**
D. **Sleep debt > 10 hrs**
E. **Time zone change - days in zone > 3**

NTSB Course IM303, “Investigating Human Fatigue Factors”

# Suggested Reading


- **Miller, J. C. (2006). *Fundamentals of Shiftwork Scheduling*. TR no. 2006-0011, Brooks City-Base TX: Air Force Research Laboratory. (www.dtic.mil ADA446688)**
- **Miller, J. C. (2010). *Fatigue Effects and Countermeasures in 24/7 Security Operations*. CRISP Report. Alexandria VA: ASIS International. (available late fall 2010)**
- **Miller, J. C., & Eddy, D. R. (2008). *Operational Risk Management of Fatigue Effects II*. TR no. 2009-0030, Brooks City-Base, TX: Air Force Research Laboratory. (www.dtic.mil ADA501985)**
- **Miller, J. C., & Miller, N. L. (2010). *Shiftwork: An Annotated Bibliography*. TR no. NPS-OR-10-008, Monterey CA: Naval Postgraduate School. (available late fall 2010)**

# Review

**What are some important components of a fatigue risk management program?**

1. **Define the types of shiftwork properly and identify their presence in your operations**
2. **Quantify the specific consequences and risks of fatigue-related incidents and accidents for your operations**
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9. **Teach workers about sleep hygiene, napping and tactical caffeine use**
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11. **Encourage the use of prescription aids for individuals, if needed**
12. **Implement the use of semi-quantitative fatigue factors when analyzing the causes of incidents/accidents**

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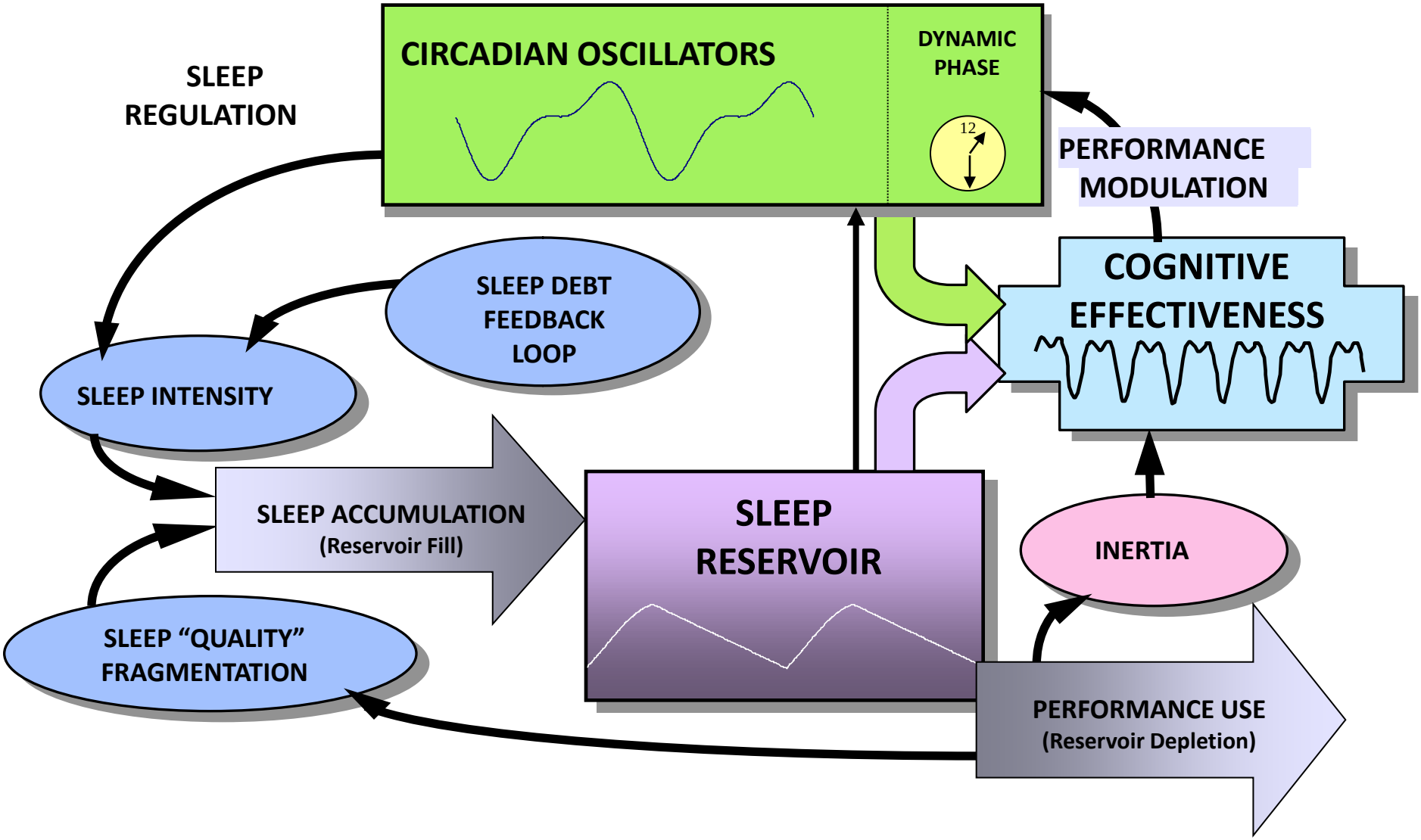
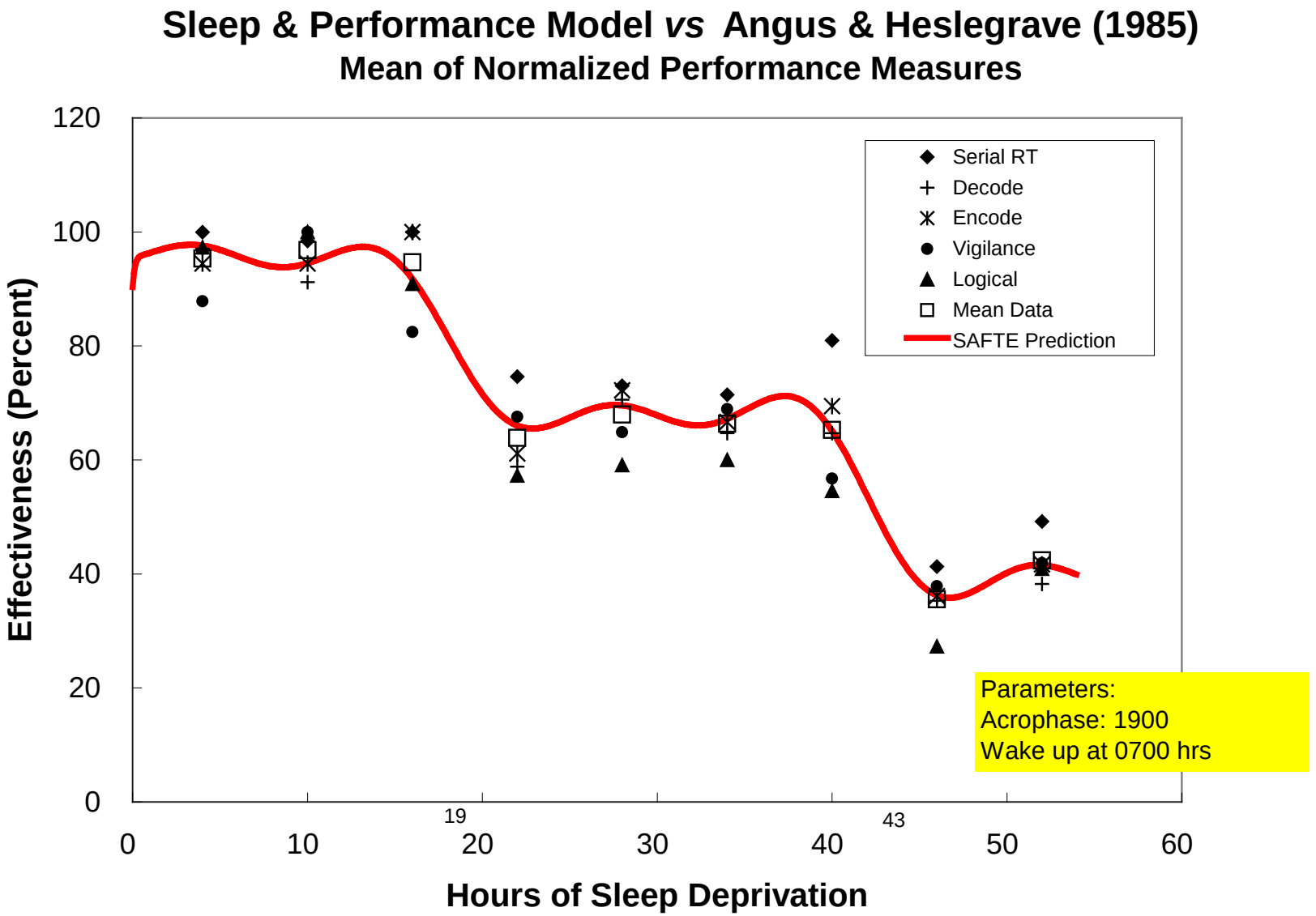
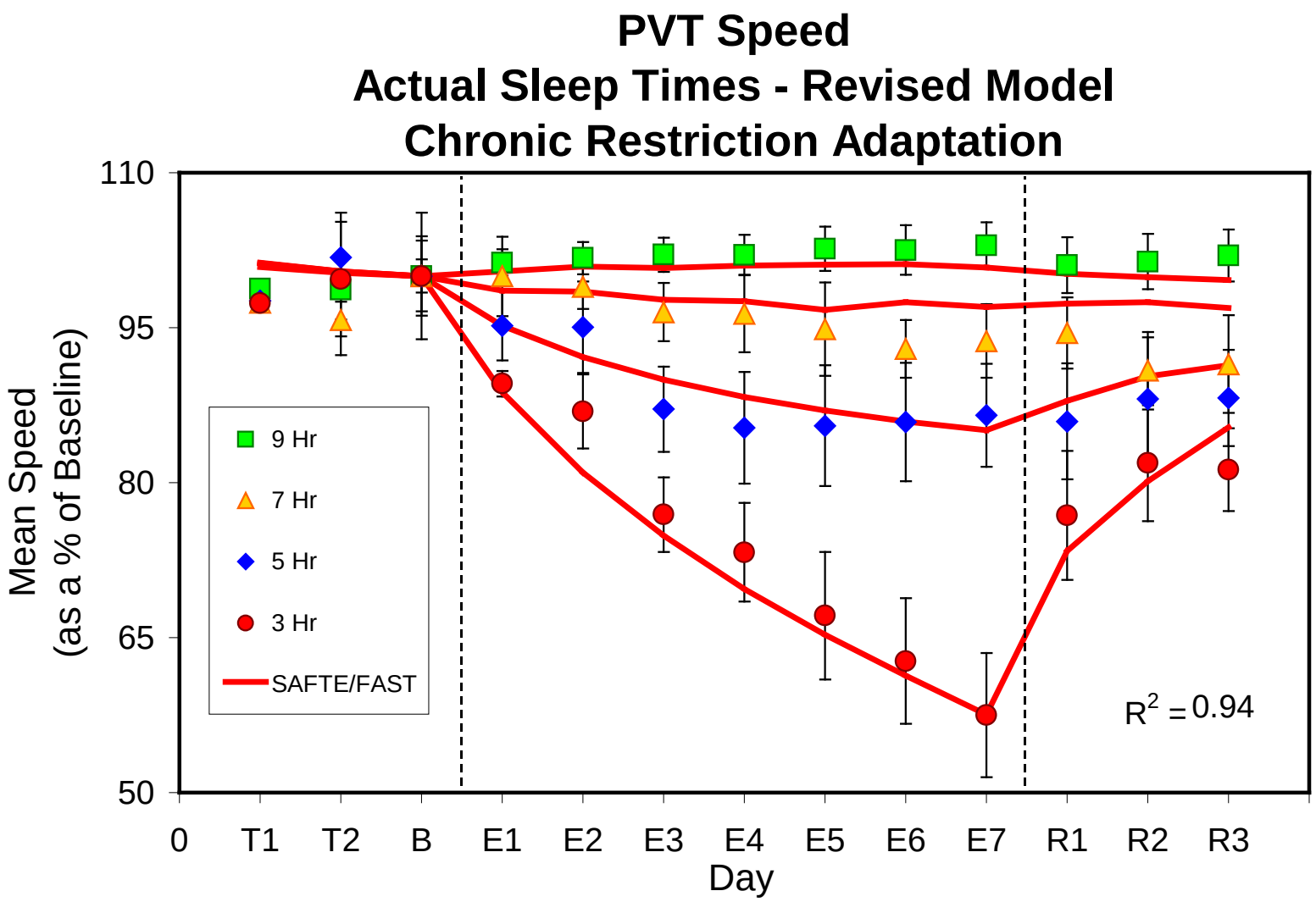


# Decline of Performance with Total Sleep Deprivation

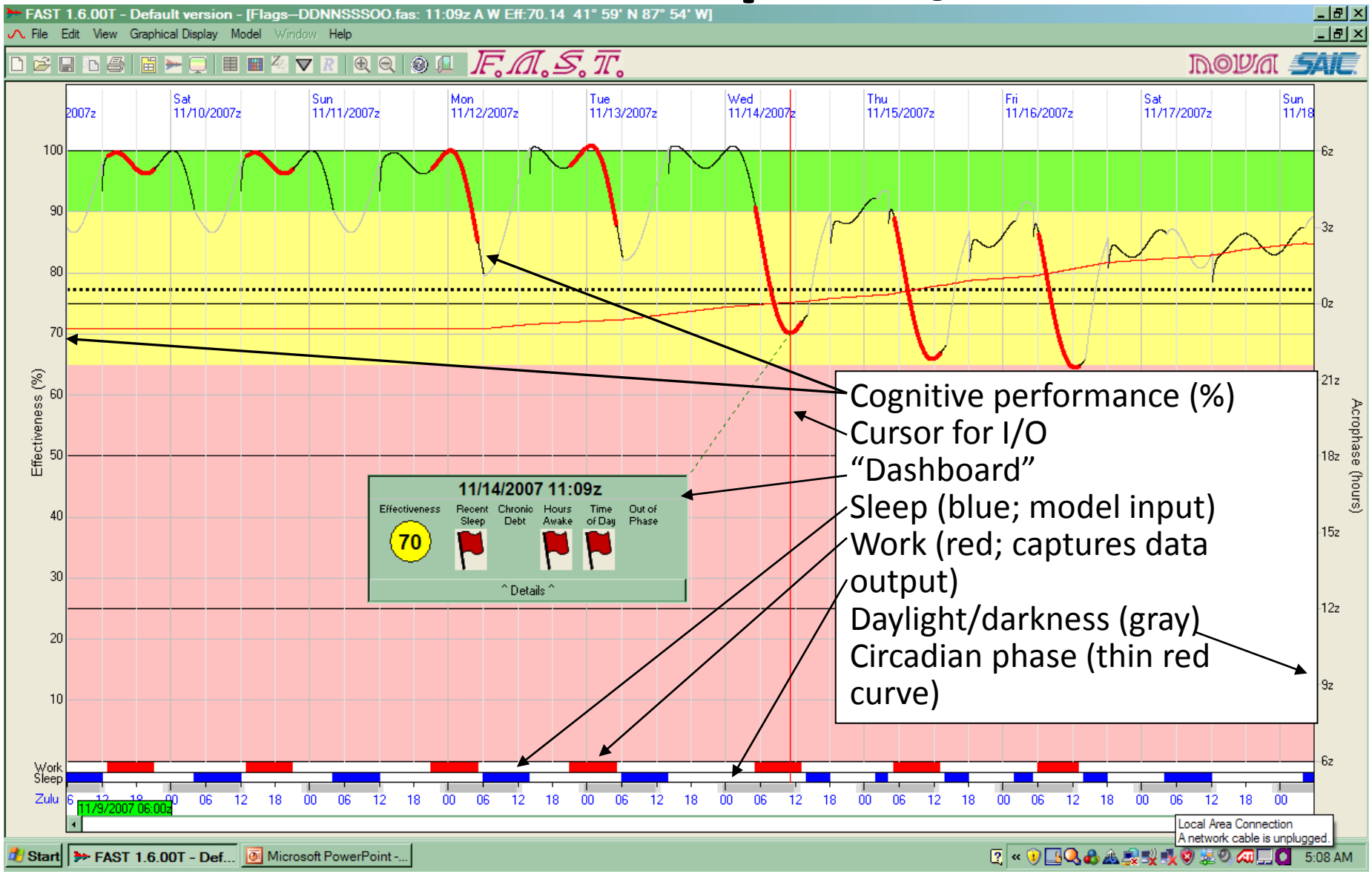
***SAFTE ™ Model (red line) Predicts the Average Results with Precision***



# Walter Reed Restricted Sleep Study
# SAFTE™ Model (red line) Predicts the Average Results with Precision



# FAST™ Graphic I/O



# COMPARE TWO SHIFT SCHEDULES