Predicting Accident Times

Knowing when sleepiness occurs can help to prevent errors leading to injury on the job.

WE ARE ALL AWARE OF DAILY UPS and downs in our abilities. Such normal fluctuations in performance have been documented for many years (e.g., Bjerner, Holm, & Swensen, 1955) and are not random throughout the 24-h day (Broughton, 1975, 1989). Knowing when industrial errors, incidents, and accidents are most likely to occur across the day/night cycle can help to focus job design and redesign activities for safety-sensitive jobs.

This article describes a mathematical model that may be used to predict the timing of errors, incidents, and accidents caused by sleepiness and inattention.

Background

The phrase *circadian rhythm* was coined decades ago to describe oscillations that have one peak per day. The term *circadian* was adapted from the Latin *circa*, about, and *dies*, day. Numerous studies have demonstrated, however, that human "circadian" rhythms in many measures of performance and physiologic activity actually have a *two-peak* daily pattern (e.g., Mitler et al., 1988).

Although Broughton (1975, 1989) was the first to bring this robust characteristic of human performance to the attention of most researchers, in 1955, Bjerner et al. reported on the daily performance fluctuations for employees at a Swedish gas company whose work was monitored over a 20-year period. In the distribution throughout the 24-h day of 74 927 meter reading errors made by these workers, most errors occurred during the night, with a major peak between 1:00 and 3:00 a.m. A smaller afternoon peak in errors occurred between 1:00 and 3:00 p.m.

Since these early observations, other, more destructive human error events have also been shown to occur with this same two-peak pattern – for example, the 24-h distribution of 6052 vehicle crashes attributable to fatigue (that is, crashes in which no mechanical failure and no alcohol or substance-related causal factors were found). These data were originally compiled and plotted by Mitler et al. (1988). A two-peak pattern was apparent in this distribution, and it was similar to that of the gas meter-reading errors. The number of crashes was elevated between about midnight and 6:00 a.m. and again between about 1:00 and 4:00 p.m.

This two-peak pattern is not restricted to behavioral measures. Similar patterns also exist in biological measures that seem relatively unrelated to behavior, such as the timing of deaths attributable to disease (Mitler, Hajdukovic, Shafor, Hahn, & Kripke, 1987) or susceptibility to toxins (Reinberg & Smolensky, 1983). Exactly why increases in people's tendency to fall asleep are temporally associated with increased susceptibility to diseases or to toxins is not known. However, one leading hypothesis is that the waxing and waning in both sleepiness and susceptibility are controlled by the same or similar biological cycles. The timing of these circadian peaks and troughs does not seem to be related to the relationship between the human circadian system and the exogenous light/dark cycle. The circadian patterns of peaks and troughs seem to be only distorted – but not temporarily repositioned – in people who work at night and

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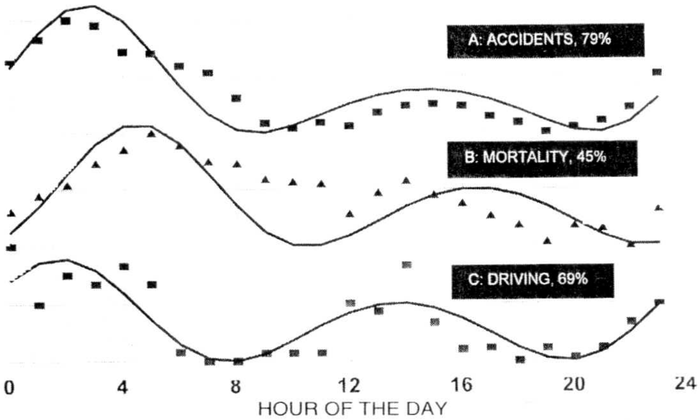

Figure 1.
Curve fits to (A) accident (Mitler et al., 1988) and (B) mortality data (Mitler et al., 1988) and to (C) driver drowsiness data (Prokop & Prokop, 1955), with percentage variance explained for each curve fit. Curve parameter values are shown in the table below.

sleep during the day (Torsvall, Akerstedt, Gillander, & Knutsson, 1989). Therefore, people probably have little voluntary control over the timing of performance deficits related to sleep disruption.

Continuous electroencephalographic monitoring for the measurement of cycles in sleep and wakefulness (Rechtschaffen & Kales, 1968) shows that physiologic sleep tendency also has its ups and downs throughout the 24-h day (see, for example, Lavie, 1986; Mitler & Miller, 1996; Webb & Agnew, 1975; Weitzman et al., 1974).

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Practical Considerations

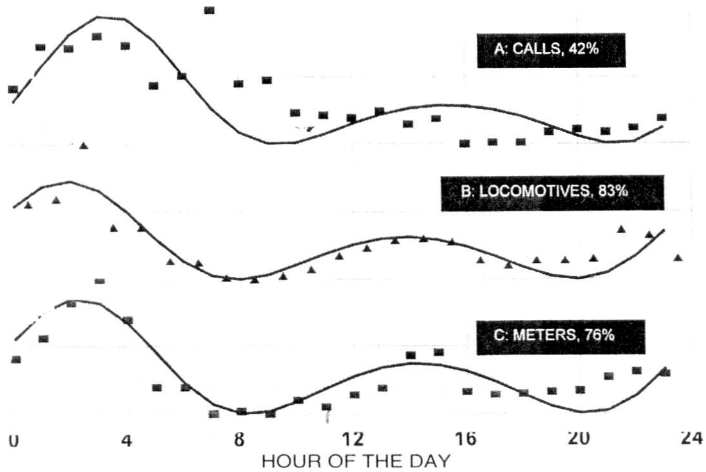
The evidence shows unequivocally that there are critical periods before dawn and in the middle of the afternoon when sleepiness and inattention may lead to errors that cause industrial incidents and accidents. How can we use this information about sleepiness to improve workplace safety?

INDIVIDUAL MODELS OF CIRCASEMIDIAN RHYTHM FOR THE SIX SETS OF DATA IN FIGURES 1 AND 2

Data Sets	q-12 h	SD	r^2
Accidents[a]	2.7	2.6	.786
Mortality[a]	4.5	4.1	.451
Driver drowsiness[b]	1.7	4.8	.687
Operators' delays in answering calls[c]	3.4	2.0	.421
Locomotive auto-brakings[d]	1.9	2.4	832
Meter reading errors[e]	2.3	2.9	.765
Medians	2.5	2.75	.684

θ-12 h = Phase lag in hours past midnight; SD = a sleep deprivation factor used in the equation; and r^2 (squared Pearson r) = the amount of variance in the data that was explained by the model.
[a]Mitler et al. (1988)
[b]Prokop & Prokop (1955)
[c]Browne (1949)
[d]Hildebrandt et al. (1974)
[e]Bjerner et al. (1955)

Figure 2.
Curve fits to (A) operators' delays in answering calls (Browne, 1949), (B) locomotive auto-braking data (Hildebrandt et al., 1974), and (C) meter reading error data (Bjerner et al., 1955), with the percentage variance explained for each curve fit. Curve parameter values are shown in the table on page 14.



First, we must recognize the huge increase that has occurred during the last century in the amount of energy a typical worker controls. For example, truck drivers today control several orders of magnitude more potential and kinetic energy than did stagecoach drivers of the 1800s. When the truck driver falls asleep on the job, there is much more at risk than when the stagecoach driver fell asleep. Nevertheless, the biology and sleep needs of both drivers are identical.

Second, we should recognize that many jobs and systems have not been designed to use human operators effectively. Any such design should exploit natural human strengths, such as pattern recognition and decision making, and it should protect the system from natural human weaknesses, such as vulnerability to attentional lapses in boring surroundings, especially during critical periods of the 24-h day and under conditions of sleep deprivation.

For example, in the transportation industry, efforts are being made to introduce structured cockpit napping for transoceanic flight crews, who must deal with long duty days and extreme jet lag (Rosekind et al., 1994, 1996). Also, efforts are being made to take circadian rhythms into account in hours of service regulations for interstate commercial drivers (Federal Highway Administration, 1996).

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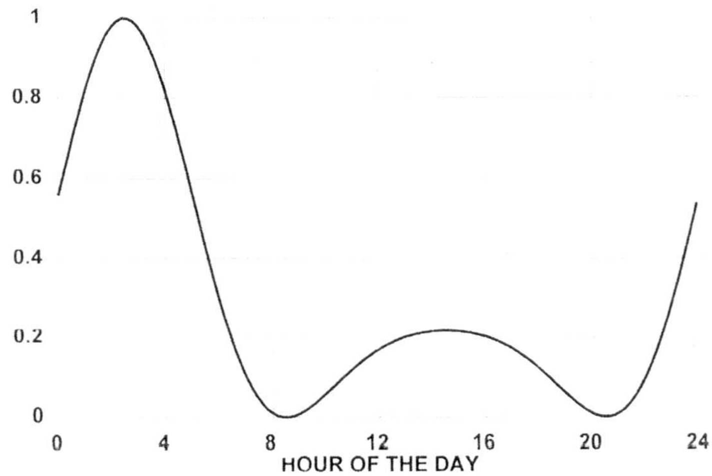
Third, we should recognize that in the modern era, it is impossible to avoid assigning a significant portion of the workforce to night work. Emergency services such as hospitals and law enforcement, and utility services such as electrical power, natural gas, sewer, telephone, and water, require around-the-clock staffing. In conjunction with this awareness, we should also recognize that

Figure 3.
Idealized curve from medians of parameter values θ and sleep deprivation (SD) in the table on page 14.



night work always compromises a person's ability to get enough sleep.

Fourth, we should recognize that the methods currently available to laboratory researchers for identifying unacceptable sleepiness do not lend themselves to widespread use in the workplace, even if some level of sleepiness could be agreed on as unacceptable for job performance. However, a number of laboratory-originated performance tests have been adapted for daily workplace use and are becoming available (Miller, 1996).

Guidelines for Application

Once we accept these facts of life, what can we do with our current information and technology? We now know when during the 24-h day industrial errors leading to incidents and accidents are most likely to occur. Therefore, it may be possible to focus job redesign and staffing redesign on those workers whose sustained alertness is required for safety. We can then integrate fundamental principles of the sleep research and human factors disciplines with the findings reviewed here. Consider the following possibilities:

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Examine, through task analyses and other appropriate methods, those safety-sensitive jobs that are most vulnerable to loss of attention. Some of these jobs require vigilance, or watchkeeping. For example, some important inspection tasks and many security positions require sustained attention in boring environments. People generally have problems remaining alert for rare but important occurrences in boring situations. Other safety-sensitive jobs require the time-sharing of attention among several dynamic cues. Vehicle operators – especially drivers and pilots in high-traffic areas – fall into this category.

Rank these jobs using a scale or set of scales that reflect each job's vulnerability to attentional lapses and the potential for loss of life, health, or property if an attentional lapse occurs. The scale(s) might be devised by managers, inspectors, quality circles, or others who observe the work environment with a critical eye. There may be more than one dimension that should be used to characterize various jobs – for example, how far the job deviates, either high or low, from moderate mental workload, and how likely an error is to injure someone. The range of the scales might be 0 to 10, 0 to 100, -10 to +10, and so forth. Once scores are obtained on such scales, it might be best to reduce the overall results to rank orders of jobs within these dimensions.

During the hiring process for safety-sensitive jobs, use interview and screening methods to identify and treat or exclude persons with sleep disorders characterized by uncontrollable sleep. For example, we use a questionnaire that highlights possible sleep disorders and then follow up with an interview. The limitations of self-reporting must be considered. Additionally, all applicants must be informed of the performance requirements of the safety-sensitive job.

Examine the recent daily patterns of errors of commission, omission, and judgment that occur in the various safety-sensitive jobs in the workplace. In this examination, do not mix data from crews with different shift-change times, because their patterns of error may be somewhat out of phase with each other. If data that are out of phase are mixed together, their patterns of oscillation will obscure each other. For example, if shifts change at 6:00 a.m., 2:00 p.m., and 10:00 p.m. for one set of jobs and at 9:00 a.m., 5:00 p.m., and 1:00 a.m. for another set of jobs, keep the data separate.

Educate workers about the intelligent management of their principal sleep periods and naps. Most people view sleep as a passive state of the brain. It is not. The brain generates sleep actively, and it needs the proper environmental conditions and time of day to do that efficiently. Simply educating workers about the conditions the brain needs to generate good sleep can help. This approach is being used for commercial truck drivers by both government regulators and motor carriers.

When staffing levels are specified and rotating shifts are designed, consider the periods in the 24-h day when there is the greatest vulnerability to sleep and error. Those who schedule rotating shifts should learn the principles of chronohygiene (Hildebrandt, Rohmert, & Rutenfranz, 1976) and the fundamental arithmetic of shift scheduling (Miller, 1992). For example, using factors of the 168-h week and the 364-day year are essential for producing shift rotation patterns that both minimize the influence of the two-peak pattern on worker errors and are acceptable to workers.

Double-check or triple-check the safety-sensitive work performed during periods of vulnerability. If the work is so critical that it is usually double-checked, then it should probably be triple-checked in the predawn and midafternoon hours. Similarly, other important work should be double-checked during those periods.

Use daily (or more frequent) fitness-for-duty testing to prevent workers who are impaired for any reason – including sleep deprivation – from trying to perform safety-sensitive jobs. A number of workplace tests are available that are brief, reliable, and self-administered (Miller, 1996).

Introduce preplanned naps into the duty periods of selected workers by adapting the approach used for long-haul pilots by Rosekind and colleagues (1994, 1996). For example, military managers assigned five people to work in a four-position workplace that required sustained attention throughout an 8-h shift. Each member of the team rotated through eight 48-min work cycles and two 48-min rest cycles within each shift. During those rest breaks, workers often took 20- to 40-min naps in a dark, quiet room set aside for that purpose.

Some Areas of Focus

Some or all of these ideas may be applied to safety-sensitive jobs that require

Model of the Two-Peak Pattern in Sleep Tendency

MITLER OBSERVED SERENDIPITOUSLY that a combination of the population growth function and the cosine function could be made to produce a distortion of the cosine curve that resembled the 24-h, two-peak pattern in human error and disease-related mortality (Mitler, 1991). In our work to date, this combination (expressed as a mathematical model of sleep tendency; Formula 2 on page 72 in Mitler, 1991) approximates well the temporal distributions of a variety of sleep-related and performance-related data. The formula includes a sleep deprivation factor (SD).

The equation accounted for 79% of the variance in the observed frequency of occurrence (Figure 1A, page 14) for more than 6000 fatigue-related auto accidents throughout the 24 h (Mitler et al., 1988). Similarly, for more than 437 000 deaths (Mitler et al., 1988), the equation accounted for 45% of the observed variance (Figure 1B, page 14).

The variance in some other 24-h observations may be explained reasonably well by this equation. It explained 69% of the variance in the frequency of falling asleep while driving (Figure 1C, page 14; see also Prokop & Prokop, 1955) but only 42% of the variance in the duration of switchboard operators' delays in answering calls (Browne, 1949; Figure 2A, page 15).

The model fits better for the last two entries in Figure 2, accounting for 83% of the variance in error-of-omission locomotive brakings (Hildebrandt et al., 1974; Figure 2B) and 76% of the variance in gas meter reading errors (Bjerner et al., 1955; Figure 2C).

It appeared that the data from tasks demanding vigilance (accidents, driver drowsiness, locomotive auto-brakings, and meter-reading errors) produced better curve fits than did data from other sources (mortality, delays in answering calls). The individual curve parameters are listed in the table on page 14. Note that increasing sleep deprivation seems to (a) leave unchanged the location of the temporal distribution of peaks in sleep tendency; (b) increase the amplitude and breadth of the nocturnal peak; (c) increase the amplitude and breadth of the afternoon peak while keeping constant the relative sizes of the two peaks; and (d) reverse the trend from wakefulness toward sleepiness between 7:00 a.m. and noon. The median time of occurrence of the larger peak for the six curve fits mentioned here was 2.5 h after midnight. The median SD was 2.75. The mean proportion of variance explained was 68.4%. The composite model is shown in Figure 3, page 15.

around-the-clock operations or operations during midafternoon. Examples include the following:

- Commercial motor vehicle operators, especially those carrying passengers or hazardous materials
- Health care workers who monitor critically ill patients, respond to medical emergencies, and perform surgery
- Maritime watchstanders, especially on ships carrying passengers or hazardous materials
- Monitors of safety-sensitive systems, such as air traffic controllers
- Pilots
- Quality control inspectors whose detection capabilities determine the safety and quality of manufactured products
- Security guards who are responsible for personal safety and the security of potentially hazardous work environments
- Shift workers who control machines with high potential for personal injury.

Careful attention to the prevention of accidents always pays off. These ideas should help managers and workers to design and implement new preventive measures that will help to keep incident and accident rates low.

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