The Commercial Mariner Endurance Management System

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In many commercial maritime environments, mariners traditionally endure harsh working conditions, extreme temperatures, long work hours (more than eight hours per day), frequent separation from loved ones, fatigue, and long service periods sometimes exceeding three consecutive months in duration. While a ship's endurance is determined by how long it can support operations at sea without replenishing supplies or requiring in-port maintenance, its crewmembers' endurance can be described as a function of physiological and psychological factors.

The term crew endurance refers to the ability to maintain performance within safety limits while enduring job related physiological and psychological challenges. Crew endurance is a function of a complex system. Factors such as the emotional state of crew members (i.e., stress level), hours worked per day, quality and duration of rest periods (sleep), physical conditioning, diet, and stability level of physiological regulating systems (the biological clock) exert a direct influence on individual energy levels, alertness, and performance (Figure 1). At the individual level, safety depends on endurance.

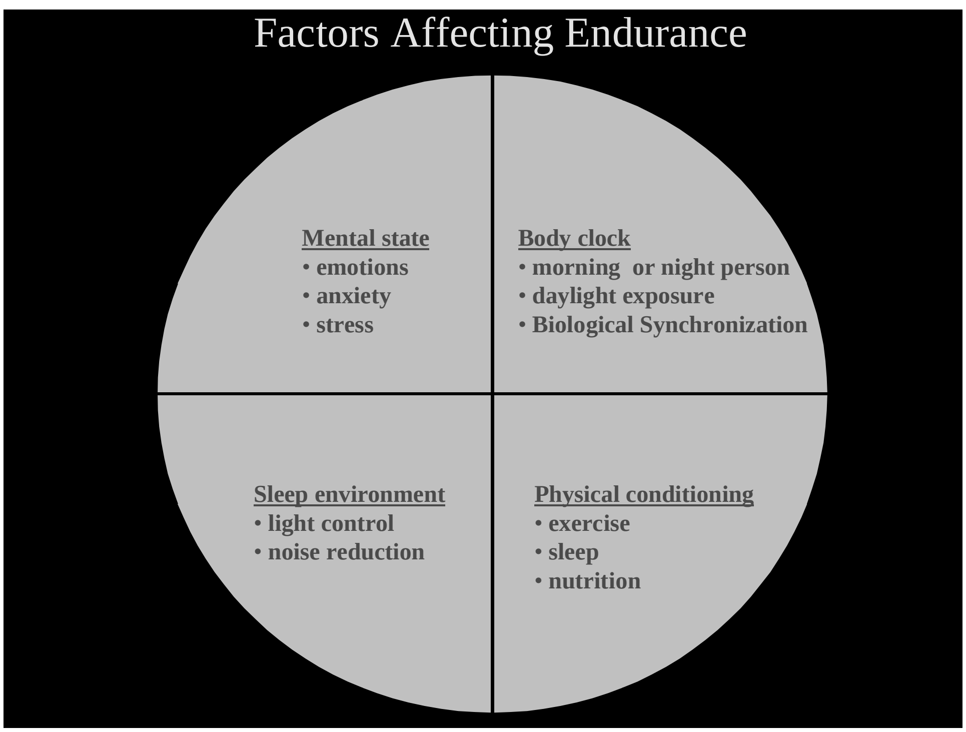

Figure 1. Endurance levels are affected by the interaction of factors that include physiological, psychological, and environmental issues.

Optimizing crew rest, and the prevention of physiological maladaptation to shiftwork schedules (or Shift-Lag), can contribute significantly to one’s endurance of harsh working conditions without compromising work performance and safety. Shiftwork maladaptation results from the inability to synchronize the human biological clock to rapidly rotating cycles of sleep and work. Adaptation to nighttime or daytime work requires the synchronization of physiological and cognitive resources under the regulation of the biological clock. The clock is a physiological mechanism composed of neural networks (e.g., deep brain nuclei) and hormonal outputs (e.g., pineal and pituitary glands) which regulate sleep (e.g., onset, and quality) as well as energy and cognitive resources availability during active periods.

Maladaptation to shiftwork schedules and lack of energy-restorative sleep can result in persistent fatigue symptoms (e.g., sleepiness, low energy, lack of motivation, depression), performance degradation during duty hours, degraded endurance, and reduced safety. Other health effects such as increased incidence of cardiovascular disease, gastrointestinal disorders, and sleep disorders have been historically documented in populations exposed to shiftwork maladaptation (Congressional report, 1991).

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Physiological Consequences of Frequent Changes in Work Schedules

Shiftwork Maladaptation and Sleep Loss

Sleep Requirements. Optimizing crew rest requires a degree of control of the sleep environment and work schedule coordination. The human brain requires approximately seven to eight hours of uninterrupted sleep, daily, to replenish cognitive and physiological resources. During sleep, the brain oscillates among periods of light, deep, and dream sleep. These oscillations are periodic, organized, and require approximately 90 minutes to complete each cycle. The 90-minute cycle is repeated throughout the night. Any interruption of this process due to noise, bright lights, or movement, interrupts the sequence, causing the brain to spend more time in light sleep. Sleep disruption reduces the efficacy of energy restorative processes and results in degraded cognitive and physical resources upon awakening.

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Shiftwork Maladaptation Prevention-Biological Clock Synchronization. Optimally, sleep must take place during a period of time established by the regulatory influences of the internal biological clock. This clock system (details in next section) regulates the timing of sleep onset and wake-up times. Due to evolutionary pressures and physiological characteristics, the human body is predisposed to work during daylight hours and sleep during nighttime hours. The body’s clock system maintains a sleep/wake schedule in synchronization with local sunrise and sunset and the concomitant duration of daylight hours. The biological clock regulates energy cycles so that alertness increases after wake-up time, peaks in the mid-morning hours, dips in the afternoon hours, peaks again in the early evening hours, and begins to decrease in the early night reaching all time lows in the middle of the night (Figure 2). The exact times of these peaks and valleys depend on specific inputs to the biological clock system, namely wake-up times, bedtimes, and daily time of daylight (and/or artificial bright light) exposure. Personnel exposed to regular work schedules that allow for consistency from day to day enjoy the benefits of a well-synchronized biological clock. This allows daily energy restorative cycles to take place regularly. In contrast, work schedules that impose frequent transitions from daytime to nighttime duty hours, and long duration shifts disrupt energy restorative processes and induce fatigue.

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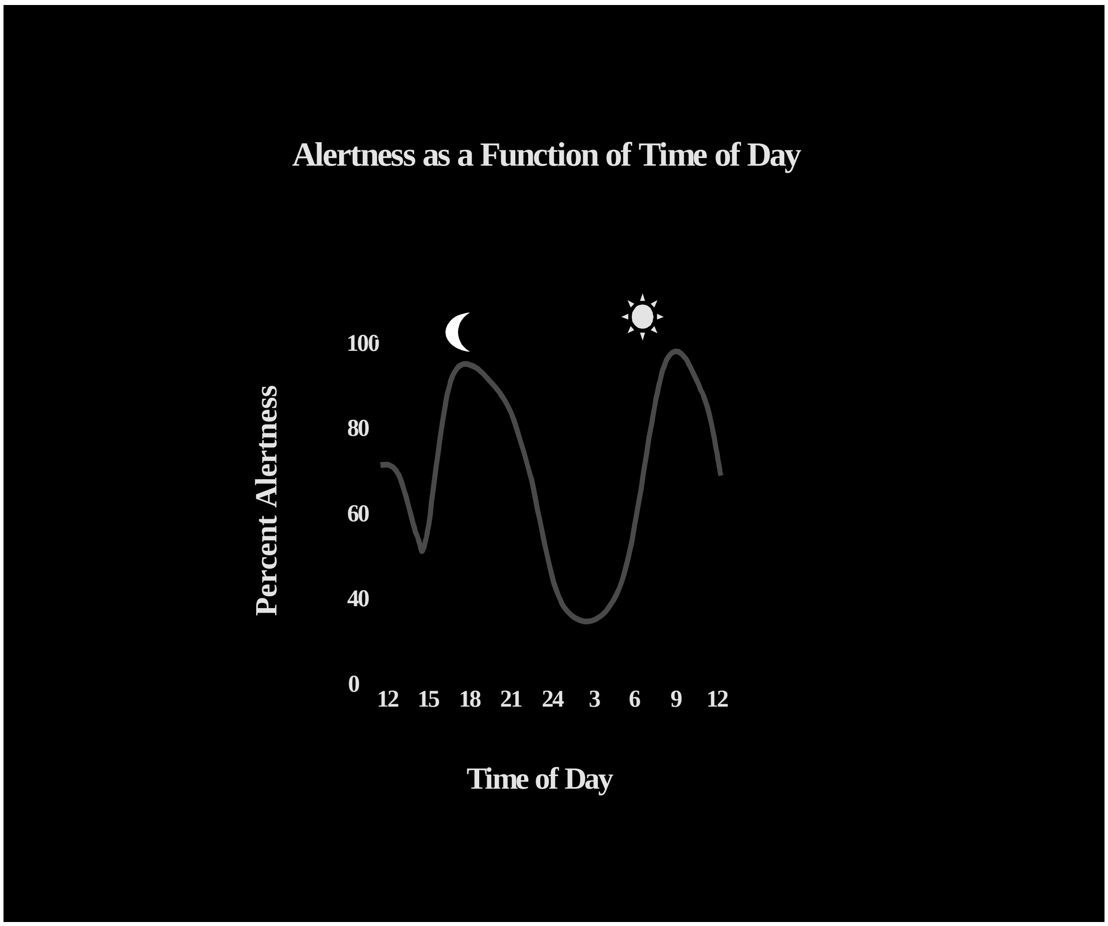

Figure 2. Alertness function characteristic of a biological clock adjusted to daytime work and nighttime sleep. Energy levels increase after wake-up time, peak in the mid-morning hours, dip temporarily in the afternoon hours, peak again in the early evening hours, and begin to decrease in the early night reaching all time lows in the late night, early morning hours.

Consequences of Frequently Varying Sleep and Work Schedules

Personnel accustomed to waking up and seeing daylight at approximately the same time of the day (e.g., 0700) will be apt to work during daylight duty hours and sleep during nighttime hours. Their biological clock will be day-oriented, thus synchronized to provide energy and cognitive resources during daylight and evening hours. Two peaks of alertness and energy availability will take place throughout the day, one in the morning and one in the early evening. Day-oriented personnel will normally experience troughs in energy and alertness immediately upon awakening, sometime in the mid-afternoon, and prior to sleep in late evening. This pattern of energy availability will be maintained consistently if personnel obtain good quality sleep (uninterrupted sleep in quiet and dark environments) daily for seven to eight hours (see Figure 2).

Interrupted sleep and reductions in duration of less than seven to eight hours per day will result in the accumulation of daily sleep debt. The consequences of this debt will be first experienced in the degradation of alertness, decision-making ability, and performance of mental function requiring logical ability. Persistent sleep debt throughout a week will result in increased daytime sleepiness and degradation of performance in cognitive and psychomotor tasks.

Inconsistent inputs to the biological clock are common when personnel work nighttime duty hours……

Disruption in the daily adjustment of the biological clock can also add to the degradation of alertness and performance. For instance, maintaining a summer work schedule that requires waking-up at 0700 most days of the week, but an earlier wake-up time (e.g., 0500) on the rest of the workdays, will send conflicting signals to the biological clock. On the days that wake-up times are required at 0500, the clock will receive daylight exposure earlier than usual resulting in an advance of wake up and bedtimes. Conversely, on the days that the clock does not receive the early morning daylight dose (at approximately 0500), bedtimes and wake-up times will be allowed to slip to a later time. This advance of time can be approximately one-half to one hour per day. These changes in the body’s timing mechanism affect the alignment of daily peaks and troughs of other physiological events such as core body temperature, cellular metabolism, and production and release of hormones and neurotransmitters.

In general, the biological clock system requires approximately three days to re-adjust to a new input, such as a two-hour advance in daylight exposure time due to earlier wake-up times. This re-adjustment will take place if the new sleep/wake schedule is consistent from day to day. However, if the inputs are inconsistent, the clock’s timing can become disorganized in such a way that the physiological rhythms under its control will no longer be expressed in a predictable pattern. The individual impact results in sleepiness, insomnia, and performance degradation in mental and motor tasks.

Inconsistent inputs to the biological clock are common when personnel work nighttime shifts. For instance, a watch schedule prescribing a seven-hour watch during the night (e.g., beginning at 2400) then five hours of time off (from 0700-1200), followed by a five-hour watch beginning at approximately 1200, can result in jet-lag-like symptoms. In this particular work schedule, if personnel work under normal lighting (e.g., engineering) or in dim light environments (e.g., the bridge at night), exposure to daylight after sunrise will set the biological clock in a daytime orientation. In a daytime orientation, the biological clock predisposes the brain and energy cycles for sleep, and not work, during nighttime. Fatigue induced performance degradation will occur during nighttime hours.

The adjustment of the biological clock requires the implementation of a specific schedule of daylight and/or bright, artificial light exposure, as well as the maintenance of a consistent sleep schedule. One way to avoid fatigue during nighttime is to reverse the biological clock's synchronization. For the clock's timing to reset energy resources to peak during nighttime, work must take place under bright lights (approximately 2000 lux) mimicking the effects of daylight. Sleep must take place in a dark and noise free environment. Lacking control of daylight and/or bright light exposure times is a significant contributor to the induction of fatigue.

If the use of bright, artificial light is incompatible with the work environment (e.g., on the bridge at night), a specific light and sleep management schedule can be designed to shift the biological clock towards a night orientation. Professionals working in the fields of circadian rhythms and sleep management should develop these light and sleep management schedules. Experimentation with light exposure schedules can result in the induction of chronic fatigue and jet-lag-like symptoms. It is recommended that organizations use consultants with proven experience in the implementation of sleep and light management plans in various work environments.

The synergistic effects of disrupted sleep (less than seven to eight hours) and biological clock disorganization can lead to fatigue, jet-lag-like symptoms, and the exacerbation of psychological maladjustment symptoms such as irritability, depression, and sometimes psychosis. Other physiological symptoms associated with this condition include cardiovascular disease and gastrointestinal disorders.

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The Commercial Mariner Endurance Management System

The Commercial Mariner Endurance Management System (CMEMS) has been derived from the Crew Endurance Management System originally developed for the Army Safety Center in the early 1990s (Comperatore, 1996) and from the Coast Guard Endurance Management System (CGEMS), the U.S. Coast Guard version. Currently, the CGEMS is being tested during real-world operations in U.S. Coast Guard's aviation and marine environments (Comperatore, Carvalhais, and Della Rocco, 1998; Comperatore, Bloch, and Ferry, 1999). Following, we provide a detailed description of the CMEMS.

In general, the CMEMS coordinates a vast network of interrelated factors such as:

a) company mission objectives (e.g., provide transport for oil companies, maintain profitable and safe operations);
b) equipment limitations (type of vessel, availability of adequate sleeping quarters, exercise, lounge facilities, and electronic mail for crew members);

c) environmental factors (e.g., voyage duration, geographical area of operations, noise and light levels in sleeping and working environments, lounge facilities, etc.);
d) crewmembers' physiological and psychological limitations (e.g., work hours, shiftwork adaptation, contact with family during a long voyage); and
e) company's crew rest and work hours policies.

The effectiveness of the CMEMS relies on its emphasis of adjusting the endurance plan to the mission objectives, and on the ability to maximize rest and alertness by implementing a practical and well-coordinated plan….

The CMEMS is designed to produce work and rest management plans that optimize alertness and performance during duty hours. This goal is accomplished by:

a) providing information to ship's department heads on how to design and implement work schedules that both meet the operational objectives of the vessel and do not result in shiftwork maladaptation;
b) providing information to crewmembers on how to maximize the benefits of rest opportunities;
c) forming a ship's working group to coordinate training, document crew rest during the implementation of new work schedules, and support the overall implementation of the CMEMS; and
d) implementing crew rest test protocols that document: 1) the timing and number of rest opportunities and environmental conditions made available for crewmembers, and 2) crewmembers efficiency in taking advantage of rest opportunities.

Figure 3 illustrates the Crew Endurance System, consisting of four levels of coordination, namely, 1) mission objectives, 2) personal endurance, 3) watch, work, and training schedules, and 4) collateral duties.

Figure 3. CMEMS model depicting the four levels and the relative flexibility of each level. (Mission objectives (Level I) is the least flexible level, indicated here by a central position. Levels increase in flexibility away from the center.)

The Center of the Model: Mission Objectives

Mission objectives are at the center of the model and these are the reference for all other coordination. Elements in this level of the system are immutable. For instance, elements of this first level for a commercial maritime company may include: a) the type of mission (e.g., oil transport, towing, etc.), b) company goals (e.g., safety, profit), c) geographical region, d) time of day of in-port activities (e.g., daytime or nighttime), and e) weather conditions. The effectiveness of the CMEMS relies on its emphasis of adjusting the endurance plan to the mission objectives, and on the ability to maximize rest and alertness by implementing a practical and well-coordinated plan.

The Second Level: Personal Endurance Plan

In the second level, the CMEMS recommends crewmember activities to maintain high levels of alertness during duty hours, maximize sleep efficiency, regulate the biological clock, and maximize the balance between family life and work demands. Table 1 depicts some of these activities. The success of these individual efforts depends on their coordination with the first, third and fourth levels of the model.

Table 1. Sample of CMEMS Suggested Personal Endurance Plan.

Level II Activities	Functional Significance
Sleep during opportunities provided by the crew endurance plan. Take naps to compensate for sleep periods less than seven hours per day.	Avoid sleep loss induced fatigue. Actively participate in the process of crew endurance maintenance.
Control of noise and light intrusions in sleep environments (e.g., wear ear plugs, block daylight in state room).	Prevent fatigue induced by unnecessary disruption of the sleep period.
Use daylight exposure schedules to synchronize work and sleep periods (e.g., seek and avoid daylight according to endurance plan).	Prevent fatigue and performance degradation induced by the disruption of the body's biological clock (Shift-Lag).
Maintain contact with family members using e-mail and phones during voyage. Plan and carry out family activities during off periods.	Maintain continuity of family life. Avoid emotional isolation.
Avoid large, high fat, meals prior to sleep.	Minimize sleep disruption induced by digestive function.

Ultimately department heads and the ship's captain develop watch/work, sleep, and light management plans that optimize sleep and maintain the timing of the biological clock. This is the ship's crew endurance plan….

The Third Level: Ship's Schedules

This level consists of scheduled activities that directly impact the mission and crew readiness. These activities need to be planned and scheduled so that they simultaneously accomplish the mission, and also, promote crew alertness. Such activities include briefings, planning sessions, meal schedules, training schedules, and schedules of instruction periods on crew endurance management for all ship's personnel. Ultimately department heads and the ship's captain develop watch/work, sleep and light management plans that optimize sleep and maintain the timing of the biological clock. This is the ship's crew endurance plan.

The Fourth Level: Collateral Duties

The elements of this level constitute activities that increase the workload established by watch schedules and departmental work hours. These activities must be scheduled to prevent the disruption of sleep management, both during underway and in-port periods. Examples of collateral duties may involve crew morale management, maintenance of electronic equipment used for crew recreation (e-mail, video players, etc.), crew counseling, etc. In cases where mariners are not out to sea for more than 24 hours per day, as is the case with many marine pilots, the impact of second jobs and travel from home to ships on crew endurance should be considered in this level of the model.

Implementation of the CMEMS

The process of implementing the CMEMS to develop a crew endurance plan requires an initial or Phase I evaluation of the impact of the ship's or company's (this applies to both) current work policies on crew rest. This evaluation must be conducted during at least a 15-30-day period to properly document duty hours, workload, and crew rest associated with periods of low and high workload. Depending on the geographical location, workload may be directly affected by seasonal changes; thus, some evaluations must be conducted during both winter and summer seasons. This evaluation provides an opportunity to obtain information on the elements that require coordination across the four levels of the system. The next step requires the development of a Crew Endurance Working Group (CEWG). The composition of this team requires officers and licensed personnel from each department. The CEWG then meets to develop a crew endurance plan from the information provided in the Phase I evaluation. The CEWG submits the plan to the command staff (e.g., Captain and Company's management) and, after approval, implements the plan during a typical voyage.

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In addition to the formation of a CEWG, the successful implementation of the CMEMS requires the implementation of an aggressive education program designed to instruct company managers, ship's officers, chiefs, and crew personnel on their contribution to the coordination and execution of the various elements of the crew endurance plan. Sleep and body clock management as well as stress management, are some of the critical blocks of instruction necessary to make certain the CEWG members, management, and personnel at large share the same critical information. Coordination of a crew endurance plan requires all levels of an organization to share the responsibility for success.

The second phase (Phase II) requires an additional crew endurance evaluation during the implementation of the crew endurance plan. As was the case with Phase I, the Phase II evaluation must be conducted over a long period of time (approximately 30 days). However, 60 days may be required in some environments depending on how frequently high workloads are experienced. It is critical to obtain information during high operational tempo to accurately determine the efficacy of the crew endurance plan. Ultimately, the Phase I evaluation determines whether a crew endurance plan is needed or not, while the Phase II evaluation tests how well a newly developed crew endurance plan is working under real-world conditions.

In both the Phase I and Phase II evaluations, wrist worn sleep monitors are necessary to objectively document the impact of watch, work, and training schedules on crew rest. These devices are the size of a large wristwatch, and provide accurate information on the quality and duration of the wearer's sleep. In addition, the use of a logbook is recommended to document crewmembers' daily activities. The U.S. Coast Guard Research and Development Center (USCG R&DC) recently developed a logbook, which is currently in use on USCG cutters under Phase I and II. The data collected using these devices can be used to determine whether crewmembers' rest periods are offered consistently and in the right environmental conditions to restore alertness and physical energy from day to day. In addition, these data will reveal how well personnel take advantage of rest periods provided by the ship's crew endurance plan. Methods to test the efficacy of crew endurance plans are provided in several reports published by the USCG Research and Development Center.

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The consistent use of the CMEMS allows company and ship management staff as well as crewmembers to use objective methods to constantly improve the work plan, safety, and personnel endurance. This system does not prescribe specific schedules, but it provides a process to maintain endurance, prevent fatigue and burnout, and enhance the safety of overall operations. CEWG members can become champions of the endurance plan aboard a commercial vessel and contribute to the maintenance of crew endurance.

In brief, the implementation of the CMEMS can help companies and ships' crews enhance their current efforts towards maintaining high levels of crew endurance and safety.

Further information on equipment, development, and implementation of crew endurance plans can be obtained by contacting the Crew Endurance Team at the U.S. Coast Guard Research and Development Center in Groton, CT (860-441-2600) or e-mail ccomperatore@rdc.uscg.mil.

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