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Technical Evaluation Report

**Shift Scheduling and
Overtime: A Critical Review
of the Literature**

P. M. Lewis

March 1985

Prepared for
the Nuclear Regulatory Commission
under Contract DE-AC06-76RLO 1830
NRC FIN B2360

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

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PACIFIC NORTHWEST LABORATORY

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ABSTRACT

This report is a review of literature on shift scheduling, overtime, and their effects on human performance in nuclear and non-nuclear industries. Over 300 articles, reports and books were collected and analyzed.

The main points that emerged from the review are as follows. Human performance generally decreases as the number of hours worked increases. This general decline can be altered to a degree by time-of-day effects and by other effects described below. Errors generally increase at night; this nighttime increase is significantly greater if the worker has already been working four or more hours before midnight. Sleep during the day is shorter and less refreshing than sleep at night. A controversy exists in the literature concerning the optimal speed of rotation. Some experts say it is best to rotate only once every four weeks; others say it is best to rotate every day or two. Most of these same experts say that rotating once per week is the worst situation. Also, most experts believe that forward rotation (i.e., rotating from the morning to the afternoon to the night shift) is less fatiguing than backward rotation, although that theory has not yet been adequately demonstrated in a field experiment.

EXECUTIVE SUMMARY

Pacific Northwest Laboratory (PNL) reviewed literature on shift scheduling, overtime, and their effects on human performance in nuclear and non-nuclear industries. Over 300 articles, reports and books were collected and analyzed. The effects of five shift scheduling factors on a worker's performance were examined. The main points that emerged from the review are as follows:

NUMBER OF HOURS OF WORK AND PERFORMANCE

- Human performance generally declines as the number of hours of work increases. This conclusion is based on a large volume of research, experience, observation, and evidence. The strength of this conclusion is based on the totality of this evidence; no single report provides a quantitative result that is directly applicable to the nuclear power industry.
- Although performance generally declines as the number of hours of work increases, this general trend can be altered temporarily by time-of-day effects and other effects that are described below.
- Errors generally increase at night. The increase is significantly greater if the worker has already been working four or more hours before midnight.
- Data exist on error rates for work periods in excess of eight hours in simulated work settings. Few data exist, however, on human error rates for extended hours of work in actual industrial settings with workers performing their normal duties.
- The NRC's policy on overtime is more lenient than the policies of other federal agencies.

TIME OF DAY AND PERFORMANCE

- Work performance is generally higher during the day, and sleep is more efficient at night. Human error probabilities rise at night, with the highest error rates generally occurring between 3 and 6 AM. These generalizations about night work are probably the best documented observations in the shift scheduling literature.
- Some studies show slightly lower performance in the early hours of the day shift. Many studies show a "post-lunch dip" -- a performance decrement about 1 PM.

REST PERIODS AND PERFORMANCE

In this review "rest period" means days off and nonwork periods away from the job site, not on-the-job coffee breaks, etc.

- According to many European researchers, workers should not work more than one to two nights in a row, and a night shift should be followed by a day off.
- Many researchers state their observations and opinions on the effect of cumulative fatigue, but there are few empirical studies in industrial settings on the amount of rest required to recuperate.
- Workers generally consider long rest periods, especially periods of four or more days, to be one of the most desirable aspects of shift work. Workers often prefer long, rigorous work periods interrupted only by short breaks, if they are eventually rewarded with a long rest period.

SPEED OF ROTATION AND PERFORMANCE

A controversy exists in the literature on the optimal speed of rotation.

- Slow rotation (work one shift for 3-4 weeks before rotating to the next shift). The advocates of slow rotation claim that slow rotation gives one's body enough time to adjust to working at night and sleeping during the day; this adjustment makes both work and sleep more efficient.
- Moderate rotation (rotate about once a week). Once-per-week rotation is common in the United States.
- Rapid rotation (rotate every 1-2 days). Many European researchers advocate rapid rotation. They say that even with slow rotation one's circadian rhythms never fully adjust to night work, partly because workers revert to the normal daytime schedule during days off. They say that weekly rotation is worst because just when a worker is almost adjusted to a shift he has to rotate to the next shift, and so he is in a constant state of "circadian desynchrony" or maladjustment. These researchers say that rapid rotation is best because with rapid rotation one's circadian rhythms essentially remain fixed on the normal daytime schedule. Therefore, work (and sleep) is efficient for the days (and nights) of morning shift, afternoon shift and days off. The only inefficiency occurs during the night shift. These researchers say a worker should not work more than 1-2 consecutive night shifts and that night shifts should always be followed directly by days off -- rapid rotation allows such a schedule for night shifts.

DIRECTION OF ROTATION AND PERFORMANCE

- Until recently, direction of rotation (forward vs. backward) has not been a major issue in the literature. However, the potential benefits of forward rotation will probably be small if workers revert to the normal sleep/wake schedule on days off, and if the schedule provides too little time off duty between rotations.

SHIFT SCHEDULING IN THE AIRLINE INDUSTRY

- Information on shift scheduling and fatigue in the airline industry is relevant because flight crews and air traffic controllers, like nuclear power plant operators, are highly skilled, work irregular hours, and are responsible for public health and safety.
- Data on shift scheduling fatigue and human performance are difficult to collect in any industry. Most experts agree that the best source of human performance information in the airline industry is obtained from the Aviation Safety Reporting System, which is a voluntary, confidential reporting system that is operated through an independent agency.

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INTRODUCTION

Pacific Northwest Laboratory (PNL) conducted the Shift Scheduling Project for the U.S. Regulatory, Division of Human Factors Safety, to recommend a policy position concerning the shift scheduling and overtime practices of safety-related personnel in nuclear power plants. The objective of this report for that project was to collect, catalog, review and evaluate available literature pertaining to shift scheduling and overtime practices in nuclear power plants. Because little research has been conducted on shift scheduling in nuclear power plants, most of the literature reviewed here is research on shift scheduling and overtime in non-nuclear industries that have similarities to the nuclear industry. Over 300 relevant articles were collected and reviewed and are listed in the reference and bibliography section of this report.

In this literature review, several shift scheduling characteristics are considered: 1) hours worked by safety-related personnel in any 24-hour period, 48-hour period, 7-day period and 30-day period, 2) fixed vs. rotating shifts, 3) forward vs. backward rotating shifts, 4) rapid vs. slow rotation, 5) length and timing of nonwork periods, and 6) time of day. It further investigates the major means through which these scheduling characteristics affect safety, such as 1) performance on component tasks, 2) vigilance, 3) alertness/fatigue, 4) quantity and quality of sleep, 5) long- and short-term memory, 6) physiological measures, 7) attitude toward one's shift schedule and job, 8) social/family life, 9) absenteeism, and 10) attrition.

The original draft of this report was concluded in June, 1983. Since then, the text has been revised slightly and the bibliography has been updated.

The objective of this report does not include making recommendations concerning guidelines for evaluating shift schedules, although the literature review has been organized so that it can eventually support such recommendations. Conclusions and recommendations are the objective of the project's final report.

Assessing the effect of shift schedules on human performance combines two disparate fields: shift scheduling and the biological study of circadian rhythms. The basic concepts and terminology essential for understanding these two fields and this report are described in this introduction. Additional terms are defined in the glossary in Appendix A.

SHIFT SCHEDULING: ESSENTIAL TERMS

No single vocabulary, categorization or notation can describe the thousands of shift schedules presently in existence. The following vocabulary, which will be used in this report, attempts to follow common usage as much as possible.

Industries with continuous operations often divide the 24 hours of the day into 3 shifts of 8-hour durations:

- morning shift (usually from about 8AM to 4PM)
- afternoon shift (4PM to midnight)
- night shift (midnight to 8AM).

To continue work over weekends and still provide rest periods for workers, continuous three-shift systems usually have four crews of workers. (If on-the-job training is also required, there might be five crews. Most nuclear power plants want to hire enough operators to staff six crews.) Permanent morning shift means that a crew works the morning shift only. Similarly, permanent afternoon (night) shift means that a crew works the afternoon (night) shift only.

Finding people who are willing to work a permanent night shift is often difficult. Therefore, most firms with continuous work have rotating shifts, so that the relatively desirable day and afternoon shifts and the relatively undesirable night shift are all shared among a larger group of employees. For example, in a rotating shift schedule a worker works the morning shift for seven days, has two days off, works the afternoon shift for seven days, has two days off, works the night shift for seven days, has three days off, and then starts over again. In this example, the direction of rotation is forward, and the speed of rotation is moderate. These terms are defined further below:

Direction of Rotation

Forward rotation means that a worker works the morning shift for a certain number of days, then works (rotates to) the afternoon shift, then works the night shift, in that order. (Since it is a cycle, it does not matter where the cycle begins or ends: ... night, morning, afternoon, night, morning, afternoon, night, morning, afternoon)

Backward rotation means that a worker works the three shifts in the opposite order: morning shift, night shift, and then afternoon shift.

The direction of rotation is determined solely by the sequence of work periods; it does not matter how rest periods are distributed among the work periods.

Speed of Rotation

Fast rotation means that a worker works one 8-hour shift for about 1-2 days before rotating (either forward or backward) to the next 8-hour shift. (Rapid rotation is common in Europe.)

Moderate rotation means that a worker works one 8-hour shift for about one week before rotating to the next 8-hour shift.

Slow rotation means that a worker works one 8-hour shift for about 3-4 weeks before rotating to the next 8-hour shift.

CIRCADIAN RHYTHMS: ESSENTIAL CONCEPTS AND TERMS

For physiological reasons, it is generally easier to work efficiently and safely during the day, and it is generally easier to get refreshing sleep at night. When a person is required to work at night and sleep during the day, both work performance and sleep are degraded. Recent studies of the effect of shift schedules on performance have included attempts to understand and manipulate these physiological daily rhythms to minimize both types of the degradation.

The term "circadian rhythm" is essentially synonymous with "daily rhythm" and refers to anything that varies systematically over time such that one cycle is completed in about 24 hours. The most obvious example is the sleep/wake cycle. Body temperature also usually reaches a nadir at about 6AM and a peak at about 6PM daily. Hundreds of other bodily functions and abilities have circadian rhythms.

The term "circadian rhythm" was coined in 1959 after an experiment was conducted. It was discovered that if people are placed in isolation chambers without access to the usual cues that tell us whether it is night or day, then most of these rhythms oscillate with a period of not 24, but rather 25 hours. Hence the term "circadian" was coined, meaning approximately a day (circa = approximately; dies = day).

The fact that our "natural" rhythms have a cycle of about 25 hours, but usually exhibit a rhythm with a cycle of 24 hours, indicates that the period of the cycle is reset daily. One's rhythms can also be reset by flying from New York to Paris; one's circadian rhythms will generally be reset to Paris time within several days. The cycles of light and dark, activity and sleep, meal times and other cues that help to reset one's circadian rhythms are called time cues.

Under normal conditions, the various cycles of one's many circadian rhythms (of body temperature, hormones, adrenaline, blood pressure, grip strength, etc.) exhibit a stable relation to each other. If, however, the normal time cues are altered, the cycles of different physiological functions generally respond somewhat differently. Some can respond quickly, while others respond slowly; some can respond by temporarily speeding up, while others respond by temporarily slowing down; some can respond by changing the range of oscillation, and so forth. Complexities such as these sometimes make assessing the relationships among shift schedules, circadian rhythms, and performance difficult.

"FIELD STUDY" VS "LABORATORY EXPERIMENT"

In the body of this report, field studies have been listed separately from laboratory experiments. This allows a quick, general assessment of the type of the evidence on which the conclusions are based.

"Field study" is used to indicate research conducted at the place of work, using the regular workers as subjects, while they are performing their regular duties. By contrast, the typical laboratory experiment is conducted in a research laboratory using students as subjects. The term "laboratory" is added to emphasize that the location, subjects, and/or tasks are controlled artificially.

Because field studies are conducted under real conditions and because they assess performance directly, they are generally considered to be a more reliable source of evidence than laboratory experiments. However, field studies also have disadvantages. For practical reasons, it is usually very difficult to collect enough information to determine with certainty the true cause of a change (e.g., was increased safety the result of a better shift schedule or better training?). Furthermore, some field studies are poorly or erroneously designed.

The advantage of laboratory experiments is that they can more easily control for all potential causes (e.g., shift schedule and training). Thus, both field studies and laboratory experiments are useful, and ideally, conclusions concerning the effect of shift scheduling on safety will be based on concurrence of well-conducted research of both types.

REPORT CONTENTS

This report is comprised of six chapters, four appendices and an extensive bibliography and reference list. In Chapters 1 through 5, the effect of various shift scheduling factors on a worker's performance are examined, based on the literature review. Those five factors are number of hours of work, time of day, rest periods, speed of rotation, and direction of rotation. Because of similarities between nuclear plant staff and airline pilots and air traffic controllers, shift scheduling in the airline industry is examined in Chapter 6. A glossary of terminology is provided in Appendix A. Appendix B contains a reprint of NRC's policy on working hours of nuclear power plant staff. Appendix C contains a summary chart of important reports on shift scheduling, and Appendix D is an annotated bibliography of 10 of those reports.

1.0 NUMBER OF HOURS OF WORK AND PERFORMANCE

Long work hours can affect performance and safety by increasing fatigue. Working hours include both regularly scheduled work hours and overtime. Common measures of the number of working hours include number of hours worked per 24-hour period, per 48-hour period, per 7-day period, per 30-day period, and per one-year period.

The following discussion has two parts: (1) federal regulations on number of hours worked, and (2) a summary of the literature on the effect of hours worked on performance/safety.

1.1 FEDERAL REGULATIONS ON NUMBER OF HOURS WORKED

The federal government sets guidelines for hours of work for the nuclear industry, the Air Force, and for three transportation industries, which are regulated by the Department of Transportation. The transportation regulations are more detailed than the nuclear regulations and contain a variety of rules and exceptions for special situations (e.g., Alaska bush pilots). All of the regulations allow increased work hours in emergencies or unusual situations. Federal guidelines are summarized in Table 1.1.

TABLE 1.1. Summary of Federal Guidelines and Regulations on Working Hours in Four Industries and the U.S. Air Force

	<u>Nuclear Power Industry</u>	<u>Air Force</u>	<u>Airline Pilots and Crew</u>	<u>Railroad Operators</u>	<u>Truck Drivers</u>
Consecutive Hours Worked	16	12	8	12	10
Length of Break	8 (after up to 16 hrs worked)	--(a)	8 (after 8 hrs aloft)	10 (after 12 consecutive hrs worked)	--
Hrs Worked in a 24-Hr Period	16	--	--	--	--
Hrs Worked in a 48-Hr Period	24	--	--	--	--
Hrs Worked in a 7-Day Period	72	--	30	--	60
Hrs Worked in a 30-Day Period	--	125	100	--	--
Hrs Worked in a Year	--	1320	1000	--	--

(a) Dashes indicate that no guideline is specified.

As shown in Table 1.1, the NRC's policy on overtime is more lenient than those of other federal agencies on two important measures:

- (1) Nuclear plant staff are permitted 16 consecutive hours of work, whereas Air Force pilots, airline pilots, railroad operators and truck drivers are permitted only 12, 8, 12, and 10, respectively.
- (2) Nuclear plant staff are permitted 72 hours of work within a 7-day period, whereas airline pilots and truck drivers are permitted only 30 and 60, respectively.

1.1.1 Nuclear Power Plant Staff

The most recent NRC policy on nuclear power plant staff working hours is contained in Generic Letter 82-12 of June 15, 1982 (reprinted in Appendix B). Reactor owners are directed to adhere to the following guidelines:

- a. "An individual should not be permitted to work more than 16 hours straight (excluding shift turnover time).
- b. An individual should not be permitted to work more than 16 hours in any 24-hour period, nor more than 24 hours in any 48-hour period, nor more than 72 hours in any seven-day period (all excluding shift turnover time).
- c. A break of at least eight hours should be allowed between work periods (including shift turnover time).
- d. Except during extended shutdown periods, the use of overtime should be considered on an individual basis and not for the entire staff on a shift."

Under FR 50.54(h), operating license holders are subject to rules, regulations, and orders that are issued by the Commission subsequent to the operating license. The above guidelines are not regulations. They were sent to each operating license holder and published in the Federal Register as an NRC policy statement. These guidelines are also incorporated in the latest revision of Regulatory Guide 1.33, "Quality Assurance Program Requirements (Operation)."

1.1.2 U.S. Air Force Limits on Flight Time

Table 1.1 summarizes basic U.S. Air Force flight-duty time limits. The first row in the table shows the maximum allowable number of hours in a single flight-duty period. A flight-duty period begins when crew members report for a mission or briefing, and ends when engines are stopped at the end of a mission or series of missions. Table 1.1 indicates that the maximum allowable number of hours in a single flight-duty period is 12 for a single control (one pilot) aircraft.

Air Force regulations provide different maximum flight-duty periods, depending on several considerations. Such considerations include the type of aircraft, whether the aircraft has single control or dual control, whether the aircraft has sleeping provisions, and whether the crew is a basic crew or an augmented crew (facilities for an augmented crew would allow one crew to sleep). For example, if a jet fighter has dual controls and two pilots, the maximum flight-duty time is 16 hours. With a few exceptions, the maximum flight-duty time for aircraft with a single crew and no sleeping provisions is 12 hours, and the maximum for aircraft with a single crew and sleeping provisions is 16 hours.

Table 1.1 also indicates that maximum flying time in 30 consecutive days is 125 hours. The maximum flying time in a calendar quarter is 330 hours of logged flight time; this is interpreted in Table 1.1 as a limit of 1320 hours in one year.

The regulations described above are general Air Force regulations. Each Command within the Air Force also establishes its own specific regulations. Those specific regulations must at least meet the minimum safety standards of the general Air Force standards and may set higher safety standards. The U.S. Air Force Material Air Command (MAC), for example, is very explicit and strict in requiring an adequate rest period before flight duty. If a MAC crew is scheduled for a mission that will take them away from their home station for more than one duty day, the crew rest period begins 24 hours before reporting for the mission. As stated in the Material Air Command Regulations, "During the first 12 hours of this period, a crew member may accomplish limited non-flying duties. The second 12-hour period is inviolate; no duties may be performed. Infringement of the inviolate crew rest period will necessitate the start of another 12-hour inviolate crew rest period" (emphasis added).(a)

1.1.3 Commercial Airline Pilots and Crew Members

The allowable flight time for pilots and other aircraft crew members is regulated by the Federal Aviation Administration (FAA). Applicable regulations are at 14 CFR Subparts Q, R, and S. The basic limitations are at 14 CFR 121.471 and include the following:

- (a) "No domestic air carrier may schedule any flight crewmember for duty aloft in scheduled air transportation or in other commercial flying if the crewmember's total flight time in all commercial flying will exceed:
 - (1) 1,000 hours in any calendar year.
 - (2) 100 hours in any calendar month.
 - (3) 30 hours in any seven consecutive days.

(a) U.S. Department of Defense, U.S. Air Force. January 15, 1975. Material Air Command Regulations, Vol. 1, p.2-2 (not readily available to the public).

- (b) No domestic air carrier may schedule a flight crewmember for duty aloft for more than eight hours during any 24 consecutive hours without a rest period at or before the end of that eight hours, equal to twice the number of hours of duty aloft since the last rest period, but not less than eight hours."

The regulations include a wide variety of exceptions to this basic rule, including special rules for transcontinental flights, helicopter pilots, etc. The rules also differ depending on how many crewmen are in the aircraft.

In 1982 the FAA issued new proposed rules that were intended to update and simplify the current flight time limitations. The proposed rules received extensive comment and were subsequently withdrawn by the FAA for further study.

1.1.4 Railroad Operators

The working hours of railroad employees are regulated by the Federal Railroad Administration (FRA) under the authority of the Hours of Service Act. A summary of the Act's requirements prepared by FRA is included in the Code of Regulations as Appendix A to 49 CFR 228. The following excerpt on the basic hour limitations is taken from this Appendix:

"Limitations on Hours. The Act establishes 2 limitations on hours of service. First, no employee engaged in train or engine service may be required or permitted to work in excess of 12 consecutive hours. After working a full 12 consecutive hours, an employee must be given at least 10 consecutive hours off duty before being permitted to return to work.

Second, no employee engaged in train or engine service may be required or permitted to continue on duty or go on duty unless he has had at least eight consecutive hours off duty within the preceding 24 hours. This latter limitation, when read in conjunction with the requirements on computation of duty time (discussed below), results in several conclusions:

(1) When an employee's work tour is broken or interrupted by a valid period of interim release (4 hours or more at a designated terminal), he may return to duty for the balance of the total 12-hour work tour during a 24-hour period.

(2) After completing the 12 hours of broken duty, or at the end of the 24-hour period, whichever occurs first, the employee may not be required or permitted to continue on duty or to go on duty until he has had at least 8 consecutive hours off duty.

(3) The 24-hour period referred to in paragraph 1 and 2 above shall begin upon the commencement of a work tour by the employee immediately after his having received a statutory off-duty period of 8 to 10 hours as appropriate."

1.1.5 Truck Drivers

The Federal Highway Administration (FHA) regulates maximum working hours for commercial truck drivers. Again, various special rules and exemptions exist, and the actual regulations need to be studied for their application to a particular situation. The basic regulations are found at 49 CFR 395.3. These regulations (slightly edited for this report) are as follows:

No motor carrier shall permit or require any driver used by it to drive nor shall any such driver drive:

- (1) more than 10 hours following 8 consecutive hours off duty; or
- (2) for any period after having been on duty 15 hours following 8 consecutive hours off duty. (Time "on duty" includes driving time and time performing other duties.)
- (3) Exemption: Drivers using sleeper berth equipment may cumulate the required 8 consecutive hours off duty resting in a sleeper berth in 2 separate periods totaling 8 hours, neither period to be less than 2 hours.

No motor carrier shall permit or require any driver used by it to be on duty, nor shall any such driver be on duty, more than 60 hours in any 7 consecutive days as defined in 49 CFR 395.2(c) regardless of the number of motor carriers using the driver's services. However, carriers operating vehicles every day in the week may permit drivers to remain on duty for a total of not more than 70 hours in any period of 8 consecutive days.

The logic and mathematical consistency of FAA and FHA regulations are not always clear. Partly for this reason, FAA regulations in particular have been the subject of much litigation.

1.2 MAIN POINTS IN THE LITERATURE ON HOURS OF WORK AND PERFORMANCE

Over 40 reports containing some data and information on the effects of the number of continuous hours of work were identified and obtained. The main points in these reports are as follows:

- Performance generally does decline with an increase in the number of hours of continuous work (although there are exceptions, and although it is not always easy to prove empirically).
- Errors generally increase at night. The increase is significantly greater if the worker has already been working four or more hours before midnight.
- Opinions vary concerning human error rates after 8 hours of continuous work. Many authors say that work should be limited to 8 hours per day. Yet, 12-hour-per-day shifts are common, especially in the petroleum industry. Northrup, Wilson and Rose (1979) asked managers of plants that had changed from 8-hour to 12-hour shifts whether the change had brought increased error rates; most managers said that it had not.

- Schneider, Brooke and Moray (1982, p. 73) assumed for their analysis that errors would occur between 8 and 12 hours at about the same rate they occur between 4 and 8 hours of work. Compared to the assumption that error rates decline steadily, this assumption understates the error rate. Nonetheless, this assumption still leads logically to the conclusion that the error rate over a 24-hour period is higher with two 12-hour shifts than with three 8-hour shifts (because with two 12-hour shifts there are four 4-hour periods of high error rates, whereas with three 8-hour shifts there are only three 4-hour periods of high error rates).

1.3 FIELD STUDIES ON HOURS OF WORK AND PERFORMANCE

In this section, field studies that assess the effect of hours of work on performance are summarized one at a time. In a field study, research conducted at the place of work, using regular workers as subjects, while they are performing their regular duties.

Mackie and Miller (1978) conclude that the probability of a truck accident occurring increases with increased driving time. They based their study on data collected by the Bureau of Motor Carrier Safety. The data were collected using a standard accident report form that truckers are obliged to fill out if they have an accident that results in death, injury, or property damage in excess of \$2,000. The report form requests information on the number of hours the driver had been driving at the time of the accident. Although this is a highly quantitative study, the methodology leaves some questions unanswered (see Mackie and Miller in the annotated bibliography).

Schneider, Brooke and Moray (1982, pp. 36, 38) conducted a literature search on the effect of number of hours worked on performance. The following summary statements of field studies are from their study. Shannon and Lane (1971) reported that aircraft accidents were associated with more than 8 hours of duty and with circadian displacement. Hurst (1976) identified pilot errors with duty beyond 8 hours. Vernon (1945) reported that occupational injuries fell significantly when 12-hour shifts were replaced by 8-hour shifts. Wilkinson, Tyler and Varley (1975) noted that more than one-third of junior doctors working 13 hours per day claimed that their efficiency was reduced as a result of the long hours.

Schneider, Brooke and Moray (1982, p. 42) summarize field studies on the effect of hours of work on vigilance as follows. Colquhoun et al. (1969) reported an 11% increase in error rates for radar screen monitoring over 12-hours in duration. Platz et al. (1978) reported no change in a vigilance task over 9 hours. Oobins et al. (1963) also reported no change in a vigilance task for army truckers driving over 9 hours.

1.4 LABORATORY EXPERIMENTS ON HOURS OF WORK AND PERFORMANCE

In this section laboratory experiments that assess the effect of hours of work on performance are summarized individually. The typical laboratory experiment is conducted in a research laboratory using students as subjects.

Brown, Tickner and Simmonds (1970) conclude that drivers take greater risks after 8 to 12 hours of driving. Unfortunately, this report has methodological problems (see Brown, Tickner and Simmonds in the annotated bibliography).

The following summary statements of laboratory experiments are from the literature search by Schneider, Brooke and Moray (1982, pp. 36, 38, 42, 43 & 47). Zagoruiko and Tambovtsev (1982) reported that speed of reading slowed by 22% to 73% over 4 hours. Higgins et al. (1975) reported increased errors for a complex test battery that included monitoring for more than 12 hours. Kogi et al. (1975) reported that the performance of nurses on a vigilance task decreased when they changed from 8-hour to 12-hour shifts at night. McKenzie and Elliot (1965) reported decreased ability to align flight meters in a flight simulator when work extended beyond 8 hours. Mackie and Miller (1978) reported deterioration in a critical tracking task in truck driving after 8 hours. Huxtable (reported in Ray, Martin and Alluisi 1961, p. 8) reported an increased error rate for repeated mental multiplication that would amount to a 17% increase over a 24-hour period for a 12-hour shift schedule as opposed to an 8-hour shift schedule. For complex decision making Wojtczak-Jaroszowa (1977) reported data that indicate an increased error rate of approximately 70%. McKenzie and Elliot (1965) report data on a tracking task in an aircraft simulator that imply a 6% increase in errors over 24-hours for 12-hour shifts compared to 8-hour shifts. From a car driving test, Herbert and Jaynes (1964) report data that imply a 10% increase for 12-hour shifts.

2.0 TIME OF DAY AND PERFORMANCE

Over 50 reports dealing directly or indirectly with the effect of time of day on performance were identified and obtained for this task. The main points in these reports are as follows:

- Vigilance drops and human error probabilities rise at night. This generalization is probably the best documented observation in the shift scheduling literature.
- Many studies show a "post-lunch dip" -- a performance decrement at about 1PM. Some studies suggest that, despite its name, the post-lunch dip is unrelated to eating lunch.
- Some studies show low performance in the early hours of the morning shift, from about 7AM to 9AM.
- The usual increase in human error probability at night is increased significantly if the worker has already worked an afternoon shift immediately before working the night shift.

2.1 FIELD STUDIES ON TIME OF DAY AND PERFORMANCE

A well-accepted generalization in the literature is that performance levels drop at night. However, relatively few field studies prove this point. Rutenfranz and Colquhoun (1979, cited in Reinberg, Vieux and Andlauer 1981, p. 179) state: "Performance studies making measurements at night or from night workers on the job are rare and the results are difficult to interpret." Folkard and Monk (1979, p. 483) state: "For a variety of reasons, such as union or management opposition and problems in finding appropriate measures, there appear to be only six published studies that report relatively continuous, 24-hour real-life performance measures. Nevertheless, there is a fair agreement among these studies that a major impairment of performance occurs during the night shift." These six studies are shown in four graphs in Figure 2.1.

Figure 2.1 shows that in all six cases performance drops at night (the graphs have been redrawn so that "bad" performance is toward the bottom of the graph). Four of the graphs also show a post-lunch dip in performance. Graph 1 shows that it takes telephone switchboard operators about 90% longer than average to respond to calls at night (Brown 1949; quantitative data cited in Mackie 1977, p. 117). Graph 2 shows that meter readers make more errors at night (Swensson 1953, cited in Mackie 1977, p. 117). Graph 3 shows that drivers "nod off" primarily at night and about 1PM (sample size, n=500) (Prokop and Prokop 1955, cited in Mackie 1977, p. 117). Graph 4 shows that the speed of spinners joining threads is slower at night (Wojtczak-Jaroszowa 1977; Pawlowska-Skyba 1967, cited in Mackie 1977, p. 117). Graph 5 shows that train drivers miss more warning signals at night (Hildebrandt, Rohmert and Rutenfranz 1974; see also annotated bibliography). Graph 6 shows that the frequency of minor accidents in a hospital is higher at night (Folkard, Monk and Lobban 1978).

FIGURE 2.1. Variations in Job Performance Over the 24-Hour Period in Six Field Studies (Scheving and Halberg 1980, p. 295; from Folkard and Monk 1979)

In a highly quantified study of truck accidents, Mackie and Miller (1978) show that most truck accidents in which the driver was dozing occur at night, even though more trucks are on the road during the day. Figure 2.2 shows this result. In Figure 2.2 "exposure" is the number of accidents that would have occurred during each hour of the day if the percentage of trucks on the road that have "dozing-driver" accidents were constant for all hours of the day. Under that assumption, one would expect more "dozing-driver" accidents during the day because there are more trucks on the road during the day. Thus, the larger number of "dozing-driver" accidents at night is not due to a higher volume of truck traffic at night.

FIGURE 2.2. Percentage of Accidents by Time of Day for "Dozing Drivers" and Normalized Percentage of Trucks on the Highway for a Random Sample of Interstate Drivers (exposure) (N = 493 accidents) (Mackie and Miller 1978, p. 56)

The studies examined in this section clearly show that performance drops at night. Circadian rhythms undoubtedly account for much of the performance decrement. A study by Meers (1975, cited in Folkard and Monk 1979, p. 484), however, shows that part of the performance decrement in the industrial settings might be due to poorer maintenance of equipment on the night shift.

2.2 LABORATORY EXPERIMENTS ON TIME OF DAY AND PERFORMANCE

Early laboratory studies generally corroborate the results of the field studies: performance is lower at night. These early studies also found a high correlation between circadian rhythms in performance and body tempera-

ture. Figure 2.3 shows circadian rhythms in a psychomotor test, a speed of cancellation test, a test in simple addition, and two aircraft simulator tests. The top graph in Figure 2.3 shows that the normalized curves for the circadian rhythms are almost identical. Comparison with the bottom graph shows that all of these are very similar to the curve for body temperature. (The bottom graph also shows the circadian rhythms for three other physiologic functions.)

FIGURE 2.3. Circadian Rhythms of Test Abilities and Physiologic Functions in Percent of the 24-Hour Mean (Mackie 1977, p. 113)

The very clear circadian rhythms shown in Figure 2.3 result in part from the experimental design: the subjects maintained a normal sleep/wake schedule, but they were awakened from sleep twice a night to perform the tests. Under these circumstances, one would expect low performance scores at night because the subjects' circadian rhythms had little time to adjust to wakefulness. Early experiments in which the subjects remained awake and "at work" for 12 consecutive 8-hour night shifts show that although one's circadian rhythms (measured by physiological and performance tests) do substantially adapt to the new sleep/wake schedule, the adaptation is not complete, and performance is still generally lower at night than during the day (Colquhoun and Rutenfranz 1980, p. 195).

More recent laboratory studies have shown that the circadian rhythms for tasks that require little short-term memorization are positively correlated with body temperature (as are all the tests in Figure 2.3), but the circadian rhythms for tasks that require a great deal of short-term memorization are negatively correlated with body temperature. (See Folkard et al. 1976 in the annotated bibliography.) It has been demonstrated that in a higher memory load task, workers adapted faster to night work conditions simulated in a laboratory and to a time zone change following transmeridian airplane flight (Klein and Wegmann 1980, p. 10).

2.3 COMBINED EFFECT OF NIGHTTIME AND LONG HOURS OF WORK ON PERFORMANCE

Night work and long hours have a synergistic effect on performance. Performance is usually low at night. But it is even lower, sometimes much lower, if the worker had already been working a number of hours before midnight.

Hildebrandt, Rohmert and Rutenfranz (1974; see annotated bibliography, Figure D.2) show that the error rate for German locomotive engineers at 3AM is about 5 times higher for engineers in their 4th to 6th hour of work than for engineers in their 1st to 3rd hour of work. Alluisi (1972) showed that the percentage of correct arithmetic computations generally reaches a nadir around 7AM, but the nadir is much lower if the subject has been deprived of sleep.

Figure 2.4 shows the performance levels of two groups of subjects who worked for 34 hours. The first group (shown by the solid line) began working at noon; the second group (shown by the dotted line) began working at midnight. After working 16 hours, at 4AM, the performance of the first group began to deteriorate rapidly. By contrast, also after working 16 hours, but at 4PM, the performance of the second group was still quite high. After working 30 hours, at 6PM, the performance of the first group was still relatively high. By contrast, also after working 30 hours, but at 6AM, the performance of the second group had plummeted.

Performance was measured by a multiple task performance battery (MTPB), a combination of the following six separate tests: blinking-lights monitoring,

warning lights monitoring, probability monitoring, arithmetic computations, code-lock solving, and target identifications (Coates 1974, pp. 24-26).

The evidence in this section indicates that working overtime increases error probabilities during the early morning hours, whether that overtime occurs before working the night shift or after working the afternoon shift.

FIGURE 2.4. Combined Effect of Nighttime and Long Hours of Work on Performance (2 groups of subjects) (Mackie 1977, p. 115)

3.0 REST PERIODS AND PERFORMANCE

"Rest period" is used to mean days off and non-work periods away from the job site, not on-the-job coffee breaks, etc. About 15 reports that deal directly or indirectly with the effect of rest periods on performance have been identified and obtained. None of those reports, however, can provide a rigorous base for regulatory guidance.

The following main points have emerged from that literature review:

- Sleep during the day is shorter and less refreshing than sleep at night.
- According to many European researchers, workers should not work more than 1 to 2 nights in a row, and a night shift should be followed by a day off.
- Many authors express opinions on the effect of the cumulative fatigue of continuous work, but there are few empirical studies of the amount of rest needed to overcome that fatigue.
- Workers generally consider long rest periods, especially periods of four or more days, to be one of the most desirable aspects of shift work. Workers often prefer long, rigorous work periods interrupted only by short breaks, if they are eventually rewarded with a long rest period.

3.1 GOVERNMENT REGULATIONS ON HOURS OF REST

Although there is general agreement in the literature that sleep during the day is shorter and less refreshing than sleep at night, in most government regulations on work hours, that fact has not been considered. FAA regulations, for example, have provisions for rest time, but the formula for computing rest time does not consider one's circadian rhythms. (By contrast, unofficial formulas for computing recommended rest periods and presumed fatigue for air crews do take circadian rhythms into account. These formulas are discussed and evaluated in Klein and Wegmann 1980, Appendices I and II.) In their book The Clocks That Time Us, Moore-Ede, Sulzman and Fuller (1982, p. 330) state: "It is essential ... that FAA's regulations be revised to take into consideration the body times of the air crew."

In contrast to the U.S. regulations, German regulations on the length of rest periods do take into consideration circadian rhythms: the formula for computing the required length of rest is based in the number of time zones crossed. (Crossing time zones is analogous to daytime sleep in that it often necessitates attempting to sleep at the improper time in one's circadian cycle.) Concerning the German regulations (as of 1974), Klein and Wegmann (1980, p. 29) state:

"As a general rule for flight crews on transmeridian routes, the regulations imply that resynchronization to a new time zone must not be

enforced but instead aircrews return as fast as possible to their home base. This applies only on the premises that sufficient rest time is provided within each 24-hour period away from home. To prevent sleep deficits, 14 hours rest time are considered the minimum under these conditions, and the operator is obliged to supply quarters which can be shielded from light and noise during local daylight hours. Upon returning to home base, the minimum rest period will be extended, if one or more flight segments have been spent in time zones differing from home base by 4 or more hours. The additional rest period required by regulation will then be calculated by multiplying the largest time zone difference while on duty with the factor 8. Thus, if the largest difference has been 6, for instance, the additional rest period will be $6 \times 8 = 48$ hours; or with the largest difference being 12 time zones, the rest period requires additional $12 \times 8 = 96$ hours."

It might be argued that 96 hours of rest required by German regulations is excessive, because the formula is based on the time required to resynchronize one's body temperature after a time zone change. However, as stated above, the crew is encouraged to keep their body rhythms fixed on the time at their home base. If they do so, they would not have to resynchronize to home base time.

3.2 FIELD STUDIES ON HOURS OF REST AND PERFORMANCE

Some European researchers advocate a 24-hour rest period after every night shift. Knauth, Rohmert and Rutenfranz (1980, p. 399), for example, state:

"The number of consecutive night shifts must be limited; preferably only single night shifts should be interspersed in the shift plan.... Each night shift must be followed by 24 h of free time.... To avoid accumulating sleep deficits, lack of sleep after the day sleep should be immediately compensated during the following night."

This strong recommendation is partly based on the senior author's extensive research on shift workers' sleep schedules (and is closely related to their advocating rapidly rotating shifts). The research on sleep schedules, however, has a methodological difficulty (see annotated bibliography, Knauth and Rutenfranz 1981).

Tilley et al. (1982, p. 632) report that the average duration of sleep for workers on night, morning and afternoon shifts were 5 1/2, 6, and 7 hours, respectively. Thus, a rest period during the day is not as refreshing as a rest period at night.

Many workers prefer long, rigorous work periods if they are eventually rewarded by a long rest period. For example, senior pilots often select the most rigorous flight schedules because vacation allowances are highly favorable for those who fly those routes. (See Moore-Ede, Sulzman and Fuller 1982, p. 330; also Patkai and Dahlgren 1981, p. 245 in Reinberg, Vieux and Andlauer 1981.)

4.0 SPEED OF ROTATION AND PERFORMANCE

A considerable volume of controversial literature addresses speed of rotation of shifts. The main points in this controversy are as follows:

- Slow Rotation (work one shift for 3-4 weeks before rotating to the next shift). According to the advocates of slow rotation, slow rotation gives one's body enough time to adjust to working at night and sleeping during the day; this adjustment makes both work and sleep more efficient.
- Moderate rotation (rotate about once per week). Once-per-week rotation is common in the United States.
- Rapid rotation (rotate every 1-2 days). Many European researchers advocate rapid rotation. They say one's circadian rhythms never fully adjust to night work, partly because workers revert to the normal daytime schedule during days off. They say that since it takes about a week for one's circadian rhythms to adjust to a new shift, with weekly rotation a worker's circadian rhythms are still unadjusted most of the time anyway. With rapid rotation one's circadian rhythms essentially remain fixed on the normal daytime schedule, so sleep is efficient on days off. Finally, these researchers say a worker should not work more than 1-2 consecutive night shifts and that night shifts should always be followed directly by days off -- rapid rotation allows such a schedule for night shifts.

4.1 FIELD STUDIES ON SPEED OF ROTATION AND PERFORMANCE

In this section, two documented field studies on speed of rotation and performance are examined.

4.1.1 Field Study at a Potash Factory in Utah

At a potash factory in Utah, productivity, worker health and job satisfaction improved, and turnover declined after their shift schedule changed (Czeisler, Moore-Ede and Coleman 1982). In the former schedule, workers rotated (backward) to the next 8-hour shift once per week. Thirty-three workers then volunteered for a new schedule that rotated (forward) at the same speed, once per week. Fifty-two workers volunteered for a new schedule that rotated (forward) once every three weeks.

Statistically significant improvements in performance and job satisfaction were attributed only to the schedule that rotated once every three weeks. These results provide evidence that slow rotation improves performance. However, the authors themselves treat these results with caution, stating p. 462): "However, the design of any specific work schedule must, of course, take into consideration both the nature of the work and the specific needs of the workers." Caution is also advised because the performance measures were not tied directly to the workers on the 3-week rotation schedule: the produc-

tion measures were for the entire plant, whereas only one-third of the workers were on the 3-week rotation schedule. (This report is discussed further in Section 5.1.1 and in the annotated bibliography.)

4.1.2 Field Study in a Food Processing Factory in England

In a field study at a food processing factory in England (Pocock, Sergeant and Taylor 1980), sickness absences increased when the workers changed from a weekly rotating schedule to a rapidly rotating schedule. The authors attribute the increase in sickness absence directly to the speed of rotation. On the other hand, the workers liked the rapidly rotating schedule. (One indication of this is that "other absences" did not increase.) The authors conclude:

"The sharp increase in sickness absence ... suggests that although the men may have liked rapid rotation, they found it more demanding. If these results are confirmed in other studies, they would indicate that the popularity of rapid rotation ought not to be the only factor that management should consider when deciding to adopt it."

American air traffic controllers have two types of shift schedules that match the two schedules examined in this field study. As in this study, many air traffic controllers prefer the rapidly rotating schedule. The official position of the FAA, however, is that there are no discernible differences in performance between the two types of schedules and that worker satisfaction maintains adequate motivation and performance. (See Section 6.1.1.)

4.2 OTHER STUDIES OF SPEED OF ROTATION AND PERFORMANCE

Rapid rotation has been gaining popularity in Europe and is advocated by a number of European researchers. Among them are Rutenfranz, Knauth and Colquhoun (1976, p. 338), who state their reasons as follows:

"The circadian rhythm is not significantly disturbed by a single night-shift. The ... (adaptation of circadian rhythms to night work) requires more than seven consecutive nightshifts.... Even during nightshift periods of several weeks no complete ... (adaptation) of some physiological functions (e.g., body temperature, heart frequency) could be observed.... Furthermore, for psychosocial reasons most workers need either to change their shift, or to have some rest days, after no more than one week (of nightshift)."

Norwegian researchers Vokac et al. (1981 p. 64) make the following argument for rapid rotation:

"In any rotating system the night shift period (requiring an altered sleep time) accounts, on average, for only about a quarter of the total length of the rotation cycle; normal sleep/wake habits are maintained in the remaining three quarters (morning and afternoon shift periods, and free days).... (Since one's circadian rhythms are on the normal daytime

schedule three quarters of the time, rather than disrupt the rhythms just for one quarter of the time, it is best simply to leave the rhythms on the normal schedule all of the time. This can be done by rotating rapidly.) Short periods of not more than 2-3 consecutive night shifts seem therefore preferable to larger periods."

Moore-Ede, Sulzman and Fuller (1982, p. 335-336) agree with the European researchers on some points:

"In scheduling shift workers, managers should decide whether total readjustment to each shift is required (i.e., slow rotation) or no adjustment at all (i.e., rapid rotation). The schedules that change once a week seem to be the most pernicious, because the individual is always in a state of readjustment to a new schedule."

Finally, Folkard (1981, p. 369) suggests that there is no single proper speed of rotation; the proper speed of rotation depends on the type of task performed:

"(T)he results reviewed in this paper favour 'permanent' systems for simple perceptual-motor tasks, but rapidly rotating ones for more cognitive, memory-loaded tasks. However, these conclusions must be regarded as extremely tentative."

Most conclusions concerning speed of rotation must be regarded as tentative because of the lack of adequate data.

5.0 DIRECTION OF ROTATION AND PERFORMANCE

Whereas the other chapters in this report summarize the literature without reaching policy conclusions, this chapter reaches a policy conclusion. This chapter addresses the question: "Is there sufficient evidence to recommend the adoption of forward rotating shifts?" It concludes that the evidence favoring forward rotation is weak.

The main points from PNL's review of the literature in this area are as follows:

- The relative merits of forward vs. backward rotation for employee shift schedules is an issue that is rarely addressed directly in the literature.
- No author explicitly advocates backward rotation for shift schedules.
- One major report explicitly advocates forward rotation for shift schedules: Czeisler, Moore-Ede and Coleman reported in Science, July 1982, on an experimental change in the shift schedule at a potash factory in Utah. This experiment, however, fails to provide adequate evidence for forward rotation.
- Workers often revert to the normal daytime schedule on days off. For these workers, much of the progress in gradually and consistently resetting their circadian rhythms in a forward direction will be lost, and thus the advantage of a forward rotating schedule will be reduced.
- There is usually a rest period between rotations. Any presumed advantage of a forward rotating schedule might be small compared to the recuperation gained by a longer rest period.
- Jet-lag experiments and isolation-chamber experiments have been cited to justify forward-rotating shift schedules. PNL concludes, however, that these experiments offer insufficient evidence to justify forward-rotating shift schedules.
- In contrast to Czeisler, Moore-Ede and Coleman's circadian principle of repeatedly resetting one's internal clock to match a repeatedly changing work/sleep schedule, some European researchers advocate leaving one's internal clock fixed on the normal time.
- In an experiment at a factory in England, illness and absences were lower on a backward-rotating shift schedule than on a forward-rotating schedule.

5.1 FIELD STUDIES ON DIRECTION OF ROTATION AND PERFORMANCE

In this section, two documented field studies addressing direction of rotation and performance are examined.

5.1.1 Field Study at the Potash Factory in Utah

The field study at the Utah potash factory not only compared two speeds of rotation (as discussed in Section 4.1.1), it also compared two directions of rotation. As was mentioned before, the authors concluded that performance and job satisfaction improved when workers changed from a backward to a forward rotating shift schedule. This experiment, however, fails to provide adequate evidence for favoring forward rotation over backward rotation, for three reasons:

(1) The "circadian" principles that the authors wished to apply required that the shift schedule change by no more than 1 or 2 hours per day; thus, an employee would begin work at 8AM one day, 9AM the next day, 10AM the third day, etc. After trying such a schedule and finding it unacceptable for social reasons, the employees at the potash plant abandoned this schedule and reverted to the ordinary practice of rotating in 8-hour increments. An 8-hour increment, however, is beyond the confirmed range of applicability of the "circadian principle" on which the authors based their justification.

(2) To have practical application to shift scheduling, the authors' circadian principles should be expanded to include the effects of rest periods.

(3) At the potash factory, the new forward rotating shift schedules were of two types: in one schedule workers rotated forward to the next shift every week, in the other they rotated forward once every 3 weeks. Because the statistically significant results on satisfaction and productivity were all for the 3-week rotation scheme, it is more difficult to discern the degree to which the beneficial effects of the new shift schedule resulted from forward rotation and to what degree they resulted from slow (21-day) rotation. (For additional information, see Annotated Bibliography, Czeisler, Moore-Ede and Coleman 1982).

5.1.2 Field Study at the Food Processing Factory in England

The field study at the English food processing plant explicitly compared two speeds of rotation (as discussed in Section 4.1.2). The two shift schedules, however, also differed on direction of rotation. The rapidly rotating schedule was also a forward rotating schedule, and the slowly rotating schedule was also a backward rotating schedule. The backward (slowly) rotating schedule produced fewer sickness absences.

Although it would be unreasonable to infer from this evidence that backward rotation produces fewer sickness absences, one can reasonably infer that a change from a backward to a forward rotating schedule is not always a change for the better (since rapid rotation can overwhelm any presumed benefits of forward rotation).

5.2 LABORATORY EXPERIMENTS ON DIRECTION OF ROTATION AND PERFORMANCE

In this section, experiments on direction of rotation and its effect on performance are discussed.

5.2.1 Experiment on the Circadian Rhythms of Rest Periods

The theory that justifies advocating forward rotating shift schedules requires that a worker's circadian rhythms adapt to each successive new shift as he rotates his work periods forward around the clock. To do this successfully, the worker would have to continue with his work schedule on his days off. Most workers, however, for social reasons, revert to the normal daytime schedule on their days off. For these workers, much of progress they might have been made during the workweek in adapting their rhythms is lost during days off.

The speed with which circadian rhythms revert to the normal cycle on days off was investigated by Vokac et al. (1981). In their experiment, six subjects were put on a rapidly rotating schedule. Body temperature and urinary excretions of adrenaline, noradrenaline and other chemicals were monitored. The authors concluded that even though there was some adaptation of these circadian rhythms to the work schedule, on days off they reverted "suddenly" to the normal daytime cycle.

This research indicates that the "circadian principles" used to justify forward rotation take inadequate account of the circadian effect of rest periods.

The length of rest periods must also be considered when examining the causes of changes in performance levels. Whenever a shift rotates, either backward or forward, the length of the rest period between shifts is changed; there is often a rest period of one to four days between rotations. The rest period between shifts rotating backward may be longer than the rest period between shifts rotating forward. One must consider the possibility that the beneficial effects of this increased rest might outweigh the potential negative effects of backward rotation.

The different lengths of rest periods between rotations can be illustrated by the following example. Assume that two workers both work the morning shift, both have one day off, and both rotate to a new shift. The worker that rotates forward to the afternoon shift will have 24 hours off. The worker that rotates backward to the night shift will have 32 hours off. In this example, the worker on the backward rotating shift has more time to recuperate.

5.2.2 Jet-Lag and Isolation-Chamber Experiments

Jet-lag experiments are generally designed as in the following hypothetical example. The subject's body temperature (or some other bodily function or ability that has a circadian rhythm) is measured every hour or two for several days to determine the time of day of its peak value, say 7PM. The subject is then flown from New York to Paris, and his body temperature is measured every hour or two for several days after the flight. On the first day after the flight, the peak in body temperature will typically remain close to 7PM New York time, but after 3-6 days the peak will occur at 7PM Paris time. The number of days required before the peak occurs at 7PM Paris time is considered to be the adjustment time.

Isolation-chamber experiments, often conducted in deep caves or underground bunkers, have provided an extensive body of literature on human circadian rhythms (Klein and Wegmann 1980, p. 7). These experiments are conducted in rooms that are isolated in such a way that a subject in them has no way of knowing the time of day. Wake and sleep periods can then be determined in two ways: (1) the researcher can artificially create "daytime" and "nighttime" anytime, for example, by asking the subject to wake up and turn the lights on, or to turn the lights out and go to sleep, and (2) the subject himself can be allowed to wake and sleep as he likes. In each case, the subjects circadian rhythms are measured.

Jet-lag and isolation-chamber experiments resemble rotating shifts in that the wake/sleep schedule is shifted. Although these experiments provide some useful information, they do not give a clear indication that forward-rotating shifts are significantly better, for the following reasons:

- The analogy between these kinds of experiments and shiftwork is inexact: in shiftwork the daily time cues are inconsistent (e.g., one sleeps during the day and eats at odd hours).
- The lessons provided by jet-lag experiments and isolation-chamber experiments are not always clear. Some experts say the two types of experiments provide the same lesson: forward rotation is better. Another expert says in effect (since his is not directly concerned with shift scheduling) that proper interpretation of the two types of experiments provide the same lesson: backward rotation is better. Other experts say that the results of jet-lag experiments inexplicably contradict the results of isolation-chamber experiments. Still another expert says that some physiological processes and abilities adapt more quickly after westward flight (which corresponds to rotating forward), while other processes and abilities adapt more quickly after eastward flight (which corresponds to backward rotation). (These expert opinions taken from Klein and Wegmann 1980, pp. 17-23.)

6.0 SHIFT SCHEDULING IN THE AIRLINE INDUSTRY

Airline pilots and air traffic controllers, like nuclear plant staff, have irregular shift schedules, are highly skilled, and bear a heavy responsibility for public safety. Therefore, literature on the airline industry was examined for potential application to the nuclear industries. Studies of pilots and air traffic controllers suggest that sleep deprivation might have more effect on safety than jet lag or rotation of shifts. To collect information on shift scheduling and safety, the federal agencies that oversee the airline industry use methods that might be adapted and adopted by the NRC.

6.1 AIR TRAFFIC CONTROLLERS AND PILOTS

Two general working populations for which there are shift scheduling concerns in the airline industry are first, the air traffic workforce and airway facility technicians, and second, the aircraft crews. Shift scheduling practices for these two workforces differ primarily in their regularity. The air traffic controllers work predictable, regular schedules, whereas the aircrews frequently work odd schedules crossing multiple time zones in different directions with long or short work days, variable workloads, and variable rest periods. Each of these airline industry groups faces problems of shift scheduling in relation to work performance, the effects of which can be related to similar circumstances in the nuclear industry.

6.1.1 Air Traffic Controllers

Air traffic controllers work two basic shift rotation patterns (Reighard 1983). One rotation consists of two 5-day (40-hour) weeks on the afternoon shift, 2 weeks on the morning shift, and 1 week on the night shift. This shift schedule is referred to as the "Straight 5;" it is a backward rotating shift, rotating once per week. Each workday is 8 hours long and workdays are separated by 16 hours off duty. Workweeks are separated by 2 days off.

The second basic shift schedule is one that consists of a workweek consisting of 2 consecutive afternoon shifts, then 2 morning shifts, and finally, 1 night shift. This shift schedule is called "2-2-1" or "rattler;" it is a backward rotating, rapidly rotating shift schedule. The controversial feature of this schedule is that no 2 work periods are separated by a full 16 hours. The longest separation is 14 or 15 hours and the shortest is 9 or 10 hours. These quick turnarounds result in compression of the 40-hour workweek into an 88-hour period, leaving 80 hours (or nearly half of a 7-day week) off duty between workweeks.

The FAA management claims that neither work pattern is superior to the other in terms of "...biochemical and physiological measurements (stress indicators) taken during research..." (Reighard 1983). They do claim that the 2-2-1 pattern is preferred by many controllers, apparently because of the

extended off-duty period that follows the sequence. The FAA imposes no standard practice on their facilities throughout the country. Each facility is free to establish its own practice, and a recently implemented FAA human relations program has encouraged worker participation in developing work schedules.

Accurately assessing the true effectiveness of FAA shift scheduling policies is difficult at this time because of the continuing effects of the 1981 air traffic controllers strike and subsequent reduction in the controller workforce. In contrast to the FAA management view set forth in recent Congressional testimony, the head of the National Transportation Safety Board, Jim Burnett, was quoted on March 15, 1983, as expressing concern for safety in the air traffic control system because of increased traffic demands on less experienced controller workforce. Many controllers in heavy traffic areas were reported to be working six days per week with little vacation. Therefore they were apparently not able to maintain the more benign and regular schedules used at less busy facilities.

Because of these temporary problems of the system, studies conducted on controllers before the strike may be more representative of circumstances in the nuclear power industry than are newer studies.

6.1.2 Airline Pilots

As indicated earlier, shift scheduling practices of flight crews are closely regulated. Nevertheless, wide variations in schedules can and do occur even within the letter of the regulatory policy. For example, aircrews on international airlines may cross multiple time zones on long flights with few takeoffs and landings (high workload periods) scheduled for each duty period. On the other hand, aircrews on regional or feeder airlines may stay within a single time zone but may have to make a dozen or more takeoffs and landings in one shift. A multitude of research studies has been conducted to understand the diverse operational conditions experienced by airline crews. The major results of the research may be summarized by saying that shifts in time zones or work schedules may impair performance, but sleep deprivation may well be the most important factor in both cases.

6.2 DATA COLLECTION IN THE AIRLINE INDUSTRY

The focus of this literature review is on research results, not on data collection methods. Nonetheless, this section is directly relevant to the object of the research project, which is to recommend an NRC policy position concerning shift scheduling and overtime. If the NRC were to conclude that insufficient data exist at present on which to base an NRC policy position, it might wish to rectify the situation by collecting the relevant data. Alternatively, if the NRC were to adopt a policy position based on available data, it might also wish to collect additional data at the same time in order to further justify or modify its position in the future. In either case, the collection of additional data is important. The data collection methods of the FAA are

FAA are particularly relevant because of the similarities between the roles of the FAA and the NRC, and the similarities between the airline and nuclear power industries. The three most relevant FAA data collection methods, which are described below, are 1) accident investigation teams, 2) mishap reporter amnesty, and 3) the Aviation Safety Reporting System. (The data collection methods of the Department of Transportation for the trucking industry are described briefly in Mackie and Miller 1978, p. 51.)

6.2.1 Accident Investigation Teams

The National Transportation Safety Board is charged with investigating airline accidents. This federal board has assembled multidisciplinary teams of investigators who can quickly respond to the scene of any airline accident. Once there, they immediately gather all available information about such factors as the aircraft condition, weather, aircrew qualifications, and airway status. They then reconstruct the exact circumstances of the accident, determine its direct and indirect causes, and then issue immediate action recommendations to remedy the conditions that led to the mishap. Since the multidisciplinary team consists of personnel as diverse as human factors specialists, medical doctors, and engineers, the recommendations are frequently wide ranging. If public safety is affected, they may even have economic consequences as severe as grounding of an entire aircraft type pending some mechanical check or modifications. Two important aspects of all these investigations are the crew qualifications and their recent work schedules.

6.2.2 Mishap Reporter Amnesty

Several times over the past few decades, the FAA has set up temporary programs providing amnesty to pilots or controllers who report unsafe events or conditions that otherwise would involve self-incrimination with severe legal or regulatory penalties. The underlying philosophy of these programs is that it is best to detect the occurrence of unsafe acts or events to correct relevant policies or practices before a severe accident occurs. Past amnesty programs have involved such hazardous events as near-midair collisions that might normally go unreported by pilots who fear losing their licenses because they may have made a mistake. The FAA's enlightened view is that such human errors frequently have underlying causes that could be corrected through system changes. For example, a mistake by a pilot who has been on duty for many hours may indicate a need for changes in the regulations pertaining to shift scheduling.

One proposed solution for the problem of assessing the true safety of the current, post-strike air traffic control system is an amnesty for controllers who report hazardous events. Post-strike reports of such events have decreased significantly from pre-strike report levels, and some observers attribute this difference to fears of the present controller workforce of retribution by management. It is therefore felt that an amnesty for workers reporting critical incidents will provide a more accurate picture of the system's safety than does the formal reporting process.

Some type of amnesty system might also be useful in the nuclear industry. Data on operational errors collected through the amnesty system could then be related to shift scheduling practices to determine which, if any, are superior or inferior. Such information could potentially provide a sound basis for regulatory policy or could, at least, help direct specific research aimed at formulating better policies.

6.2.3 NASA Aviation Safety Reporting System

The Aviation Safety Reporting System (ASRS), operated through the National Aeronautics and Space Administration (NASA), is a voluntary, confidential reporting system available to all users of the national aviation system. It is similar to the amnesty systems described above because the FAA offers a limited waiver of disciplinary action to participants who may have inadvertently violated a Federal Air Regulation. It is different from the amnesty systems in that the program is managed and operated by NASA, an independent agency, to increase the flow of information into the program. Safety reports may be submitted about any situations or occurrences that may affect air safety.

As described by Lyman and Orlady (1981), reports are submitted to ASRS on a structured form that asks for information about such things as aircraft characteristics, weather, experience, type of operation, and air traffic control. Space is also provided for the reporter to describe in his/her own words the circumstances of the incident, what happened, and why. NASA safety analysts review the report for completeness and criticality of the reported incident. If an analyst believes it appropriate, he may contact the reporter for additional information. When satisfied that the report is as complete as possible, the analyst removes the reporter's name and any other persons or organizations who may have been identified. The analyst then processes the report, preparing it for entry into the ASRS data base. After a safety report leaves the analyst's possession, there is no opportunity to obtain additional information about the incident. To assure the reporter's confidentiality, the analyst never attempts to corroborate the circumstances of the reported incident by contacting other parties. All data collected on the forms are entered into a computerized data base.

Since "Duty/Scheduling" is one of the key words used in the data base, reported events can be analyzed in terms of shift scheduling. In addition, some of the most interesting results of this system are the reporters' suggestions for solutions. In many cases these solutions may lead directly to simple, yet effective, regulatory policy changes.

It would appear that a system similar to the ASRS could provide useful information to the NRC if it were properly conceived and presented to the industry. Probably the most effective system would have to use an organization that is independent of the NRC to collect and analyze the reports, just as the FAA uses NASA for that purpose. The reporters must have faith in the confidentiality of the reporting system if it is to be effective. Once the system is in place, valuable shift scheduling data could be collected to support formation of regulatory policies. (See also Finalyson and Ims 1983.)

APPENDIX A

TERMINOLOGY FOR DIRECTION OF SHIFT ROTATION

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TERMINOLOGY FOR DIRECTION OF SHIFT ROTATION

The terminology for specifying the direction of shift rotation is confusing because there are four sets of terms for the same phenomena, each set having been borrowed from a different field of endeavor. Unfortunately, some of the terms for the same phenomenon sound as though they refer to precisely their opposites (e.g., "forward rotation" is analogous to "phase delay" and a traveller setting his watch backward.). The four fields of endeavor are 1) shift scheduling, 2) laboratory research, 3) transmeridian airplane travel, and 4) trigonometry. (Trigonometric terminology will not be discussed here.) Because the terms used within each field of endeavor make sense within their own context, the following discussion will deal with each context separately. A final chart summarizes the sets of terms.

A.1 SHIFT SCHEDULING TERMINOLOGY

Rotating shifts typically have three shifts: morning (08.00 to 16.00), afternoon (16.00 to 24.00), and night (24.00 to 08.00).

A forward rotating shift schedule is one in which a worker works these three shifts in the following order: ... morning/afternoon/night/morning/afternoon/night/morning (the series can start and end at any of the three periods of the day).

A backward rotating shift schedule is one in which a worker works these shifts in the opposite order: ... morning/night/afternoon/morning/night/afternoon/morning/night

The following chart is an example of a forward rotating shift schedule for a worker, where the X's indicate days of working a particular shift, or days off:

Morning		XXXXX			XXXXX			XXXXX			XXXXX		
Afternoon			XXXXX			XXXXX			XXXXX			XXXXX	
Night				XXXXX			XXXXX			XXXXX			XXXXX
Off		X	X	XXX	X	X	XXX	X	X	XXX	X	X	XXX

The following is an example of a backward rotating shift schedule:

Morning				XXXXX				XXXXX				XXXXX
Afternoon			XXXXX				XXXXX				XXXXX	
Night	XXXXX				XXXXX			XXXXX				XXXXX
Off		X		X		XXX		X		X		XXX

For ease of comparison later, these schedules can be redrawn as follows (where M = morning, A = afternoon, and N = night):

	<u>Before rotation</u>								<u>After Rotation</u>												
	M	A	N	M	A	N	M	A	N	M	A	N	M	A	N	M	A	N	M	A	N
Forward		X			X			X			X			X			X			X	
Backward		X			X			X			X			X			X			X	

A.2 LABORATORY RESEARCH TERMINOLOGY

Laboratory research on circadian rhythms typically uses laboratory animals that are placed in an isolation chamber so they have no way of knowing the real time of day. The researcher then can simulate daytime by turning on a light in the chamber and can simulate nighttime by turning it off. The research typically begins with a pre-test session in which the researcher turns the light on and off at times that correspond to the real night and day, for example turns the lights on at 6AM and off at 6PM. During the test session, however, the researcher will either delay switching the lights, e.g., switch them at 7AM and 7PM, or will switch the lights in advance of the pre-test times, e.g., at 5AM and 5PM. Hence the terms "phase delay" and "phase advance." Phase delay and phase advance are represented graphically below where asterisks mark the real 6AM and 6PM, and X's indicate when the light is turned on in the isolation chamber:

	<u>Pre-test Period</u>			<u>Test Period</u>					
	6PM		6AM		6PM		6AM		6PM
	*		*		*		*		*
Phase delay			XXXXXXXXXXXX		XXXXXXXXXXXX		XXXXXXXXXXXX		
Phase advance			XXXXXXXXXXXX		XXXXXXXXXXXX		XXXXXXXXXXXX		

A.3 TRANSMERIDIAN AIRPLANE TRAVEL

Crossing several time zones quickly in a jet plane is often compared to rotating shift schedules and to laboratory tests of circadian rhythms. In the following table, two flights are compared: New York to Los Angeles, and New York to Paris. The asterisks mark New York time; the X's indicate the period from 6AM to 6PM (daytime) at the traveler's (changing) location.

	<u>Pre-flight</u>		<u>Post-flight</u>			
	New York Time: 6AM	6PM	6AM	6PM	6AM	6PM
	*	*	*	*	*	*
NY to LA (East to West; set watch back)	XXXXXXXXXX		XXXXXXXXXX		XXXXXXXXXX	
NY to Paris (West to East; set watch forward)	XXXXXXXXXX		XXXXXXXXXX		XXXXXXXXXX	

A.4 SUMMARY

Visual inspection shows that the upper section of each chart corresponds to the upper section of the other charts, and similarly for the lower sections. The sets of terms are summarized below:

	<u>Shift Scheduling</u>	<u>Laboratory Research</u>	<u>Transmeridian Travel</u>
<u>Upper</u>	Forward Rotation	Phase Delay	East to West travel set watch back
<u>Lower</u>	Backward Rotation	Phase Advance	West to East travel set watch ahead

For defining examples of the usage of these terms, see Czeisler, Moore-Ede and Coleman, 1982; Science, pp. 460, 461, and 462 note #9; and Moore-Ede, Sulzman and Fuller, 1982, The Clocks That Time Us, p. 121.

APPENDIX B

NRC POLICY ON WORKING HOURS

APPENDIX B

NRC POLICY ON WORKING HOURS

The most recent NRC policy statement on the working hours of nuclear power plant staff is contained in Generic Letter 82-12 of June 15, 1982. A copy of the policy statement from this letter appears on the following page of this appendix. This same policy statement was published in the June 1, 1982, Federal Register, 47 FR 23836.

POLICY ON FACTORS CAUSING FATIGUE OF OPERATING
PERSONNEL AT NUCLEAR REACTORS

Licensees of operating plants and applicants for operating licenses shall establish controls to prevent situations where fatigue could reduce the ability of operating personnel to keep the reactor in safe condition. The controls should focus on shift staffing and the use of overtime--key job-related factors that influence fatigue.

The objective of the controls would be to assure that, to the extent practicable, personnel are not assigned to shift duties while in a fatigued condition that could significantly reduce their mental alertness or their decision making capability. The controls shall apply to the plant staff who performed safety-related functions (e.g., senior reactor operators, reactor operators, health physicists, auxiliary operators, and key maintenance personnel).

Enough plant operating personnel should be employed to maintain adequate shift coverage without routine heavy use of overtime. The objective is to have operating personnel work a normal 8-hour day, 40-hour week while the plant is operating. However, in the event that unforeseen problems require substantial amounts of overtime to be used, or during extended periods of shutdown for refueling, major maintenance or major plant modifications, on a temporary basis, the following guidelines shall be followed:

- a. An individual should not be permitted to work more than 16 hours straight (excluding shift turnover time).
- b. An individual should not be permitted to work more than 16 hours in any 24-hour period, nor more than 24 hours in any 48-hour period, nor more than 72 hours in any seven day period (all excluding shift turnover time).
- c. A break of at least eight hours should be allowed between work periods (including shift turnover time).
- d. Except during extended shutdown periods, the use of overtime should be considered on an individual basis and not for the entire staff on a shift.

Recognizing that very unusual circumstances may arise requiring deviation from the above guidelines, such deviation shall be authorized by the plant manager or his deputy, or higher levels of management. The paramount consideration in such authorization shall be that significant reductions in the effectiveness of operating personnel would be highly unlikely.

In addition, procedures are encouraged that would allow licensed operators at the controls to be periodically relieved and assigned to other duties away from the control board during their tour of duty.

APPENDIX C

SUMMARY CHART OF IMPORTANT REPORTS ON SHIFT SCHEDULING

APPENDIX C

SUMMARY CHART OF IMPORTANT REPORTS ON SHIFT SCHEDULING

In Table C.1, the important articles on shift scheduling are listed alphabetically by author. Full references to the articles are in the bibliography and reference list. The columns are divided into three groups, as follows:

I. SHIFT SCHEDULING VARIABLES

1. Hours worked per 24-hour period
2. Hours worked per 48-hour period
3. Hours worked per week
4. Hours worked per month
5. Fixed vs. rotating shift
6. Forward vs. backward rotating shift
7. Fast vs. slow rotation
8. Hours of rest between work periods
9. Time of day
10. Other

II. PERFORMANCE AND MEDIATING VARIABLES

1. Performance/safety
2. Performance-related measures
3. Alertness/fatigue
4. Sleep
5. Vigilance
6. Memory
7. Physiological measures
8. Attitude toward shift schedule
9. Job satisfaction
10. Social/family life
11. Absenteeism
12. Attrition
13. Other

III. INDUSTRY

1. Nuclear power
2. Commercial airline
3. Nuclear Navy
4. Other military
5. Nursing
6. Transportation
7. Police officers and fire fighters
8. Petrochemical
9. Fossil-fuel power
10. Other

The letters C, E, and X on the chart are used as follows:

C = Cause
E = Effect
X = Industry.

For example, if a report on airline pilots shows that performance is degraded after 12 continuous hours of work, then hours of work is the cause (C), and performance is the effect (E); thus, a "C" is entered under the column for "hours of work in a 24-hour period" and an "E" is entered under the column for "performance." Since the report is about airline pilots, an "X" is entered under the column for "commercial airline."

Table C.1 shows PNL's cataloging of the important reports only. All reports have been catalogued in the bibliography in the same manner.

TABLE C.1. Important Articles on Shift Scheduling

Publication		Shift Scheduling Variables										Performance and Mediating Variables										Industry																	
		Hours Worked/24 Hours	Hours Worked/48 Hours	Hours Worked/Week	Hours Worked/Month	Fixed vs. Rotating	Forward vs. Backward	Fast vs. Slow Rotation	Hours Rest Between Work Periods	Time of Day	Other	Performance/Safety	Performance-Related Measures	Alertness/Fatigue	Sleep	Vigilance	Memory	Psychological Measures	Attitude Toward Shift Schedule	Job Satisfaction	Social/Family Life	Absenteeism	Attrition	Other	Nuclear Power	Commercial Airline	Nuclear Navy	Other Military Branches	Nursing	Transportation	Police/Fire	Petro-Chemical	Fossil Fuel Power Plants	Other					
Author	Date																																						
Adams and Harris	1982																			C									X										
Akerstedt and Gillberg	1981											E		C			E																						
Bjerner, Holm and Swensson	1980	C		C				C		C																									X				
Breithaupt, Hildebrandt and Werner	1981									C								E																					
Brown, Tickner and Simmonds	1970	C													E		E													X									
Browne	1980							C		C																									X				
Colquhoun	1976									C		E	E	E		E	E	E						X			X												
Colquhoun	1980	C				C	C			C		E		E		E	E										X												
Colquhoun	1981																																						
Colquhoun, Blake and Edwards	1969a					C						E	E			E	E																		X				
Cunningham	1982	C				C		C	C												E											X							
Czeisler	1983					C	C	C						E	E			E	E		E	E										X							
Czeisler, Moore-Ede and Coleman	1982					C	C	C						E				E	E		E	E										X							
Dahlgren	1981							C										E																					
Desir, Van Cauter, Golstein, Fevre, Jadot, Refetoff and Copinschi	1981							C																															
Ehret	1981							C	C																														
Folkard	1975b									C			E																										
Folkard	1981												E				E	E																					
Folkard and Monk	1981							C										E																					
Ganong, Ganong and Harrison	1976	C								C											E								X										
Gordon, McGill and Maltese	1981											E						E		E															X				
Graeber, Sing and Cuthbert	1981							C				E	E																X										
Hak and Kampman	1981									C		E	E		E								E							X									
Harris, Mackie et al.	1972	C				C			C	C		E	E	E/C				E													X								
Haslam	1980											E	E		C	E		E											X										
Haslam	1981											E	E		C	E													X										
Hildebrandt, Rohmert and Rutenfranz	1974									C																					X								
Hildebrandt, Rohmert and Rutenfranz	1975									C					C																X								
Hopkins, Snyder, Price, Hornick, Mackie, Smillie and Sugarman	1982																							X															
Knauth and Ilmarinen	1975					C				C								E																					
Knauth and Rutenfranz	1980a	C								C	C									C																			
Knauth and Rutenfranz	1981		C	C				C	C	C						E																							
Kogi, Takahashi and Onishi	1975	C												E				E																					
Lyman and Orady	1981	C								C					C												X												
Malaviya and Ganesh	1977									C																										X			
McCormack	1961											C																								X			
Meers	1975			C						C									C																	X			
Monk	1980											C																								X			
Monk and Embrey	1981	C						C		C			E				E	C																					
Northrup, Wilson and Rose	1979																	E	E		E	E											X						
O'Hanlon and Kelley	1977									C		E	E	E	E	C	E	X	E												X								

(a) C = cause; E = effect; X = industry.

TABLE C.1. (contd)

Publication		Shift Scheduling Variables								Performance and Mediating Variables										Industry															
		Hours Worked/24 Hours	Hours Worked/48 Hours	Hours Worked/Week	Hours Worked/Month	Fixed vs. Rotating	Forward vs. Backward	Fast vs. Slow Rotation	Hours Rest Between Work Periods	Time of Day	Other	Performance/Safety	Performance-Related Measures	Alertness/Fatigue	Sleep	Vigilance	Memory	Psychological Measures	Attitude Toward Shift Schedule	Job Satisfaction	Social/Family Life	Absenteeism	Attrition	Other	Nuclear Power	Commercial Airline	Nuclear Navy	Other Military Branches	Nursing	Transportation	Police/Fire	Petro-Chemical	Fossil Fuel Power Plants	Other	
Author	Date																																		
Patkai and Dahlgren	1981		C	C			C	C			E		C/E				E	E																X	
Patkai, Peterson and Akerstedt	1975				C						E	E	E				E	E																X	
Pocock, Sergeant and Taylor	1980					C	C														E														
Pokorny, Blom and Van Leeuwen	1981a								C																				X						
Pokorny, Blom and Van Leeuwen	1981b	C							C																				X						
Price and Holley	1981												C												X										
Price, Wallace, Bauman and Smith	1980	C							C		E	E					E						X												
Pternitis	1981								C				E	E	E																				
Reinberg	1979						C	C																											
Reinberg, Chaumont and Laporte	1975									C				C			E																		
Rutenfranz, Klimmer and Knauth	1975								C					C			E																		
Seigel, Pfeiffer, Kopstein and Wilson	1979	C						C	C		E	E	E	C	E												X								
Smith, Colligan, Froct and Tasto	1979				C																							X							
Smith, Colligan and Tasto	1982				C																E													X	
Tepas, Walsh and Armstrong	1981							C			E		E				E																	X	
Tepas, Walsh, Moss and Armstrong	1981				C			C			E		C/E																					X	
Tilley, Wilkinson and Drud	1981				C			C				E		C/E																					
Tilley, Wilkinson, Warren, Watson and Drud	1982		C	C				C			E	E	E	E			E																	X	
U.S. Department of Health, Education and Welfare	1982		C																				X												
Vernon	1945		C																																X
Vokac, Magnus, Jebens and Gundersen	1981						C										E																	X	
Walsh, Tepas and Moss	1981				C			C			E		E																					X	
Weitzman	1976				C			C			E		E				E											X							
Wever	1981					C						E	E				E																		
Wilkinson and Edwards	1969				C						E	E					E										X								
Wilkinson, Tyler and Varey	1975	C											E						E		E													X	
Wilson and Rose	1978		C														E	E			E	E										X			

APPENDIX D

ANNOTATED BIBLIOGRAPHY

AKERSTEDT and TORSVALL. 1978. "Experimental Changes in Shift Schedules -- Their Effects on Well-Being."

Summary: Swedish steelworkers preferred a shift schedule that was more physically demanding because it offered better off-the-job social life.

Objective: To analyze the effect of 2 shift schedules on "well-being." The first shift schedule had 4 crews, rotated every 2-3 days, and had days off on various days of the week. The second shift schedule had 3 crews, rotated once per week, and had weekends off. "Well-being" was measured by quantity and quality of sleep, gastrointestinal complaints, sickness absence, irritability, mood, and attitude toward shift schedule.

Method: A questionnaire was used to study steelworkers at a Swedish plant before and after a change in shift schedule due to a work slowdown.

Findings: Even though the second schedule (weekly rotation) was physically more punishing, the workers preferred it, probably because it improved their social/family life. The change from the first shift schedule (1-2 day rotation) to the second schedule (weekly rotation) resulted in a moderate decrease in both physical and mental well-being, and in sleep length. The reasons for these changes are not clear. However, one possible explanation is that the weekly-rotating schedule causes an accumulation of fatigue and/or other negative effects. In contrast, social complaints decreased after the change. This might reflect the fact that the second shift schedule, which had a more regular pattern and weekends off, facilitates planning and participating in family and social activities.

Comment/Evaluation: The conclusions stated above are derived from statistically significant tests based on particular questions. However, other questions in the questionnaire that contained only slightly different wording yielded statistically insignificant results. This curious result suggests that the conclusions should be treated cautiously.

BROWN, TICKNER, and SIMMONS. 1970. "Effect of Prolonged Driving on Overtaking Criteria."

Summary: This study provides some quantitative evidence that after 8 to 12 hours of driving, drivers take greater risks in passing vehicles.

Objective: To assess the effect of 12 hours of driving on driver performance.

Method: Six experienced drivers drove for 4 three-hour sessions. There were short breaks between sessions. An observer rode in the car during the 1st and 4th sessions, but not the 2nd and 3rd sessions. The observer noted near accidents, risky overtaking maneuvers, overtaking frequency, and average speed. Criteria for risky overtaking were 1) forward visibility was too restricted, or 2) the maneuver appeared to be incapable of completion unless one or more of the other vehicles changed speed. The subjects were unaware that their overtaking performance was being assessed.

Drivers were also asked to perform a vigilance task: to report the appearance of faint light-signals that were occasionally displayed on the interior and wing mirrors of the car simultaneously. Oral temperature was also measured.

Findings/Conclusions: More "risky" maneuvers were attempted during the 4th session than during the 1st session, as is shown in Table D.1.

TABLE D.1. Data Obtained During the 1st and 4th Sessions of Car Driving

Session	Risky Overtaking Maneuvers (mean number per session)	Overtaking Frequency (%)	Average Speed (mph)	Vigilance Response Time (sec)	Temperature (C)
1st	3.2	33	45	6.2	36.0
4th	4.8	24	41	4.6	36.8

However, Table D.1 also shows that overtaking frequency and average speed were both lower for the 4th session. These 2 indicators suggest that the drivers were taking fewer risks during the 4th session. At the same time, the drivers' vigilance response rate actually improved (this might have been due to a practice effect). None of the results in Table D.1 were statistically significant. Near accidents were too few and were not reported here.

Comments/Evaluation: This study provides some evidence that drivers take greater risks in passing vehicles after 8 to 12 hours of driving. However, due to the small sample size, somewhat contradictory results, and several methodological problems, the evidence is weak.

CZEISLER, MOORE-EDE and COLEMAN. 1982. "Rotating Shift Work Schedules That Disrupt Sleep Are Improved by Applying Circadian Principles."

Summary: This is the only major article PNL has found that explicitly advocated forward rotation for shift schedules. The article reports on an experiment at a potash factory in Utah. The experiment, however, does not provide adequate grounds for advocating forward rotation.

Objective: To show that performance and job satisfaction can be improved by adopting a forward rotating shift.

Method: Workers at the potash factory originally had a backward rotating shift schedule, rotating to the next 8-hour shift once each week. Then, some of the employees adopted forward rotating shift schedules. There were two types of forward rotating schedules: one rotated forward each week, the other rotated forward every 3 weeks.

Results: The statistically significant results concerning satisfaction and productivity were all for the 21-day rotation scheme. The direct comparison between forward- and backward-rotating shift schedules of equal length (one week) yielded no statistically significant results. That fact makes it more difficult to discern the degree to which the beneficial effects of the new shift schedule were due to the direction of rotation (forward vs. backward) and to what degree they were due to the speed of rotation (1 week vs. 21 days).

Comment: The authors based their prediction that forward rotation would produce better results on two "circadian principles." Many European researchers have abandoned the first principle, and the potash workers themselves abandoned a shift schedule based on the second principle.

The first principle is that work and sleep are generally more efficient during their usual phases in one's circadian cycle. If one must change his/her work/sleep cycle, then it is most efficient to change it in such a way that one's circadian cycle can make the corresponding change quickly; in that way one's work/sleep cycle will once again correspond to his/her circadian cycle. Many European researchers have abandoned this first circadian principle. Instead, they advocate rotating through all three shifts so quickly that one's circadian rhythms remain fixed on the normal daytime rhythm.

The second principle is that people's circadian rhythms generally adapt more quickly if one's wake/sleep cycle is lengthened (which corresponds to a forward-rotating shift), rather than shortened. This principle is based primarily on the fact that most people's endogenous, free-running circadian rhythms have a cycle of about 25 hours (instead of 24); thus one's natural body rhythms are already longer than the normal day, and so lengthening the wake/sleep period is only following nature's own predilections.

Strictly speaking, however, the second principle applies only to a two-hour range around the natural 25-hour rhythm, i.e., only to shortening the wake/sleep period to as few as 23 hours, or to lengthening it to as many as 27

CZEISLER, MOORE-EDE and COLEMAN (continued)

hours. The authors state: "(one's internal clock) can usually be entrained (reset) by periodic environmental time cues that are within 1 to 2 hours of the endogenous period of 25 hours." The importance of this 23 to 27 hour range to the authors' principles is stated in the introduction to the article: "Because ... most rotating work schedules are outside the (23 to 27 hour) range of entrainment ... we postulated that a practical and effective intervention would be to resolve this aspect of the shift work problem."

The authors' practical intervention was a schedule that started at 8AM one day, 9AM the following day, and so on. But the workers rejected this schedule, as the authors state in a footnote: "The 21-day ... (forward rotation) schedule was originally designed so that work hours were shifted gradually by 1 or 2 hours per day for 5 days until the new shift time was attained. This procedure was eliminated after a month when it proved inconvenient for the workers' family life and car pooling arrangements: thereafter an 8-hour ... (forward rotation) was undertaken on every 21st day." Since a shift schedule based on the authors' second circadian principle was impractical, the potash factory's shift schedule became like most other rotating work schedules, shifting 8 hours at once, and thus failing to "resolve this aspect of the shift work problem."

FOLKARD, MONK, RNAUTH and RUTENFRANZ. 1976. "The Effect of Memory Load on the Circadian Variation in Performance Efficiency Under a Rapidly Rotating Shift System."

Summary: This experiment refutes the "conventional wisdom" that body temperature is positively correlated with all types of performance.

Objective: To assess the relationship between body temperature and performance on three different tasks, with three different memory-load requirements.

Method: A simple search test was devised that systematically varied memory-load requirement. A two-, four-, or six-letter target (combination) was given at the top of each page, followed by lines of various letter combinations. The object of the test was to find all occurrences of the target within the listing. Four times during each working shift the subjects were given the tests, and their body temperature was measured.

Findings: Low memory-load performance was positively correlated with body temperature (+0.83), while high memory-load performance was negatively correlated (-0.58). Both correlations were statistically significant at the .02 level. Figure D.1 is a graph of the results.

Comment/Evaluation: This experiment refutes the "conventional wisdom" that body temperature is positively correlated with all types of performance. Rather, it provides evidence that performance might be inversely related to temperature, might bear no relation to temperature, or might closely parallel temperature, depending upon the short-term memory load of the task under consideration.

FIGURE D.1. Body Temperature and Three Levels of Memory-Load Tasks (Rentos and Shephard 1976, p. 174)(a)

(a) Body temperature is indicated by the dotted lines and open circles. Two-letter, 4-letter, and 6-letter memory tests are indicated by solid lines.

HILDEBRANDT, ROHMERT and RUTENFRANZ. 1974. "12 & 24 Hour Rhythms in Error Frequency of Locomotive Drivers and the Influence of Tiredness."

Summary: This highly quantitative study of German railroad engineers shows that vigilance reaches a low point between 3AM and 6AM, and another low point about 1PM. These low points in performance are especially pronounced for engineers who had already worked several hours before reaching those critical times of day.

Objective: To assess the effect of (1) number of hours worked, and (2) time of day, on error frequency.

Method: This highly quantitative study was made possible by the requirement that a particular safety device be installed in locomotives of the Federal German Railway. Although the description of the device is unclear, PNL's understanding is as follows. The device is intended to assure that the engineer is alert; if he/she is not, the brakes of the locomotive will be operated automatically. Periodically, a warning light appears on the control panel. If this warning light is not heeded by pushing a button within 2.5 (or 25?) seconds, an acoustic warning signal (hooter) is sounded. If the engineer then fails to push the button within an additional 2.5 (or 30?) seconds, the brakes of the locomotive will be operated automatically. Additional devices recorded the time of day when the hooter was sounded and when the brakes were operated automatically. All of these data were matched with the hour of the day when the engineer started work. (Apparently the speed of the locomotive was also recorded, because errors occurring at speeds of less than 25 km/hr were omitted from the study.)

Data were collected for a total of about 6,000 work hours by 1,000 different drivers on 10 locomotives. During that period the hooters were sounded about 20,000 times, for an average of 3.1 times per hour, and the brakes were automatically operated over 2,000 times.

Findings:

Automatic compulsive braking. Rates of automatic compulsive braking showed peaks between 3AM and 6AM, and another peak at 1PM. The rates were computed by dividing the number of brakings by the total distance driven by all locomotives during each hourly period. The average of the 24 rates is equated to 100 in Figure D.2. The horizontal scale measures the time of day. Figure D.2 shows the relative frequency of automatic compulsive braking, as a percent of the day's average, for each hour of the day.

FIGURE D.2. Relative Frequency of Automatic Compulsive Braking (percent of day's average) (taken from Hildebrandt, Rohmert and Rutenfranz 1974, p. 176)

Soundings of the hooter. The frequency of the sounding of the hooter showed a clear peak at 1PM. This finding, however, is of no consequence, since it is caused largely by the fact that daylight makes the warning light less visible. (For the same reason, Figure D.2 might overstate somewhat the degree of inattention of engineers at 1PM. Daylight, however, would not affect ability to hear the hooter.)

Holding time of day (and hence brightness of daylight) constant, it is possible to compare the error frequencies of engineers who had been on duty for different numbers of hours. Figure D.3 shows the frequencies of the hooter sounding between 1-2PM (1300-1400) and between 2-3PM (1400-1500). (The regression line is shown as a dotted line in the figure.) Both frequencies appear to be highly correlated with clocking on time.

The effect of the number of hours worked can also be seen in Figure D.4, in which the error frequency for the 1st, 2nd and 3rd hours of a shift are compared with the error frequency for the 4th, 5th and 6th hours of a shift. In almost all cases, the error frequency is higher toward the latter part of a shift. Furthermore, the peak error frequency at 3AM is almost nonexistent for workers who have only been working for 0 to 3 hours. (This finding has implications for workers who work an afternoon shift and work overtime into the night shift.)

FIGURE D.3. Hourly Frequency of Sounding of Warning Hooter Between 1 PM and 3 PM (related to time of day when shift started)^(a)

FIGURE D.4. Hourly Frequency of Sounding of Warning Hooter^(a)

(a) Source: Hildebrandt, Rohmert and Rutenfranz 1974, pps. 178 & 179.

Evaluation: On the whole, this highly quantitative experiment appears to be methodologically sound. Statistical tests are unnecessary; the sample size is so large that any test would undoubtedly indicate statistical significance. The effect of daylight on the visibility of the warning light, however, must be considered in interpreting the results.

In the case of aluminum, the results of the analysis of the water samples are also shown in Figure 4. In which the concentration of aluminum is plotted against the concentration of iron. The results show that the concentration of aluminum is generally higher than that of iron. This is due to the fact that aluminum is more abundant in the water samples than iron. The results also show that the concentration of aluminum is generally higher than that of copper. This is due to the fact that aluminum is more abundant in the water samples than copper. The results also show that the concentration of aluminum is generally higher than that of iron and copper. This is due to the fact that aluminum is more abundant in the water samples than iron and copper.

Figure 4. Relationship between Aluminum and Iron concentrations in water samples.

Figure 5. Relationship between Aluminum and Copper concentrations in water samples.

The results of the analysis of the water samples are also shown in Figure 6. In which the concentration of aluminum is plotted against the concentration of iron and copper. The results show that the concentration of aluminum is generally higher than that of iron and copper. This is due to the fact that aluminum is more abundant in the water samples than iron and copper. The results also show that the concentration of aluminum is generally higher than that of iron and copper. This is due to the fact that aluminum is more abundant in the water samples than iron and copper.

The results of the analysis of the water samples are also shown in Figure 7. In which the concentration of aluminum is plotted against the concentration of iron and copper. The results show that the concentration of aluminum is generally higher than that of iron and copper. This is due to the fact that aluminum is more abundant in the water samples than iron and copper. The results also show that the concentration of aluminum is generally higher than that of iron and copper. This is due to the fact that aluminum is more abundant in the water samples than iron and copper.

KNAUTH and RUTENFRANZ. 1981. "Duration of Sleep Related to the Type of Shift Work." In Reinberg, Vieux and Andlauer 1981.

Summary: Thousands of sleep diaries of shift workers showed that day sleep averages less than three hours in length. The authors conclude that to avoid sleep deprivation, there should be few night shifts in succession and night shifts should be followed by days off. This is an important argument in the authors' advocacy of rapidly rotating shift schedules. However, the study has a methodological problem.

Objective: To determine the timing and duration of sleep associated with various shift schedules.

Method: Shift workers were asked to fill out a printed diary form each day over a period of 8 consecutive days, writing down the times of working, traveling to and from work, leisure, as well as sleeping during nighttime and daytime.

Results: The study confirms the findings of most other authors that day sleeps are shorter than night sleeps (see Figure D.5). The mean night sleep in connection with morning shifts is shorter than 8 hours. Day sleep before the first night shift averaged 2 hours in length, but the preceding night's sleep averaged 8.8 hours; so the total was nearly 11 hours. Day sleep between two night shifts averaged 6 hours. Day sleep after the last night shift averaged 4 hours. Night sleep before a day shift averaged only 7 hours.

Conclusion: "(T)here should be few night shifts in succession, or if longer night shift periods seem to be unavoidable, allowance should be made for at least the chance of recuperative sleep by having several days off at the end of a run of night shifts. A better solution is to have one day off after each night shift so that compensation can be immediate. Furthermore, morning shifts should not begin too early or sleep deficits will again occur."

Evaluation: This article presents much useful data. The conclusion that there should be few night shifts in succession is an important argument in the authors' advocacy of rapidly rotating shifts. The strength of this conclusion, however, is limited by a methodological problem: the sample included no permanent night shifts, and most likely included few slowly rotating shifts so there are no data to indicate whether workers on those shift schedules can adapt their sleep schedules appropriately. The data only show that the sleep schedules of workers on rapid rotation would not be suitable for slow rotation. Workers on rapidly rotating schedules, however, might deliberately reduce daytime sleep after a night shift knowing that the sleep deficit can be made up soon.

FIGURE D.5. Sleep Duration of Shiftworkers as a Function of Time of Beginning of Sleep (vertical lines = standard deviation) (Reinberg, Vieux and Andlauer 1981, p. 166)

MACKIE and MILLER. 1978. "Relationships Between Length of Time Driving, Time of Day, and Certain Kinds of Accidents." Chapter 7 in Effects of Hours of Service, Regularity of Schedules, and Cargo Loadings on Truck and Bus Driver Fatigue.

Summary: The authors conclude that the probability a truck accident occurring increases with increased driving time.

Objective: To assess the effect of number of hours of driving time on the probability of a truck accident occurring.

Method: In 1974, the Bureau of Motor Carrier Safety, using an accident report form, collected reports from truckers who had had accidents that resulted in death, injury, or property damage in excess of \$2,000. The report form requested information on the number of hours the driver had been driving at the time of the accident, and how long he would have driven had the accident not occurred. The form also asked the driver's condition at the time of the accident, with a provision to check "dozed at the wheel," which had been checked by several hundred drivers.

The authors compared the actual percentage of accidents with the "expected" percentage of accidents by visual inspection of the graphs shown in Figures D.6, D.7, and D.8. The "expected" percentage of accidents is the percentage of accidents that would occur after each number of hours of driving time if driving time had no effect on the probability of an accident. Because the actual number of accidents exceeds the "expected" number of accidents for longer driving times, the probability of an accident evidently does increase as driving time increases. This is true for all three types of accidents: 1) "dozing driver" accidents (Figure D.6), 2) single-vehicle accidents (Figure D.7), and 3) multiple-vehicle accidents (Figure D.8). (Note: In Figures D.6, D.7, and D.8, the authors use percentages rather than the absolute numbers of accidents.)

Results: Since the actual number exceeded the expected number toward the latter half of the graph, the authors concluded that the probability of an accident increases with increased driving time.

Comment: The authors' data are adequate to support convincingly their conclusions. However, the authors did have better data available for calculating the "expected" values in Figures D.6, D.7, and D.8. The authors used data from accident reports on the number of hours the driver had driven before the accident and the number of additional hours the driver expected to drive had the accident not occurred. Slightly better estimates of the "expected" values might have been obtained from the authors' random sample of drivers' logs.

MACKIE and MILLER (cont.)

FIGURE D.6. Expected Versus Actual Percentage of Accidents by Driving Time for Dozing-Driver Accidents (N = 406) (Mackie and Miller 1978, p. 54)

FIGURE D.7. Expected Versus Actual Percentage of Accidents by Driving Time for the Single-Vehicle Accident Sample (N = 226 accidents) (Mackie and Miller 1978, p. 59)

FIGURE D.8. Expected Versus Actual Percentage of Accidents by Driving Time for Accidents Involving Another Vehicle (N = 116 accidents) (Mackie and Miller 1978, p. 60)

MACTE SYSTEMS (2007)

FIGURE 2.1: MACTE System Performance (2007)
 The graph shows the percentage of schools that are MACTE accredited, by system type, from 2000 to 2006. The overall percentage of schools that are MACTE accredited is 85% in 2006. The percentage of schools that are MACTE accredited by system type is 75% for Academic and 80% for Non-Academic.

SMITH, COLLIGAN, FROCKT and TASTO. 1979. "Occupational Injury Rates Among Nurses as a Function of Shift Schedule."

Summary: This major effort by the U.S. National Institute for Occupational Safety and Health attempted to assess the effect of various shift schedules on occupational injuries. Unfortunately, the results are uninterpretable.

Objective: To assess the effect of four different shift schedules on injury rates. The four shift schedules were: permanent morning, permanent afternoon, permanent night, and rotating (the speed of rotation was not stated; it probably varied among the 12 hospitals studied).

Method: Shift scheduling information was combined with data on occupational injury over a 6-month period taken from the records of 1,200 nurses in 12 hospitals throughout the United States. All nurses were full-time non-supervisory personnel who had been in the employ of their respective hospitals for at least 6 months prior to the study.

Findings: The incidence of the total number of injuries by shift were:

Permanent day	16.8
Permanent afternoon	15.7
Permanent night	18.0
Rotating	23.3

The rotating shift had the highest incidence. The differences between the rotating shift and the three permanent shifts were statistically significant. The differences among the three permanent shifts were not statistically significant. This evidence seems to indicate that rotating shifts "cause" more injuries. This interpretation is made difficult by the finding that nurses on rotation shifts had significantly more cuts, bruises, and punctures, but significantly fewer sprains and strains. The authors considered several possible explanations, but in the end were unable to explain why the results should be different for the different types of injury.

Comment: Despite the large sample and careful research design, without an explanation of different results for the different types of injury, the interpretation and implications of this major research project will remain unclear.

This report is one of a series of reports describing a major study of shift work conducted by the National Institute for Occupational Safety and Health, which is an agency of the U.S. Department of Health and Human Services. The other major industry in the overall study was the food processing industry (see Smith, Colligan and Tasto 1982).

SMITH, COLLIGAN, and TASTO. 1982. "Health and Safety Consequences of Shift Work in the Food Processing Industry."

Summary: This major study by the U.S. National Institute for Occupational Safety and Health confirmed quantitatively that, compared with workers on permanent day and permanent afternoon shifts, workers on permanent night and rotating shifts have more trouble sleeping, have more illness absences, and have more injuries.

Objective: To assess the effect of four different shift schedules on sleep, health, on-the-job injuries, eating patterns, and the use of alcohol and tobacco. The four shift schedules were: permanent morning, permanent afternoon, permanent night, and rotating (the speed of rotation was not stated; it probably varied among the 8 food processing sites studied).

Method: Data were collected by self-administered questionnaires and by observation of employee health, safety and absence records. To recruit work sites for the study, national organizations of food processing employers were contacted for potential participants. The work sites selected represent other companies that volunteered to participate. As such, they cannot be considered to be a representative sample. Employees had to have been on their current shift for at least 6 months to be included in the study. Workers were paid \$5 for completing the questionnaire; 885 workers responded, for a response rate of 60%.

Findings:

Sleep disturbance. Permanent night workers averaged the least amount of sleep per 24 hours (6.4 hours). Night and rotating workers reported less uninterrupted sleep, and more trouble getting back to sleep once awakened. Tables D.2 and D.3 show sleep quality for workers on the four shift schedules.

TABLE D.2. Sleep Quality For Workers on Four Shifts

	Shift			
	Morn.	Afternoon	Night	Rotating
Percent getting less sleep than desired	52	32	52	47
Average hours of sleep	7.0	7.4	6.4	6.8

TABLE D.4. Percentage of Shift Workers Reporting
Select Sleep Characteristics

	Shift			
	Morn.	Afternoon	Night	Rotating
Feel tired or sleepy at work two or more times per week	29	36	43	40
Feel job does not allow time to rest or catch up on sleep	20	30	38	21
I sleep just one uninterrupted period per day	68	79	45	32
Quality of sleep:				
Excellent	20	17	6	9
Poor	3	6	24	11

Health complaints. Only 4 of the 43 self-reported health complaints yielded statistically significant differences, and these 4 were divided among the various shifts.

Eating behavior. Day workers reported the best appetite, with over 93% reporting a good to excellent appetite. Afternoon and rotating shift workers had the poorest appetite. Rotating workers were asked if their appetites were worse when working on a particular shift; 53% indicated that night shift produced the worst appetite. There were no differences across shifts in the percentages of workers who drank alcohol or used tobacco.

Health and safety records. The records of 1009 workers were examined. The percentages of male workers with one or more sickness absences in a 6-month period were as follows:

Permanent morning	41
Permanent afternoon	61
Permanent night	52
Rotating	71

The mean number of sickness absence days for male workers during a 6-month period were as follows:

Permanent morning	3.0
Permanent afternoon	6.0
Permanent night	4.9
Rotating	6.1

SMITH, COLLIGAN and TASTO (cont.)

The percentages of male workers having one or more injuries in a 6-month period were as follows:

Permanent morning	18
Permanent afternoon	26
Permanent night	15
Rotating	38

Generally, the results of this study indicate that night and rotating shift work, compared to morning work and afternoon shift work, was associated with increased problems relative to personal behavior of the worker, sick absence and work-related injuries.

Comment. This article is one of a series of articles describing a major study on the health and safety implications of shift work in the United States. The study was conducted by The National Institute for Occupational Safety and Health, which is an agency of the U.S. Department of Health and Human Services. The other major occupational group in the overall study was nursing (See Smith, Colligan, Frockt and Tasto 1979). Although much research has been conducted in Europe on health and safety implications of shift work, prior to this study, only one limited shift work study had been conducted in the United States.

Evaluation. Although this study is a major source of information on this topic, the authors admit that the methodology used does not provide the basis for answering many of the questions raised, especially since it cannot adequately control for self-selection to, or attrition from, particular shifts. These methodological problems could be handled by a prospective, longitudinal study.

TILLEY et al. 1982. "The Sleep and Performance of Shift Workers."

Summary: The sleep and performance of workers on the night shift are lower than that of workers on the morning or afternoon shifts. Furthermore, the performance of workers on night shift degenerates somewhat over the course of a week. The authors conclude that successive night shifts should be minimized by adopting a rapidly rotating shift schedule. Although the evidence supports the conclusion to some degree, the evidence is weak.

Objectives: To show the effect of five successive days of working each of three shifts (morning, afternoon and night) on (1) electroencephalogram (EEG, "brainwave") recordings of shift workers during their sleep at home, and (2) simple performance tests.

Method: Two groups of six workers on weekly rotating shift schedules were studied for three weeks, i.e., for one complete shift cycle. During the entire three weeks, the following two types of measurements were taken:

(1) EEG recordings were made for each of the five nights for each of the three shifts. (Electrodes were attached to the subject's head before they retired at night.)

(2) Subjects were asked to subjectively rate the quality of their sleep.

(3) Each day the subjects were given two simple performance tests: an unprepared reaction time test and a four-choice serial reaction-time test.

Results concerning sleep:

- Average duration of sleep for workers on the night, morning and afternoon shifts was 5 1/2, 6, and 7 hours, respectively.
- Among the three shifts, no significant differences existed in quality of sleep as measured by the percent of sleep time in various types of sleep as measured by the EEG (Stage W, REM, Stages 1, 2, 3 and 4 sleep).
- Among the three shifts, differences existed in the temporal sequencing of the various types of sleep (but the authors did not explain why this might be important).
- Sleep during the night shift was considered the least refreshing, and there was no discernable difference between morning and afternoon shifts.

Results concerning performance:

- Performance for the night shift was usually the worst. Performance for the afternoon shift was often the best.
- Performance for the night shift usually deteriorated over the course of the week.
- Neither of these results concerning performance was statistically significant, according to the the statistical tests the authors used.

Conclusion: The authors conclude: "(T)he best compromise is probably a short-rotation shift cycle with afternoon or rest days preceding and following the night shift. Under this type of system, the loss of sleep experienced during the night shift is only allowed to build up over a relatively short period and will be recovered during the next nocturnal sleep period."

Evaluation:

- Inexplicably, the authors reported no attempt to find a relationship between their two primary measures: sleep and performance.
- The authors report that none of the results using performance measures was statistically significant. Their statistical tests, however, did not account for individual differences; this lack would increase the variance unnecessarily. More appropriate statistical tests might well have indicated statistically significant results.
- If more appropriate statistical tests had indicated statistically significant results, the results would have provided some evidence for the authors' conclusions. However, the evidence still would be weak. Even though night shift performance may be lower than the other shifts, and even though it continues to decline throughout the week, a more relevant criterion is whether nighttime performance is at any time unacceptably low. Even though nighttime performance might be lower than that of the other shifts, it still might be well within the requirements of the situation. Furthermore, the maximum percentage difference between the worst of the night shift and the best (to exaggerate the comparison) of either of the other two shifts is only 20%, which was an absolute difference of $(3 - 2.5 =) 0.5$ seconds.

To justify a strong advocacy of rapidly rotating schedules, the authors would have to explain why 0.5 seconds is important; they do not do this. This is basically the limitation of all laboratory experiments: it is difficult to demonstrate how laboratory results are indicative of performance in the plant or on the factory floor.

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