Shiftwork and Fatigue: Understanding the Human Machine

Andrew Moore-Ede
Director of Client Services
• Virtually every function in the body follows a predictable Circadian (daily) rhythm that is controlled by our Biological Clock (SCN)
  
  • Hormone Secretions, Digestion, Body Temperature
  • Sleep and Alertness levels

• Disrupted circadian rhythms create health, safety and performance challenges for shiftworkers
HUMAN DESIGN SPECS:
Circadian Rhythm of Alertness

Alertness Level (MSLT)

Time of Day

Most Olympic Track & Field Records Set

Fifteen-fold Increase In Industrial Accidents

Full Alertness

Moderate Alertness

Reduced Alertness

Drowsy

Dangerously Drowsy
Productivity decreases at night by 5-10%.

What are the Costs and Risks of Shiftwork?
Extended hours operations cost U.S. businesses over $200 billion annually (~$11,000 per employee)
COSTS OF SHIFTWORK: Absenteeism

- Five times higher for extended hours employees (12.4% vs. 2.4%)

- Major reasons cited for Absenteeism:
  - Balancing work/family life
  - Reduced sleep (i.e. fatigue)
  - Higher incidence of sickness/health issues
COSTS OF SHIFTWORK: Turnover

- Shiftworkers average: 9.8% per year, vs. 3.4% overall
- Turnover of new hires in double digits
- Average cost of replacing an extended hours employee: $30,115
- Turnover costs $2,255 per extended hours employee per year, compared to $624 per day worker
Shiftworkers exhibit higher rates of certain health issues:

<table>
<thead>
<tr>
<th>Health Issue</th>
<th>Frequency Increase</th>
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</thead>
<tbody>
<tr>
<td>Obstructive Sleep Apnea</td>
<td>300%-400% higher</td>
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<tr>
<td>Gastrointestinal Disorders</td>
<td>200%-300% higher</td>
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<td>Cardiovascular Disease</td>
<td>200%-300% higher</td>
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<tr>
<td>Musculoskeletal Problems</td>
<td>150%-200% higher</td>
</tr>
<tr>
<td>Health and Wellness Costs</td>
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COSTS OF SHIFTWORK:
Average Cost of an Accident/Injury: Day vs. Night

Average Night Cost = $10,200  Average Day Cost = $6,200

Increased cost of nightshift accidents based on insurance company claims data
COSTS OF SHIFTWORK:
Productivity

Fatigue Causes:
- Reduced reactions times & coordination
- Miscommunication / misunderstanding
- Decreased motivation (burnout)
- Impaired decision making (risk-taking)

Productivity decreases at night by 5-10%

...Which Leads To:
- Inappropriate/slow response
- Low morale
- Increased human error/procedural deviations
Fatigue Risk Management Systems

The optimal way to manage and reduce employee fatigue risk and improve productivity
FATIGUE RISK MANAGEMENT SYSTEMS
Emergence as Global Standard for 24/7 Operations

1890  Commercialization of electric light
1908-1999  Hours of Service regulations attempt fatigue control by limiting the number of hours of work per day, per week and/or per month
1970-1990  Advances in circadian sleep science show fatigue inadequately controlled by limiting work-rest hours – “compliant but unsafe”
1990-2005  Early development of comprehensive fatigue risk management systems (FRMS)
2005-2017  Widespread international adoption and introduction of regulations & standards requiring FRMS
Fatigue Risk Management System: 5 Defenses & Feedback Loop

**Goals**

**Actions**

**Metrics**

**Incidents & Accidents**

**Fatigue Risk Root Cause Analysis**

**Defense 1**
- Sufficient Staffing Levels
- Workload-Staffing Balance
- Proportional 24/7 staffing

**Defense 2**
- Sufficient Sleep Opportunity
- Shift / Duty scheduling, Overtime policies, Fatigue risk models

**Defense 3**
- Sufficient Sleep Obtained
- Employee training Sleep disorder treatment & compliance

**Defense 4**
- Sufficient Workplace Environment
- Workplace design, Regulating Blue Light

**Defense 5**
- Sufficient Alertness Behavior
- Peer monitoring Fitness for duty audit, Fatigue monitoring

**SLEEP**

**ALERTNESS**
CAUSES OF INADEQUATE STAFFING

- Increasing production but not automation or employees
- Creep from 5 to 6 to 7 day operations with 3 crews
- Workload fluctuates across 168 hour week but shifts are equally staffed
- Employees addicted to overtime, management likes low headcount, cautious about hiring

SYMPTOMS OF INADEQUATE STAFFING

- Excessive average overtime
- Increased absenteeism rates
- Unplanned open shifts
- Increase in fatigue-related errors/incidents
- Burn-out, high stress levels
Working 60+ hours per week (e.g., 5 x 12-hr shifts) was associated with a 23% increased hazard rate.

Source: Dembe et al. 2005 (Occup Environ Med), based on 89,729 person years of work.
DEFENSE TOOL - CAS FATIGUE MODEL VALIDATION
Employee CAS Fatigue Score vs. Accident Rate

Best predictor of human error risk is CAS fatigue score calculated from previous 7-14 days work-rest pattern.

High Risk Employees

Low Fatigue
Average Fatigue
High Fatigue

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**FATIGUE RISK FACTORS**

- Duration of shift
- Number of consecutive working days
- Time off between shifts
- Time off between blocks of consecutive shifts

**OTHER CIRCADIAN FACTORS**

- Fixed versus rotating
- Speed of rotation
- Direction of rotation
- Start/end times of shifts
- Regularity/Irregularity of shift times
### WHAT’S THE BEST SHIFT SCHEDULE?

#### Unlimited number of schedules for a 7-day operation

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SHIFT SCHEDULE DESIGN CONSIDERATIONS
Best Schedule is Site Specific

- Involve employees in the process
- Transfers ownership of the new schedule to the employees
- Ensures best schedule is achieved
- Avoids costly distractions/disruptions (and sometimes permanent damage) that accompanies many scheduling changes
- Will improve employee health, safety, and quality of life
- Will improve operational efficiency
CAUSES OF INADEQUATE SLEEP DURATION & QUALITY

- Giving sleep a low priority
- Poor sleep planning
- Bedroom not suited for day sleep
- Lack of family awareness/support
- Undiagnosed/untreated sleep disorders

SYMPTOMS OF INADEQUATE SLEEP DURATION & QUALITY

- Chronic sleepiness & fatigue
- Sleep episodes on the job
- Microsleeps on the highway
- Snoring, multiple wakings, apneas
- Fatigue-related errors/incidents
Training On Managing Fatigue and a Shiftwork Lifestyle Should Cover:

- Human Design Specs
- Getting Better Sleep
- Staying Safe and Alert
- Nutrition & Health
- Family & Social Life

Multiple delivery modes

- Classroom training (“Managing a Shiftwork Lifestyle”)
- Train-the-Trainer – building internal competence
- Fatigue Training Online – with testing & certification
- Newsletters, booklets, video
BENEFITS OF FATIGUE TRAINING
Improved Sleep Duration

Average duration of daytime sleep obtained (when working night shift) prior to and after shiftwork lifestyle training.

Source: Dawson 2009
FRMS DEFENSES IN DEPTH
#4: JOB & WORKPLACE DESIGN

**SLEEP**

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**Defense 5**
Job Task & Workplace Environment Fatigue
KEY DETERMINANTS OF SAFETY & PERFORMANCE

- Light
- Temperature
- Humidity
- Sound Level
- Sound Pattern
- Aroma
Growing Awareness of the Health Risk of Light at Night

Shiftwork that involves circadian disruption is “probably carcinogenic to humans”

“Epidemiological studies have found that long-term night-workers have a higher risk of breast cancer risk than women who do not work at night. These studies have involved mainly nurses and flight attendants. The studies are consistent with animal studies that demonstrate that constant light, dim light at night, or simulated Chronic jet lag can substantially increase tumor development.

Other experimental studies show that reducing melatonin levels at night increases the incidence or growth of tumors.”

The primary human concern with nighttime lighting include...
potential carcinogenic effects related to melatonin suppression, especially breast cancer.

Other diseases that may be exacerbated by circadian disruption include:

- Obesity
- Diabetes
- Depression
- Mood Disorders
- Reproductive problems

NIH Workshop: Shift Work at Night, Artificial Light at Night, and Circadian Disruption

Exposures to artificial light at night (ALAN) or changes in the timing of exposures to natural light (such as with ‘jet lag’) may disrupt biological processes controlled by endogenous circadian rhythms, potentially resulting in adverse health outcomes. NTP is interested in understanding the health effects of circadian disruption related to ALAN and shift work. NTP’s Office of the Report on Carcinogens (ORoC) and Office of Health Assessment and Translation (OHAT) plan to conduct health hazard assessments focusing on cancer (ORoC) and non-cancer health outcomes (OHAT).
2001 Discovery: Circadian Clock (SCN) uses blue wavelengths to track day and night*

Risks of Light at Night Increased by Blue-Rich Energy-Efficient Lighting

LED Lighting provides:
- Improved Energy Efficiency
- Extended Lifetime (Reduced Replacement & Labor Costs)
- AND Increased Bio-Active Blue Exposure Risk

Lumens per Watt

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It’s Not “Good Blue” vs. “Bad Blue”… It’s Time of Day

Daytime Electric Light

**Day Benefits**
- Increased Alertness
- Increased Vigilance
- Increased Productivity
- Sleep Improvement
- Mood Improvement
- Health Improvement

Nocturnal Electric Light

**Night Costs**
- Sleep Disruption
- Breast/prostate/colon cancers
- Obesity/diabetes Type 2 metabolic syndrome
- Cardiovascular disease
- Depression/mood disorder
QUESTION:

If blue light exposure at night disrupts circadian rhythms, what’s the best light solution for shiftwork operations?
Multiple SPDs of polychromatic white light tested for 24/7 human effectiveness

- **Controlled for:** Daytime Light Exposure, Work Schedule, Illumination (Lux), Diet and Environment
- **Simulation:** 24/7 day and night work shifts
  - Full length 12-hour shifts
- Sleep Lab facility including EEG
- Blood tests (lipids, cardiac markers)
- Glucose Tolerance tests (Diabetes)
- 24 hour urine melatonin collection
- Salivary Melatonin 30 minute intervals
- Blood pressure
- Alertness & performance tests
- Mood and Depression scale test
- Human Subject testing under IRB approval

**LED product development guided and optimized by medical research**
Developing Day and Night LED Chips to Control Blue Light

CIRCADIAN® Day LED
- Bio-Active Blue
- 20% at 400 nm
- 3900K

CIRCADIAN® Night LED
- Bio-Active Blue
- 2% at 400 nm
- 3100K

LM-79 Fixture Data
Is there a solution? Bright White Energy-Efficient LED Light 24/7 with Low Blue Night and High Blue Day

Timing the Dosing of Bio-Active Blue Light

HIGH

% Bio-Active Blue

LOW

NIGHT

DAY

NIGHT

High Quality White Light 24/7

CIRCADIAN® Autonomous Control Board

CIRCADIAN® Light Engine with Day & Night LED Chips
Blue-Depleted White Light Restores Melatonin at Night

![Graph showing comparison of melatonin levels between Conventional Blue Pump LED and Blue Pump LED.](image-url)
One of the greatest myths in sleep physiology is that:

“Melatonin is the Sleep Hormone”

In fact…

- Nocturnal animals are most active when melatonin peaks at night

- Infusions of physiological levels of melatonin do not induce sleep
  - Only high pharmacological doses of melatonin are sophorific

- No correlation between the percent suppression of melatonin by light at night and percent change in sleepiness

- Alertness can be increased by blue-depleted light which restores melatonin

**Melatonin is really the darkness hormone and not the sleep hormone**
FRMS DEFENSES IN DEPTH
#5: FATIGUE MONITORING

**SLEEP**

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  - Fitness for duty audit, Fatigue monitoring

**ALERTNESS**

**Goals**

**Actions**

**Metrics**

- Excessive overtime Staffing Imbalance
  - Schedule Driven Fatigue Risk
  - Sleep Deprivation Lifestyle stress
  - Workplace Environment Fatigue
  - Fatigue-related Errors
FRMS DEFENSES IN DEPTH
#6 ROOT CAUSE ANALYSIS & FEEDBACK

**SLEEP**

- **Defense 1**: Sufficient Staffing Levels
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**ALERTNESS**

- **Fatigue Risk Root Cause Analysis**

**Metas**

- **Excessive overtime Staffing Imbalance**
- **Schedule Driven Fatigue Risk**
- **Sleep Deprivation Lifestyle stress**
- **Workplace Environment Fatigue**
- **Fatigue-related Errors**
**Evidence of Sleepiness and/or Inattention**

How mentally stimulating was the work task immediately prior to the incident?

Somewhat Monotonous

How mentally stimulating was the work environment immediately prior to the incident?

Monotonous/Boring

Were any of the following signs of sleepiness observed before the incident?

- Had the individual frequently complained about fatigue or sleepiness over the prior week? no
- Were any signs of sleepiness (e.g. yawning, eye closure, head nodding, fixed "zombie" gaze) observed before the incident? yes
- Was there any evidence of a lapse of attention (e.g. failure to stop, brake, steer or respond to machinery or warning signal) at the time of the incident? unknown
- Did the individual admit to falling asleep or nodding off? no
- Was there any evidence of use of prescription or illicit pharmaceuticals within the last 48 hours? no

![Fatigue scale](image)
Developing a Fatigue Risk Management Plan

**OBJECTIVES**

1. Fatigue Risk Mitigation: Policies, Practices & Technology
2. Fatigue Risk Management Communication & Training
3. Fatigue Risk Data Collection and Analysis
4. Fatigue Risk Management Program Evaluation

**CONTROLLING FATIGUE HAZARDS**

- Senior Management: makes a commitment to reducing fatigue in operation
- Project Team: Conduct gap analysis to identify existing fatigue programs and gaps in defense
- Develop a written *Fatigue Risk Management Plan*

**CONTINUOUS IMPROVEMENT**

- Developing a Fatigue Risk Management Plan
1. Fatigue is inherent in all shiftwork operations

2. Costs, risks and liabilities of fatigue are substantial ($11,000 USD per shiftwork employee)

3. FRMS are the optimal way to manage and reduce employee fatigue risk and improve productivity

4. Take Action: Create a FRMS Plan, Strengthen Defenses (staffing, scheduling, training, environment, policies, etc.)