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Shipboard Crew Fatigue, Safety and Reduced Manning

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J.K. Pollard
E.D. Sussman
M. Stearns

Research and Special Programs
Administration
Volpe National
Transportation Systems Center
Cambridge, MA 02142-1093

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16. Abstract

This report describes an exploratory first phase of an investigation of human stress and fatigue in the merchant marine. Its principal purposes were to: survey the effects of fatigue on human performance in the transportation industries; describe the state of the art in measuring fatigue; investigate the causes of stress and fatigue on merchant ships; summarize the insights gained about the implications of reduced manning as well as measures to mitigate fatigue; and discuss the results of preliminary attempts to gauge fatigue during the routing voyages using survey methods.

The findings in this report are based primarily upon about three dozen extended interviews conducted with officers on five merchant vessels during brief coastal voyages. In the course of these interviews, more than a score of variables were identified which affect fatigue and stress, which may be grouped into organizational factors, voyage and scheduling factors, ship-design factors, and physical/environmental factors. These interact in complex fashion resulting in widely different levels of fatigue on different ships and in different situations.

The physiological and behavioral methods of fatigue measurement reviewed were found to be difficult to apply during routine operations, but the self-reporting survey techniques tested eventually proved quite workable. It was concluded that organization and design factors could provide opportunities under some circumstances for the design and operation of advanced merchant ships which can be sailed safely and efficiently by well-rested crews which are smaller than are common today.

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Preface

This study was conducted for the Maritime Administration's Office of Technology Assessment by the Research and Special Programs Administration's Volpe National Transportation Systems Center (VNTSC). It is intended to provide MARAD, U.S. Coast Guard and maritime-industry officials with some understanding of the factors which contribute to stress and fatigue in the merchant marine, how these factors relate to ship automation and reduced crew size, and how changes in fatigue levels may be measured at sea.

The authors are grateful to the shipping companies who invited VNTSC staff members aboard their vessels and to all of the seamen who gave freely of their time in interviews and in completing surveys.

Particular thanks are due to Alexander C. Landsburg of the Office of Technology Assessment, who served as Technical Monitor. The authors also thank Chris Young and Commander C. F. Guldenschuh of the U.S. Coast Guard, Dr. Charles Bookman of the National Academy of Sciences' Marine Board and Eric Sager at the National Transportation Safety Board for their many helpful suggestions.

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Executive Summary

Background

This project was undertaken as an exploratory, first phase of an investigation of the relationship between crew size and fatigue in the merchant marine. Its principal purposes were to:

- describe the physiological and mental basis of fatigue,
- describe the state of the art in measuring fatigue,
- survey the effects of fatigue on human performance in the transportation industries,
- investigate the causes of stress and fatigue on merchant ships,
- explore procedures to gauge fatigue levels through survey techniques, and
- summarize the insights gained about conditions where reduced crew size might exacerbate the effects of fatigue.

Like the other freight transportation modes, merchant shipping is characterized by longer than average work weeks, nonstandard "work days", extensive night operations, and periods of intense effort, preceded by periods of relative inactivity. These factors result in, sleep disruption and deprivation. Indeed, average hours worked per week are much greater on ships than in any other mode. Sustained periods without sleep (more than 24 hours) are also far more common than in other modes. On some ships, crews experience the effects of fatigue (increased reaction time, reduced attention, diminished memory and mood changes) rather frequently. These effects are presumed to be major contributing factors in a large proportion of marine accidents.

Discussion

This review uses an operational term, ***inattention,*** or "the lack of ability to direct the mind at an object" to denote the consequences of fatigue. This operational definition makes it possible to deal with the factors that result in "fatigue" in terms of their impact on performance.

The major contributors to inattention are:

- drowsiness
- physical exhaustion
- excess mental workload
- boredom, and
- intoxication.

Fatigue Measurement

Objective methods of measuring fatigue may be divided into the physiological and the behavioral. Both approaches are extremely difficult to implement outside the laboratory.

The study reviewed a number physiological of tests for fatigue:

- brain electrical activity,
- muscle and skin electrical activity,
- heart rate and heart-rate variability,
- core-body temperature,
- catecholamine (hormone) secretions,
- respiratory patterns,
- gross body movement, and
- visual-system condition, including critical flicker frequency (a measure of the ability of the brain to discriminate flickering images), pupil size, and eye blink.

The physiological methods tend to be unsatisfactory because:

- they are invasive,
- take too much time,
- require the use of specialized and sophisticated equipment and technicians,
- require careful calibration on the individuals tested,
- require sophisticated analysis and interpretation of the data gathered, and
- entail off-line rather than real-time data analysis.

Also reviewed were several behavioral indicators of fatigue, including:

- looking behavior,
- subsidiary task performance,
- control movements,
- vehicle dynamics,
- lateral position error, and
- heading error or yaw.

The behavioral approaches surveyed are also unsatisfactory for one or more of the following reasons:

- most are not unequivocally, and sometimes only tenuously, related to fatigue,
- require a that the individual being measured undergo significant training and a relatively long calibration period,
- are not self-administering,
- are affected by factors other than fatigue, and
- produce results which are frequently ambiguous and/or require extensive expert analysis for interpretation.

A few behavioral tests have been devised which are fast and simple, but their validity as measures of fatigue has not been established.

Verbal self-report survey measures are by far the most widely and successfully used methods for developing relatively objective measures of fatigue and stress. Alternative forms of surveys were tested on each of the five research voyages taken by the authors.

Data Gathering

Five voyages were taken during the project, three aboard containerships (one German-flag) and two on tankers. Crew sizes on these vessels ranged from 17 on the German vessel to 25 on one of the tankers. Most visits were about four days in duration. Extended interviews were conducted, which in combination with the use of various self-report forms, generated numerous insights into the causes of the widely varying fatigue levels observed. The data gathered during the voyages were supplemented by port visits in Boston Harbor and meetings with shipping industry staff.

The voyages were used to:

- meet with and interview officers and crew members to obtain their perceptions of the causes of stress and fatigue;
- evaluate the usefulness of self-report sleep-, fatigue-, and stress-survey instruments; and
- observe operations and considerations which might result in fatigue under conditions of reduced manning.

Results

Crew fatigue is affected by three basic mechanisms: the number of hours worked, the ability to get regular and uninterrupted sleep, and exposure to stressful conditions, both mental and physical.

Crew size can sometimes be reduced without impacting crew fatigue through control of the total number of hours required to accomplish the ship's mission, work scheduling which reduces sleep disruption, and ship design and operations which limit adverse environmental, workload and other effects. Obviously the ability to control these factors varies widely among different shipping operations.

The presence and extent of crew fatigue vary greatly among ships as reported by the interviewees on the ships visited. In accounting for these large differences, four major clusters of variables were identified:

- organizational factors,
- voyage and scheduling factors,
- ship-design factors, and
- physical/environmental factors.

Organizational Factors

The organizational factors relate to how ships are managed. They include crew continuity, work rules, the pay system, training, standardization, paperwork, officers' "people management" skills and styles, and inspection and maintenance policies.

For example, one major sub-element among the organizational factors was ship continuity. Captains and crews who had served together aboard the same ship for years had much lower levels of fatigue than those who worked on ships characterized by frequent personnel turnover. Crew members could do their jobs with little instruction or supervision. In ships lacking such continuity, workload was increased because crew members spent many hours each day supervising and training and/or being supervised and trained.

The effects of the organizational element interact with the level of standardization of ship procedures and the level of training of the crew to have a significant impact on workload. Organizations operating ships with low levels of ship-to-ship standardization, low levels of crew continuity, and relatively inadequately trained crews will require more labor hours to accomplish their missions.

Another important organizational element identified was the pay system. On virtually all American ships, overtime constitutes a large portion of total compensation for everyone but the captain and the chief engineer. There is an expectation and a desire among the crew to put in very long hours so as to maximize income. In contrast, on the German-flag ship overtime hours are capped at 90 per month by government regulation. The interviewees indicated all of the work got done; observation indicated that it was done very well and with substantially fewer hours expended than on comparable U.S.-flag vessels. Recently enacted legislation to limit hours worked on U.S. flag vessels is likely to stimulate a variety of changes in these factors in order to comply with the new law efficiently.

Paperwork burdens were frequently mentioned causes of increased workload resulting in fatigue. The burden varied greatly among ships and countries depending on: (1) the number and types of reports required by the management of the operating company, (2) the degree of automation of report generation, and (3) government requirements.

The reliability of various systems and the level of maintenance the ship received, impacted not only the number of hours required to perform the mission but also the probability that the crew members' normal rest periods were disturbed.

Voyage and Scheduling Factors

A critical sub-element in this cluster of factors is the frequency of port calls. The fatiguing effects of making several port calls in quick succession is exacerbated when the officers must continuously monitor critical activities such as the loading and unloading of tankers.

Other sub-elements which increase the likelihood of fatigue or make the fatigue a more significant problem are operation in congested waters, unpredictable arrival and departure times (which interferes with crew sleep and circadian rhythm), and long duty tours, especially those in excess of 75 days.

Ship-Design Factors

The interviews indicated that some ship-design features, such as the level of automation and, especially, equipment reliability, affected work load, while others, such as noise, vibration, temperature, and ship motion influence the level of physical stress on the crew and the crews' ability to get regular sleep.

Physical Environment

This cluster of factors deals mainly with the weather conditions encountered in the voyage. Ships which must operate in severe weather, particularly if they are in ballast, expose the crew to a violent-motion environment, which not only interferes with sleeping but makes the accomplishment of any task much more difficult and stressful. These problems become worse when the crew must work on deck during temperature and humidity extremes.

Utility of Self-Report Surveys

Several versions of self-report surveys were tested. These survey instruments included segments on activities, duties and workload, amount and nature of sleep, and feelings of fatigue. Use of the self-report forms was much more enthusiastic when the forms were simplified to one page per day, which could be completed in two or three minutes. Attempts to break activities into fine detail as to task and time spent were fruitless and were perceived by the participants as burdensome.

The pilot self-report surveys generated only a limited quantity of data, but it tended to corroborate the authors' unequivocal observations that there were large differences in fatigue levels among ships and among different phases of a voyage on the same ship.

Conclusion

In summary, while two of the clusters of fatigue factors identified (scheduling and physical environment) are inherent in the requirements of particular types of trade, the other two clusters (organizational factors and ship design) are not. These latter provide opportunities under some circumstances for the design and operation of advanced merchant ships which can be sailed safely and efficiently by well-rested crews which are smaller than are common today.

1. Introduction

This project was undertaken to explore the relationship between fatigue and crew size on merchant ships. It is intended as a preliminary study, designed to identify relevant issues and to develop a basic understanding of how to go about planning future studies. It includes both a survey of research on fatigue effects and measurement techniques and a discussion of the insights gained into the causes of fatigue on merchant ships gained in the course of several voyages taken by staff of the Volpe National Transportation Systems Center (VNTSC). Preliminary pilot testing of survey techniques was also incorporated.

1.1 Background

For economic reasons, ship manning levels are being reduced worldwide and average U.S.-crew size has moved from about 35 to around 21 in recent years. Lately effective manning concepts have been studied and tried throughout the world in conjunction with additional automation to result in crew levels of 15, 11, and in the latest projections by some, of crew sizes of 6 to 8. This review is intended to provide information on crew fatigue and potential effects of crew-complement reduction.

While "human error" has long been believed to be the most common cause of transportation accidents, the precise relationship between fatigue and human error is not known. There is a widespread perception that an increase in fatigue for some crew members could result directly and unavoidably from the reductions in crew levels. The validity of this perception has been neither established nor refuted. Exploration of this question and related issues is the subject of this research.

Reduction in crew size can potentially have a number of direct and indirect effects including:

- an increase in the length of duty periods (particularly those involved with loading and unloading) resulting in the development of sleep deficits and sleep disruption;
- the requirement that more operational and administrative tasks be accomplished during duty periods, resulting in an increase in workload;
- a reduction in the opportunity for monitoring and supervision of crew performance, resulting in a greater likelihood that errors will not be caught and corrected in a timely fashion;
- a reduction in the opportunity for social interaction among crew members, resulting in a decrease in crew morale;
- the requirement for better trained (and cross-trained) crew members; and
- the elimination or reduction in the use of crew members for certain duties through automation, task elimination or substitution of shore-based labor.

Therefore, it is critical that the procedures, systems, and equipment used and installed on advanced ships with reduced crews be carefully designed, chosen, and integrated into a system which effectively:

- minimizes operational conditions which produce fatigue, such as,
  - exposure to environmental extremes,
  - rotating shifts and,
  - extended work periods without adequate rest;
- minimizes psychological stress;
- minimizes equipment-design factors likely to increase the probability of errors, such as,
  - poor control and display design, and
  - inappropriate allocation of command and control functions among crew members and/or among automated systems; and
- maximizes the opportunity for recovery from errors and incidents without damage to the crew or ship, e.g.,
  - sufficient crew coverage to manage worst case emergencies during critical operations, and
  - sufficient information flow to maintain crew "situational awareness" under automated operation.

1.2 Objectives

The objectives of this project are to:

- provide a working definition of fatigue and its importance in relation to lowered ship manning levels,
- review studies of fatigue in various transportation modes and describe the impacts of fatigue, as defined, on human performance and health,
- describe the state of the art in detecting and measuring fatigue,
- gather useful information for analyzing shipboard fatigue concerns,

- summarize the insights gained about conditions where reduced crew size might exacerbate the effects of fatigue, and

- explore procedures to gauge fatigue levels through survey techniques.

The results of the surveys and interviews described herein are preliminary and exploratory in nature. They are not intended as final conclusions, but rather as working hypotheses which may be of value in planning more rigorous research into these issues. Since they took place in late 1989 and the first half of 1990, they do not reflect any consideration of the implications of the Oil Pollution Act of 1990. Undoubtedly, this Act will profoundly influence many of the fatigue factors discussed in this report.

2. Definitions of Fatigue

The word fatigue has many definitions and usages. Examples of the broad range of commonly used synonyms for fatigue include exhaustion, weariness, lassitude, apathy, and ennui. These examples describe an individual's internal state. There is no single definition of fatigue which will objectively cover the potential effects of crew-size reduction on crew performance. Rather than attempt to deal with the various mental, emotional, physical and hormonal internal states which may contribute to fatigue, this paper will use an operational definition of the effect of fatigue on performance.

In evaluating any transportation system, we must consider the operational performance of the system in terms of factors such as safety and efficiency. The primary focus of this discussion is crew member performance and therefore this review will use an operational term, *inattention*, or "the lack of ability to direct the mind at an object" to denote the consequences of fatigue. The advantage of this operational definition is that it is possible to see the factors that result in "fatigue" in terms of their impact on performance. This is consistent with the working definition proposed for the January, 1990, meeting of the International Maritime Organization's (IMO) Subcommittee on Standards of Training and Watchkeeping. At this meeting it was proposed that fatigue be defined as: *the degradation of human performance, the slowing down of physical and mental reflexes, and/or the impairment of the ability to make rational judgement; induced by such factors as prolonged periods of mental or physical activity, inadequate rest, adverse environmental factors, physiological factors, and or stress or other psychological factors.*

The safe operation of any system requiring direct human control is dependent on the level of attention that the human controller provides. Any individual involved in continuous monitoring, such as a watch stander, must:

- sample the operating environment,
- select the critical aspects of the environment,
- determine the proper response(s),
- make the response(s), and
- evaluate the outcome(s) of the response(s).

To the extent that the human operator does not follow these steps, performance and safety will be degraded.

Historically, most transportation accidents are attributed to human error. Lapses of attention are believed to be the major causal factor in operator errors which result in accidents. The major contributors to inattention are:

- drowsiness,
- physical exhaustion,

- excess mental workload,
- boredom, and
- intoxication.

2.1 Contributors to Fatigue

2.1.1 Drowsiness

Except in cases where there is a known organic cause, such as narcolepsy, drowsiness can be attributed to a lack of sleep or to a disturbance in the sleep-rest cycle (dysynchronosis). Deprivation of sleep resulting from long periods of sleep loss may occur during periods of heavy weather, during periods of extended activity, e.g., port operations, and in equipment-failure emergencies. Such deprivation can be expected to result in a sleep deficit. Sleep disturbance can also be a result of inappropriate shift or watch rotation.

One area of potential concern is a loss of sleep due to activities which occur immediately prior to sailing. These activities may range from extended work periods associated with unloading and loading the vessel, and other port business, to extended periods of celebration and recreation during which alcohol and/or drugs may be used.

2.1.1.1 Sleep Disturbance

Graeber (1988), based on his studies of flight-crew performance, indicates that fatigue and sleep loss can result in the following types of effects on performance:

- increased reaction time,
- reduced attention,
- diminished memory, and
- mood changes, particularly withdrawal.

Sleep disturbance can be the result of environmental factors which produce discomfort such as high levels of: temperature, humidity, noise, mechanical vibration, and ship motion. None of these environmental factors are peculiar to a ship with a reduced crew. Factors of potential relevance to ships are extended work periods resulting in prolonged periods of reduced sleep and of sleep disruption due to irregular or inappropriate work-rest cycles.

There are complex hypotheses which explain the need for periodic sleep and dreaming. These hypotheses describe the diurnal, hormonally-regulated rhythms which cause the sleep/awake and activity periodicity and the need for a sleep period, which permits learning and reorganization of information acquired during waking hours (Hobson, A.J., 1989). Whatever the causes for the need for sleep and dreaming, it is clear that sleep deprivation leads to severe performance degradation.

This degradation may be a result of:

- mood changes related to sleep deprivation include heightened irritability and inappropriate feelings of competence (Johnson and Naitoh, 1974).

- impairment in learning, reasoning, and complex decision making due to irritability (Woodward and Nelson, 1974)

- attentional lapses and resulting errors of omission (Woodward *et al. op. cit.*).

These lapses are probably associated with an ever-increasing frequency of automatic periods of light sleep during enforced wakefulness. Missed signals may also be due to "a heightening of the threshold of stimulation-required to keep the individual from falling asleep" (Coffer and Appley, 1964).

It is the occurrence of light micro-sleeps which can be the major problem in the "vigilance" performance required in duties such as watch-standing activities which are so critical to marine safety. During these micro-sleeps, the crew member neither attends nor responds to the critical signals and conditions.

Clearly some types of tasks are more likely to be impacted by sleep loss. Woodward *et. al. (op.cit)* in their user-oriented review of the effects of sleep loss and work- rest cycles, list the tasks they believe to be most sensitive:

- monotonous tasks,

- tasks that must be learned on the job,

- work-paced tasks (as opposed to worker-paced tasks),

- high-workload activities with multiple tasks involving time sharing,

- tasks which require continuous attention and performance, and

- tasks which provide the worker with little feedback.

2.1.1.2 Work-Rest Cycles and Circadian Desynchronization

There is current interest in the relationship between work-rest cycles and worker performance in the transportation, nuclear-power, health-care, mining, and chemical industries. In these areas, human error can have drastic consequences, yet operations must be conducted on a 24-hour basis. Considerable effort has been put into providing guidance in the development of shift-work schedules

Woodward and Nelson *(op.cit.)* list the work schedules they found most likely to yield poor performance:

- continuous uninterrupted work for several hours,

- work occurring between 0200-0600 (unless the worker is thoroughly adapted and prepared),

- night-shift work when the worker has been working the night schedule for less than three to five days,

- day and night shifts on consecutive days,

- "round the clock" work with two-hour rest cycles, and

- work after the first post-sleep period after continuous duty.

The nature of errors and resulting accidents are different for individuals performing shift work from those involved in conventionally scheduled work (Andlauer and Metz, 1967). A recent paper by Wagner, J.A. (1988) supports this contention.

Wagner studied the severity, nature, and frequency of accidents involving shift workers at a taconite mine. The workers performed jobs requiring a high level of vigilance in a stressful environment such as operating a bulldozer, locomotive, grader, or other heavy equipment. The accident rate and severity differed significantly between individuals working day versus night shifts. The accident rate was lower for night-shift workers but the severity of the accidents experienced was higher. This was attributed to more "automatic" behavior and a narrowing of focus of attention by the night shift workers. It is hypothesized that the errors which resulted in the accidents were errors of omission (missed signals) which are more serious for heavy-equipment operators.

A change of shift to accommodate a short-term work requirement to compensate for crossing time zones, can lead to the disruption of the crew member's circadian rhythms[1] and sleep disruption. Backward shifts where an individual goes to sleep later at each time shift are more easily accommodated than forward shifts; because it is usually *easier to work when tired than to fall asleep when alert.*

Individuals engaged in long-distance transportation operations, particularly aircraft and ship crews, must accommodate the disruption in circadian rhythms resulting from the crossing of time zones as well as the loss of sleep and workload. Graeber *(op. cit.)* indicates that the effect of circadian-rhythm disruption on aircraft pilots may be more significant than the effects of sleep loss, even for short-haul pilots who cross only one time zone.

Research into the periodicity of sleepiness (Richardson, Carskadon, Orav, and Dement, 1982) suggests that the times of day an individual can most easily fall asleep are highly regular and predictable. Their studies of both young and old individuals found that the test subjects had regular "sleepiness peaks" during late afternoon (1530-1700) and just before dawn (0500-0600). During these periods the test subjects could fall asleep in less than half the time of their "alertness peaks" (0830 to 0930 and 1930 to 2130). Hamelin (1987), Mackie and Miller (1978), Hertz and Eastham (1986), Jones, Kelly, and Johnson (1978), McDonald (1985) have demonstrated that the most important factor in the development of fatigue in highway operations is time of day.

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1 A cyclic variation in physiological state, mental and physical activity, roughly 24 hours in duration. Portions of the cycle have been identified with drowsiness and"low performance". The timing of the cycle is affected by the normal diurnal cycle as well as the performance of work and recreational activities.

The greatest risk of an accident is between midnight and 0600 hours. Hamelin (1987) and Mackie (1978) point out that increased risk of accident is greater for drivers not used to driving during these hours, i.e., irregular shift drivers. The effect is confounded by the length of time driving (or working, in general) prior to driving during this time period, the number of days of the irregular schedule and length of time since the last effective sleep period. Mackie and Miller (1978) show that the highest accident rates occurred between 0400 and 0600 hours.

When exposure data are taken into account, the effect of circadian dysrhythmia (the increase in accidents during the 2400-0600 hour time frame) the results are striking. Accidents per vehicle mile travelled involving dozing drivers, occurred about seven times as often during early morning hours than in any other hour of the day. Virtually all of the research involving driving performance, be it accident occurrence, test-driving behavior, or subsidiary-task performance, shows the effect of degraded performance during early morning hours.

When individuals aboard ship must work during times of the day when there is reduced physiological/and psychological function, it is important to maintain regular watch assignments. The initial negative effects of reduced physiological functioning after a watch-schedule change must be recognized and compensatory mechanisms must be used. To the extent possible, critical unsupervised tasks should not be assigned to individuals who have just undergone schedule changes. Further, the impact of such changes should be lessened by schedules which favor physiological readjustments. In particular if changes must be made, the work schedule should be shifted forward (delaying the time when the individual may sleep) rather than backward (advancing the sleep period), *because it is easier to work when tired than fall asleep when alert.*

The three-watch schedule, used on voyages of more than 600 miles and on larger ships, permits an eight-hour rest period, assuming normal operations and no port call. The two-watch schedule, used on smaller ships and shorter voyages, allows a reduced number of deck officers but does not allow any more than six hours off duty. If no lay-over occurs in port, precluding continuation of the watch schedule, the two-watch or "six on, six off" system does not permit readjustment of the crew's circadian rhythms.

Port layovers almost always interrupt the watch-based circadian rhythm. Current scheduling practices require reduced use of layovers and quicker turn-arounds to improve productivity. While theoretically this would permit better maintenance of shipboard circadian rhythms, the practice leaves no time for sleep after concluding cargo operations. The deck officers must leave port with severe sleep deficits and must maintain the watch schedule without any compensatory rest time.

2.1.2 Physical and Environmental Fatigue Factors

Fatigue can result from activities which require sustained physical exertion and/or exposure to environmental stressors such as temperature and humidity extremes, excessive acoustic-noise levels, and/or severe physical vibration, mechanical shock, and extreme ship motions. Such external factors not only disrupt sleep but also directly degrade attentional processes and degrade the performance of activities ranging from simple vigilance tasks through complex decision making.

Physical fatigue is likely to result in distraction of the crew member through increased concern with internal stimuli (aches and pains) and a concomitant decrease in attention to external signals. This change in focus from external to internal stimuli can result in the missing of critical signals. The operator can be alert and "thinking" but still miss critical signals. The individual may be somnolent, while his or her attention is misdirected. Further, such physical fatigue can result in a decrease or loss of coordination and response accuracy, which can result in the requirement for a greater number of responses to achieve a desired action, which will further distract the operator from external events.

2.1.2.1 Noise and Vibration

Physical fatigue is often a problem in military and industrial settings. It is likely to be a problem for the operators of heavy equipment, who are often subjected to high noise, vibration, and mechanical-shock levels.

While the advanced-design ships which are planned for operations with reduced crew need not increase fatiguing manual labor, there are potential sources of physical stress which must be considered. Chief among these sources are violent ship motions encountered in turbulent seas; work on deck in high winds, arctic or tropical conditions; and noise, vibration, and temperature extremes produced by the ship's propulsion machinery.

In a study in which long-distance driving was simulated (Sussman and Morris, 1971), subjects exposed to high levels of acoustic noise (equivalent to the level measured in a "cab-over-engine" semi-trailer truck cab) for four hours performed significantly worse in a simulated emergency (a blowout) than did subjects exposed to less intense noise levels.

Extreme ship motions such as those produced by a violent sea can be fatiguing simply due to the efforts the crew members must make in maintaining their position and balance while performing their duties. Large amplitude vertical motions in the 0.1 to 0.6 Hz range can also produce kinetosis or seasickness in many individuals.

2.1.3 Mental Workload

Two aspects of mental workload must be considered: low work load resulting in boredom or simple inattention and excess workload resulting in erratic performance. Low work-load is a potential problem in any situation where the primary duty of the crew member is to act as a monitor. It is a particular problem where the system monitored is highly reliable and situations requiring human intervention are very infrequent. In maritime operations, watch standing at sea may provide periods of very low work-load. Excess work-load is a potential problem where a crew member must make a number of critical responses to different systems in a short period of time. In maritime operations, both responses to emergency situations and ship maneuvering in restricted port areas with heavy vessel traffic may result in periods of excess workload.

2.1.3.1 Simple Inattention

Here the operator is either not attending to the proper external stimuli or not attending to any external stimuli at all. This behavior can be described as "daydreaming" or "wool gathering." This inattention may be the result of any of a number of factors:

- inadequate supervision, resulting in inappropriate activities during duty hours,
- introspection or concern over personal problems or matters such as the accomplishment of tasks which are not part of current duties, and/or

- boredom due to the performance of a monotonous task with infrequent response requirements and/or little feedback after the response.

As noted below, an increased reliance on automation can potentially increase task monotony and make operator-error detection all the more difficult. In considering the impact of automated aircraft-cockpit systems on problems related to attention and fatigue, Graeber (*op.cit.,p.* 340) notes "By reducing workload and providing precision information processing, on-board computers have eliminated many sources of crew error, but they have simultaneously increased the subtlety of error detection."

2.1.3.2 Mental Overload

Mental overload occurs when an individual has too many stimuli to attend to and/or too many responses to make per unit time. Skilled seamen learn to handle this situation by restricting their attention to the most critical items (signal inputs and control outputs). Less-skilled individuals may choose to monitor inappropriate inputs or to make noncritical outputs. Some operators may go into "saturation" and make no response or "freeze."

2.2 Substance Abuse and Intoxication

The relevance of substance abuse and intoxication to fatigue is twofold: first, the use of these substances reduces or distorts performance; and second, the "substance abuser" cannot be relied upon to perform his duties, thus raising the burden on the rest of the crew.

Individuals who must perform under conditions which produce fatigue may use intoxicants to:

- mitigate the effects of the fatigue, or
- mitigate the effects of fatigue-related stress.

Many intoxicants have impacts on performance which are operationally similar to fatigue. They:

- reduce alertness,
- impair judgement, and
- degrade coordination.

Reductions in alertness can be a direct effect or a side effect of the use and/or abuse of a large number of substances. Exposure to some pollutants, especially carbon monoxide, produces drowsiness, unconsciousness and eventually death. The effects of ingesting alcohol, illegal drugs, and legal medications vary as widely as do their chemical formulae, ranging from depression and drowsiness through agitation to hallucination.

Alcohol abuse is arguably the single greatest cause of traumatic injury in U.S. transportation today. The Committee on Trauma Research of the National Academy of Sciences (1985) has indicated that the more severe the accident, the more likely that alcohol was involved and that more than 60% of the 44,000 annual highway fatalities are related to alcohol intoxication. Research at VNTSC (Hoxie, P., Cardosi, K. Stearns, M. and Mengert, P., 1988) suggests that more than 30% of the 1,200 annual recreational boating fatalities involved intoxication.

The use of alcohol is relatively easily detected, and blood alcohol concentration (BAC) is accurately measured using breath testing technology. BAC limits for ships' crew members have been established by the Coast Guard, based on both statistical studies of the relationship between BAC and traffic fatalities and laboratory studies of the effects of alcohol intoxication.

Accurate statistical estimates of the relationship between blood-drug concentrations and transportation accidents are not yet available, therefore it is necessary that we base our understanding of the effects of drugs on what laboratory data are currently available. In any event it is reasonable to assume that illegal drug use by transportation operators can only be detrimental to safety.

2.2.1 Effects of Drugs on Performance

To understand the impact of drugs on transportation safety, it is necessary to understand the extent to which they affect behavioral processes that are essential to the performance of critical operations. While the safety-critical performance required of general-aviation pilots, railroad engineers, bus drivers, and watch officers differs widely, such performance depends on basic sensory, motor, cognitive, and emotional processes.

2.2.1.1 Hazard Potential

The hazard potential associated with the use of inappropriate drugs by transportation personnel is a function of their acute and chronic effects on safety-critical behaviors, and the extent to which the period of their direct effect and withdrawal effect overlap with duty. The impacts of psychoactive drugs on behavior are very complex, with multi-dimensional main and side effects. To further complicate matters, such drugs frequently are used in combination, resulting in synergistic or antagonistic effects.

The use of the drugs listed in Appendix A may alter the user's:

- sensitivity to physical stimuli (external and internal),
- willingness to accept risks,
- quality of cognitive processing,
- ability to concentrate on external stimuli,
- ability to comprehend the relationship between internal mental states and external events, and
- mood and emotional state.

Degradations in any of these factors can adversely affect operator performance when the duration of the drug's effect overlaps the duty period These degradations are a particular problem for individuals experiencing fatigue and stress.

The following factors influence the likelihood of overlap:

- **The desire of the user to mitigate negative aspects of the job** - Individuals involved in stressful and fatiguing duty may use alcohol, tranquilizers and sedatives to unwind when off-duty. Individuals involved in extended and fatiguing duty may use central-nervous-system (CNS) stimulants to maintain concentration and alertness. Individuals involved in low-event activity duty may use agents such as alcohol or marijuana on the job to mitigate boredom.

- **Spontaneous reoccurrence of effects** - On-duty abstinence from alcohol after periods of off-duty heavy drinking may lead to debilitating withdrawal symptoms. The users of drugs such as marijuana and LSD may experience drug effect "flashbacks" long after initial ingestion of the drug. This problem may occur in users of drugs whose active agents are absorbed by body tissues.

- **High abuse potential** - Drugs such as heroin are likely to cause psychological dependence because their use results in the rapid onset of high levels of pleasure. They also can result in physiological dependence, because cessation of use brings on intense negative feelings. For these reasons, the user may not be able to limit drug use to off-duty periods.

- **Distortion of the perception of the drug's effect** - Drugs such as cocaine provide the user with strong feelings of well-being and the illusion of enhanced mental and physical performance. These effects increase the likelihood that individuals under the influence of the drug will engage in critical operations and even increase risk-taking behavior.

- **Reliance on the drug for treatment of chronic problems** - Drugs such as Chlordiazepoxide (Librium) are widely used to combat the anxiety and the physical stress-related illnesses that are caused by anxiety.

Appendix A contains descriptions of the fatigue-relevant effects of a number of drugs with significant hazard potentials.

3. Mental Workload in Automated Systems

A very high level of automation is anticipated on ships designed to operate with very limited crews. The impact of this automation on mental overload and/or underload represents a very real concern. The following sections describe design considerations which can help to ensure that the extensive use of automation does not result in increased boredom or increased mental fatigue.

3.1 Task Allocation for Automated Systems

In automating shipboard operations we must recognize the role of the human operator. Parasuraman (1987) stated that present technology is capable of producing automation which exceeds the human capacity to monitor. He believes workloads should be optimized to match human functioning with automation capabilities. He suggests that aircraft-cockpit automation may have passed optimum levels and exceed the pilots' attentional capabilities. As automation increases in shipboard operations, the human operator's limits in terms of vigilance, resistance to boredom, and ability to attend to a sterile and, often lonely, operating environment should be recognized.

The increased use of automation can interact with fatigue even where crew size remains the same. In discussing the relationship of aircraft-cockpit automation to fatigue, Graeber notes "The critical issue is the change that automation is bringing about in crew's job requirements. Many of the stimulating and rewarding aspects of flying may be eroded ..." (*op.cit.* p.240). Reductions in crew size can be expected to complicate the impact of task reallocation between the crew and the ship's automated systems. <u>If the automated system is properly realized, the impact on safety and efficiency should be at worst negligible and at best positive</u>. In many cases the design of new automated systems provide opportunities to optimize task allocation, resulting in improved productivity, safety, and morale.

The following workload factors should be considered in designing and operating systems:

The maximum workload conditions are likely to occur during emergencies. While it is true that humans can mobilize their resources and overcome sleeplessness and fatigue during periods of stress, their capacity for simultaneous performance of critical tasks is much more limited. Allocation of crew functions must be based on requirements imposed by operations in a degraded mode and more particularly operations under emergency conditions. Task allocations must take into account factors such as the physical location of duty stations and operations when one or more crew members are incapacitated.

The availability of a cross-trained crew will allow the trading of duties between individuals of similar skills. Such variation relieves boredom and can improve performance. Of course rotational assignments must be carefully planed to insure an appropriate chain of command among individuals of like qualifications.

The division of labor between the automated systems and the human crew must take into account the performance characteristics of each. Computers are very good at continuously monitoring routine processes and precisely controlling such process but they are poor at making decisions based on partial data. Humans are poor at monitoring reliable systems (those with low failure rates) but good at integrating and acting on data of varying quality.

Where automated systems are used to control safety-critical processes, the information required to insure that the responsible crew member(s) maintain situational awareness must be provided. If the operator is to be able to take over at a critical juncture, sufficient information must be provided so that the human can be immediately integrated into the control loop. Simple warnings of malfunctions in the ship's automated systems are inadequate; the operator must have at his or her disposal (and in usable form) the information the automated system uses to make its decisions.

3.2 Automation-Integration Considerations

If fatigue effects related to boredom and to excess mental workload are to be minimized the automated systems to be used in "the ship of the future" must be properly integrated into the mission of the ship. That is, the tasks allocated to the to crew must be sufficiently stimulating and meaningful to minimize boredom, and the automation must provide for sufficient situational awareness to permit the crew to operate during automation failures without producing mental overload.

The successful automation of any existing complex system, such as a ship, involves at a minimum achieving the existing functions more economically and usually involves providing additional features which improve the operation of the system. Success is dependent on a number of a considerations. Among the more obvious factors are:

- the **reliability** of the hardware and software which make up the system,
- staff **training** and retraining requirements,
- the system's **maintainability**, and
- incorporation of **ergonomic design** features which make the system "user friendly."

There are a number of other factors which directly and indirectly impact crew morale, confidence, and performance and are therefore critical to the successful automation of the system. These include the extent to which the automated system:

- provides the **status information** (information about the ship's function) which is required for situational awareness and user confidence;
- provides **system information** which permits the user to anticipate malfunctions and recover from malfunctions of the automated system;
- is **complementary to the existing or proposed organizational structure** (does the system change the relative emphasis of crew roles and functions in a way which is harmful or helpful to discipline or efficiency?); and
- **makes appropriate use of available staff skills** and expertise. This last consideration is often critical simply because as noted above humans are good at decision making using partial information but poor at monitoring smoothly functioning systems, while automated systems are good at process monitoring but poor at decision making with incomplete information.

3.3 Assignment of Command and Control Functions

At the most basic level, careful consideration must be given to the assignment or allocation of functions between the human operator and the automated system. The specific human-factors design requirements of a complex system, such as an advanced ship's automated bridge, have been described in sufficient detail elsewhere in terms of the display, control, lighting, layout and other ergonomic considerations involved in work-place design (see for instance, Van Cott and Kinkade, 1972).

The assignment of command and control tasks, however, is a problem with particularly salient implications when one of the major goals of the automation is to permit the operation of the system with fewer human operators.

In theory at least, four basic control-assignment options are available for any task (Wichansky and Sussman, 1979).

Automated control. Here the system is primarily monitored and/or controlled by an automated system, and human responsibilities are restricted to maintenance.

Manual control. This involves the monitoring and control of systems' functions by a human operator, with automated support limited to sensors, displays, and servo mechanisms.

Shared Responsibility. Situations involving a sharing between manual control and automation may include those in which the human interacts with an automated system, monitors or supports the functions of this system, or is monitored or supported by the system.

Optional manual or automated control. Optional control may be used in situations where either human or automated functions will be satisfactory, and task assignments are made on the basis of factors such as costs or convenience.

In making task assignments using the four preceding options, two basic rules have been postulated (Wichansky and Sussman, *op.cit.)*:

The first is that when task requirements or conditions **exceed human resources** (e.g., tasks involving extremely rapid decision making, rapid and accurate computations, extremely precise control, high levels of force application, long periods of inactivity, or exposure to adverse environmental conditions), automation is dictated.

The second is that when **human resources are available** to meet task requirements, and when task characteristics are known to be very **difficult to automate**, human assignment is dictated. Such tasks include those in which complex decisions must be based on incomplete data, flexible decision making is required, where data inputs are qualitative rather than quantitative, workload is unpredictable, and successful completion of the task requires complex-pattern recognition.

It is possible to categorize the conditions under which control tasks must be performed. In fact, task assignments cannot be properly made without understanding the differences between various operational situations. Three types of conditions may be specified:

Normal Operating Conditions. This entails routine operations where the system is functioning on a normal schedule at normal performance levels within the predicted design parameters of the system.

Abnormal Operating Conditions. This entails operation under unusual conditions resulting in significantly degraded system function, due to factors such as extreme weather, mechanical breakdown, excessive loading, or power failures. Operations under these conditions can be expected to increase stress on the crew, but should not pose a direct or indirect physical threat to personnel, cargo, other vessels or the environment.

Emergency Operating Conditions. Under these conditions, unanticipated and/or uncontrollable events, including cataclysmic system failures, extreme weather conditions, vandalism, sabotage or other criminal acts, seriously disrupt system operation and pose a significant and immediate threat to the safety of personnel and property.

3.4 User and Organizational Considerations in Automation

The successful automation of any existing complex system, such as a ship, involves at a minimum achieving the existing mission functions safely, reliably and economically as well as improving on the accomplishment of the existing functions wherever possible.

As noted above there are obvious factors that directly affect the crew's interactions with the automated system including: hardware and software reliability, training and aptitude, system maintainability, and the incorporation of features which make the system "user friendly." There are, however, a number of less obvious factors which are also critical to the successful automation of existing systems.

The following questions should be considered in evaluating the impact of automation on crew performance:

Does the system provide **current status information** (information about the ship, not about the function of the automation) which provides the user with confidence about the systems function? If the worker is not provided with backup information, he or she may elect to maintain an informal personal back-up system.

Does the system provide **system function information** which permits the user to anticipate malfunction and recover from malfunction? Such information is critical in providing the crew member with confidence with regard to the system in safety-critical operations.

Is the automated system **complementary to the ship's command structure** ? For expamle, does the system change the relative emphasis of staff and supervisory roles and functions? Any structural change in organizational communication or individual responsibility (formal or informal) resulting from the implementation of an automated system must be carefully explored.

Is the command structure itself well suited to the safe, efficient operation of a modern ship?

Does the use of automation provide **added value to the crew?** (Will the user perceive any direct advantage in learning and using the new system?) To the extent crew members benefit directly the crew will make a greater effort to adapt to the system; i.e. (the job becomes more interesting, or the individual's role becomes more influential, or the job becomes more meaningful.)

Will the system use **staff skills and expertise appropriately?** This last consideration is often critical simply because, as noted above, humans are "good" at decision making using partial information but poor at monitoring smoothly functioning systems, while automated systems are good at process monitoring but poor at decision making. Applications involving expert systems which permit shared responsibility for decision making between worker and machine must be carefully examined with regard to distribution of functions and duties.

Will continued reliance on the automation will result in a **degradation of the crew's critical skills?** Systems which do not permit the crew to maintain critical skills are questionable both in terms of safety during malfunctions and in their effects on staff morale.

4. Methodology

4.1 Background

Objective methods of detection and measurement of the attentional state of the crew members would be of great value in understanding the relationship between changes in crew size and fatigue.

In a laboratory setting with a controlled environment, the reduction in response frequency and appropriateness is readily measured. The challenge is to discriminate reliably and accurately between changes in responses due to alertness and those changes imposed by other factors operating in the real world.

The following sections review the techniques available for such alertness measurement. It should be noted that the vast majority of the available research and safety data relevant to fatigue and attention comes from studies related to highway driving. This is probably due to: the involvement of almost the entire population in automobile driving, the huge number of fatalities and injuries associated with driving, and the extensive and comprehensive data bases associated with these accidents. Of necessity a large proportion of the work cited here will be drawn from highway-related research.

Zaidel *et al.* (1978) documented a comprehensive review of related studies of the concept of attention as well as studies related to the problem of attentional performance. Additional studies of operator performance, conducted since 1978, were reviewed during this effort to update the Zaidel *et al.* study.

As noted above, fatigue measures may be considered measures of decrements in attention. Since attention and fatigue are defined as internal activities, and attentional performance is multidimensional, a fatigue measure must be based on measurement of an event, state, or activity of the operator or vehicle, which is an external indicator of the level of performance on one or more dimensions of attentional performance. In addition, since inattention is defined relative to task requirements, an indicator of attentional demand is required to evaluate the measure and establish the adequacy of performance.

Investigators have used a variety of measures on the operator and vehicle as indicators of reduced performance and these may be classified in a number of ways. Zaidel and his co-workers, for example, organized their discussion on the basis of two classes of measures: measures of driver/vehicle performance and physiological measures. To provide continuity with their report, the same approach has been taken here; although, in addition, the indicators are conceptualized as primary or secondary indicators. Measurements of events more or less directly related to attention, such as failure to detect critical signals, are considered primary indicators. Measurements of events more directly related to operator internal or physiological states, other than the attention state, are considered to be secondary indicators. For example, EEG data are more direct indicators of arousal state than of attentional performance. Such measures indicate only that a state may be considered to be consistent or inconsistent with some range of attention performance.

4.1.1 Physiological Indicators

A number of different measures of physiological state or activity have been used in studies of attentional performance. Among these, measures of brain and heart electrical activity have received the most attention. Although Crawford (1961) maintains that physiological measures provide the only suitable measures of operator fatigue, physiological measures are, at best, secondary indicators of attentional performance (Mackie and Miller, 1978). The meanings of most physiological measures with regard to alertness are quite ambiguous and useful only to indicate a state consistent with a low level of intensity of attentional effort.

Appendix B describes the various physiological approaches to fatigue determination. From these descriptions, it is evident that none of these methods is well suited to routine use aboard a working ship for fatigue assessment. They tend to be unsatisfactory because they:

- are invasive,
- are time-consuming,
- require the use of specialized and sophisticated equipment and technicians,
- require careful calibration on the individuals tested,
- require sophisticated analysis and interpretation of the data gathered, and
- usually have data analysis done "off-line " rather than in "real time."

Hence, they are not considered further in this study.

4.1.2 Behavioral Approaches

From an operational point of view, the most valid methods of measuring the attentional deficits which represent fatigue involve objective assessments of behavior. Researchers have long sought to develop techniques providing tests of fatigue levels and competence of workers who perform critical tasks. Appendix C surveys these behavioral approaches to fatigue assessment.

The tests described in Appendix C are unsuitable for the purposes of this study or routine use at sea for one or more of the following reasons:

- most are not unequivocally, and sometimes only tenuously, related to fatigue;
- require that the individual being measured undergo significant training and a relatively long calibration period;
- are not self-administering; and
- produce results that are impacted by factors other than fatigue, and which are frequently ambiguous, and/or require extensive expert analysis for interpretation.

Although a few behavioral tests have been devised which are fast and simple, their validity as true measures of fatigue has not been established. In a review of available methods for monitoring driver alertness, Bishop *et. al.* (1985) concluded that there would be significant value in research into a multivariate approach using combined tests.

In summary, no physiological or behavioral approach to the measurement of fatigue has been identified which is cheap, practical, non-intrusive and capable of generating results which are valid and consistent across all subjects. Furthermore, because this study is preliminary and exploratory in nature, it was decided that in-depth interviews and very small-scale trials of various subjective fatigue-rating scales would be the methods of choice. Since only a single researcher was planned for each voyage, the study was usually limited to observations of and discussions with the ships'officers.

5. Ship Visits

Initially, through the cooperation of the Boston Harbor Pilots' Association, three merchant vessels were boarded with the pilot to explore opportunities to conduct interviews and fatigue surveys. Although the officers of each of these vessels were cooperative, it quickly became clear that they were far too busy during port operations with ship handling, cargo operations and other activities to begin to cover all the topics that needed to be discussed. Making arrangements for the conduct of surveys was also out of the question during these short visits of only a few hours each.

With the assistance of various trade associations, several shipping companies were identified which operate large vessels representative of the types for which reduced manning trends are of greatest concern. Through the trade associations and through direct requests, all of these operators were solicited to permit conducting research aboard their vessels. Only five volunteered, with most of the remainder citing concerns about liability or pending litigation as reasons for preferring not to have government researchers aboard. Arrangements were made with the five to have TSC staff members aboard during coastal voyages in U.S. waters, typically for periods of two to five days. During these periods, crew activities were observed. Data were collected from sleep diaries, subjective fatigue-rating scales and workload log sheets. Interviews were conducted with each participating crew member to assess reactions to the survey forms, reporting burden and so forth. In addition, crew members were encouraged to discuss any and all other factors which they felt affect fatigue and stress.

The following is a brief description of the vessels and crews visited:

Voyage #1: This voyage was aboard a U.S.-flag products tanker engaged in trans-Atlantic trade. The vessel was delivering refined petroleum to various East Coast ports and normally took about eight weeks to complete a round trip. This 45,000 DWT ship employed medium-speed diesel technology in her main propulsion system. She carried a non-union crew consisting of four deck officers, a bosun, three AB's, two ordinaries, five engineers, a steward and a utility making a total of 17. Alternate crews worked one-on/one-off and were paid about 15% above total annual compensation for union-crewed vessels.

Because the crew was hand picked by the shipping company and masters and was more or less permanently attached to the vessel, everyone knew his job well and performed reliably. Although the visit was conducted during the most arduous phase of the voyage (tank-cleaning operations), no one reported or gave evidence of more-than-normal fatigue. The cargo officer and A/Bs who cleaned tanks were quite tired at the end of the day, but relieved of other duties. This was a happy ship with no sign of conflict aboard.

The crews' main complaint, aside from boredom during the long voyages, was the poor reliability of the main propulsion system. The engine design was scaled up from a lower-horsepower model and was apparently over stressed. The vessel averaged about one engine breakdown per voyage and suffered from frequent engine-room oil leaks caused by the excessive engine vibrations. Unattended engine-room operation would be inconceivable on this vessel. The engineers expected to work round-the-clock for as long as necessary about once per voyage to deal with these breakdowns.

Voyage #2: A foreign-flag containership serving East Coast and European ports on a four-week cycle provided the next voyage. The 17-man crew aboard at the time of the survey had served for an average of eight years on the ship. They normally worked for eight weeks followed by four weeks vacation, with occasional eight-week vacations so that a ratio of 13.5 vacation days per month at sea was maintained. All crews employed by this operator are permanent. Most are attached to the same ship for many years. Those which rotate among ships do so as a complete crew.

Two apprentice officers were also aboard, as well as six riding maintenance workers. One or two apprentices are on board nearly every trip, but the maintenance crews (consisting mostly of students) come across the Atlantic only in August, when the weather is most favorable for exterior paint work. There are usually two or three mechanical maintenance technicians aboard during the European port calls.

<u>This ship had no problems whatsoever in evidence</u>. Her low-speed diesel main engine had never broken down in eleven years. Other mechanical systems showed similarly high levels of durability and reliability. Every crew member knew his job and went about it with relatively little supervision. The officers reported very little fatigue, plenty of sleep and seemed to enjoy a good deal of leisure. The cargo officer sometimes had a long day in port, but had no complaints. This was a "happy" ship with an extraordinary level of cohesiveness and friendship among the officers and (apparently) among the crew, but relatively little socialization between the two groups.

Voyage #3: A short hop of under two days between West Coast ports was taken on a large U.S.-flag containership operating in trans-Pacific service on a five-week cycle. This ship had much new technology aboard with an extensive computer network for both information and control functions. She carried a crew of 21. At the time of the visit, there were also two academy cadets and some riding technicians.

The mechanical reliability of the large low-speed diesel main engine was considered good, but not perfect. There were two instances of cylinder-head cracks in the past year. Such cracks did not disable the vessel; the engine can be safely operated with several of its twelve cylinders shut down. Much more troublesome were the hundreds of alarm systems. False alarms, resulting in very loud warnings all over the ship, occurred several times each day during the visit. These faults were slowly being eliminated as the riding technicians and crew discovered their causes. However, another year or two may elapse before all the bugs are gone. In the meantime, the engineers lose a fair amount sleep because of these problems.

Under the current labor contracts, the ship operates with only a few senior officers assigned to this vessel for any length of time. Second and third mates, assistant engineers and all lower ratings were hired from union rotaries. Six different unions were involved in crewing the vessel. The combination of much new technology and the transience of most of the crew resulted in a situation in which a substantial amount of time was being spent on teaching and learning how to do various tasks. Much more supervision was required than on either of the aforementioned vessels. Several instances were observed in which an officer could not complete some computerized task without consulting someone who had been on the ship longer. Sometimes these consultations disrupted the sleep of the teacher.

Several other factors were evident aboard this ship that resulted in a great many more hours being charged than were necessary aboard the previously described vessels. The contracts of the six unions spelled out in great detail exactly what kinds of work could be performed by members of which unions. For example, welding was done by assistant engineers, but the movement of welding tools was performed by unlicensed engineers. Thus most tasks required more workers to be assigned than on the other ships. In the most extreme case, under current contracts, six persons are required to be on duty in the engine control room during arrivals and departures, although there is nothing for them to do under normal conditions. Even if the bridge engine controls failed, it is doubtful that more than two or three persons would be required to control the engine locally.

Complaints were also heard on this vessel about excessively long tours of duty. Although the operator tries to rotate crew members after two voyages (70 days), the current shortage of competent mariners in certain ratings has made it impossible to achieve this objective consistently. Those who must stay on for 105 days or longer report that they experience a substantial increase in fatigue and loss in ability to work effectively.

Voyage #4: A U.S.-flag VLCC carrying Alaskan crude to West Coast refineries was the fourth ship visited. This vessel embodied mid-1970's conventional steam technology. Though well maintained, very little automation has been added. Her crew has been reduced by only a few billets over the years and now stands at 25.

The crew is represented by an independent union, which seemed to enjoy a relatively smooth working relationship with management. Morale was high. Although only a few senior officers are permanent, the other crew members mostly rotate among other ships in the same fleet with very similar equipment. Nonetheless, a much higher level of supervision and on-the-job training was required than on the vessels with permanent crews. Much of this supervision was related to matters of preventive maintenance, especially of deck equipment.

The average number of hours worked per week was about 75, but no one complained about putting in twelve hours a day for seven days or about 84 hours a week. The principal cause of fatigue aboard this vessel was the weather and sea conditions characteristic of the northern Pacific coast. Much sleep is lost, especially northbound, as the ship in ballast rolls through heavy seas in the frequent storms. Other sources of fatigue were working in Arctic conditions and the relatively unpredictable schedules caused by weather and queuing problems at both the Valdez terminal and the receiving refineries. Fatigue is common, but unavoidable in this trade.

Increasing the manning level aboard the ship would not help with most of the fatigue problems observed, but relief crews based at Valdez would allow everyone to catch up on sleep during the period of about 20 hours that the ship is usually in port there. Reducing crew size on such a vessel would require retro-fitting various labor-saving devices, such as a hydraulic pilot lift.

As on the third vessel visited, the operator of this vessel was experiencing a shortage of desirable job applicants for some ratings and frequently requested crew members to serve longer tours of duty than they wanted.

Voyage #5: The final voyage of this phase of the investigation was taken aboard a U.S.-flag containership of recent construction serving Atlantic ports on a seven-week cycle. The 23 members of the crew worked mostly for the same operator aboard ships of the same type, but were by no means permanent. In particular, the watch officers had not worked very much under the particular captain who had assumed command just as the author came on board.

The chief engineer had also just arrived for his 84-day tour, but the departing chief was also on board to brief his relief for four days.

Although the schedule of port calls was similar to that of the vessel of the second voyage and both ships were of similar size and technology, the level of fatigue was much higher on this ship. The captain and watch officers got very little sleep during the first two days. Several factors contributed to their 18-20 hour work days:

Lack of continuity of service under the same captain or chief engineer was certainly a major factor. The senior officers seemed to spend hours each day supervising or training subordinates, which was quite unnecessary on the German vessel.

There was also a major difference in the psycho-social character of work between the German vessel and this one. On the American ship, work had a much higher social content, i.e., crew members spent a much larger portion of their time talking about matters extraneous to the job, with the result that the same task took longer. Maximizing overtime earnings was clearly a priority on this vessel.

There appeared to be substantially more paper work on this voyage. This was due in part to the fact that several crew members were beginning or ending tours of duty during the period of observation. Typing articles of engagement or disengagement, bookkeeping and paying off consumed many hours of the captain's time. Furthermore, since the ship was in its home-country, the number of salesmen, surveyors, inspectors, etc. was much greater than for the German ship. Each of these visitors generated additional paperwork for the officers.

5.1 Interviews

Except for the one voyage of only a day and a half, interviews were conducted with each of the deck and engineering officers on each vessel. Each conversation began with an explanation of the background and objectives of this study. The interviewees were then asked to comment on whatever aspects of fatigue and stress they chose. The interview had no set time limit, nor did it need to be completed in one session. More than ten separate conversations about fatigue took place with one officer. Most subjects tried to block off 30 minutes to an hour for the initial interview, but interruptions were unavoidable for others.

During the course of each voyage, additional discussions of various aspects of fatigue and stress were held whenever opportunities presented themselves. Meals, navigation watches and engineroom tours presented good opportunities. Engineers were generally harder to talk to on watch because they were often performing maintenance in noisy areas.

Because a substantial portion of each voyage took place in pilot waters, there were several opportunities to discuss these questions with pilots. In some instances the pilots were too busy to talk or simply naturally reticent. However, about a third of the pilots had both the time and the inclination to discuss fatigue. Because they had experience with a much wider range of vessels than any of the crew members interviewed, they added much useful perspective. In particular, most of them stressed that they had observed many more instances of severe stress and fatigue on ships from less-developed countries than on U.S.-flag vessels.

Whatever comments deemed pertinent were written in longhand in the interviewer's notebook and summarized in Section 7 of this report. Although the interviews were completely unstructured initially, as the study progressed, there emerged several clusters of issues that concerned many of the subjects. These were:

Factors controlled by the company and/or union

- organization of work and task distribution
- role of riders and shore personnel
- voyage scheduling
- lack of standardization of tasks
- paperwork requirements
- psychological stress and "people" management

Physical characteristics of ships

- level of automation
- level of redundancy
- reliability
- inspection and maintenance practices
- age of vessel
- physical comfort issues
- cargo requirements

Characteristics of the crew

- degree of continuity or permanence
- level of training and appropriateness
- incidence of substance-abuse problems
- morale

Voyage Variables

- weather and sea conditions of the trade route
- traffic density
- number and spacing of port calls

Port Business

- government regulations
- inspections
- maintenance, stores, and other business in port.

From the third voyage onward, subjects were asked specifically to comment on each of these topics. Some of the interviewees were also asked to participate in one or more of the daily-questionnaire surveys described below.

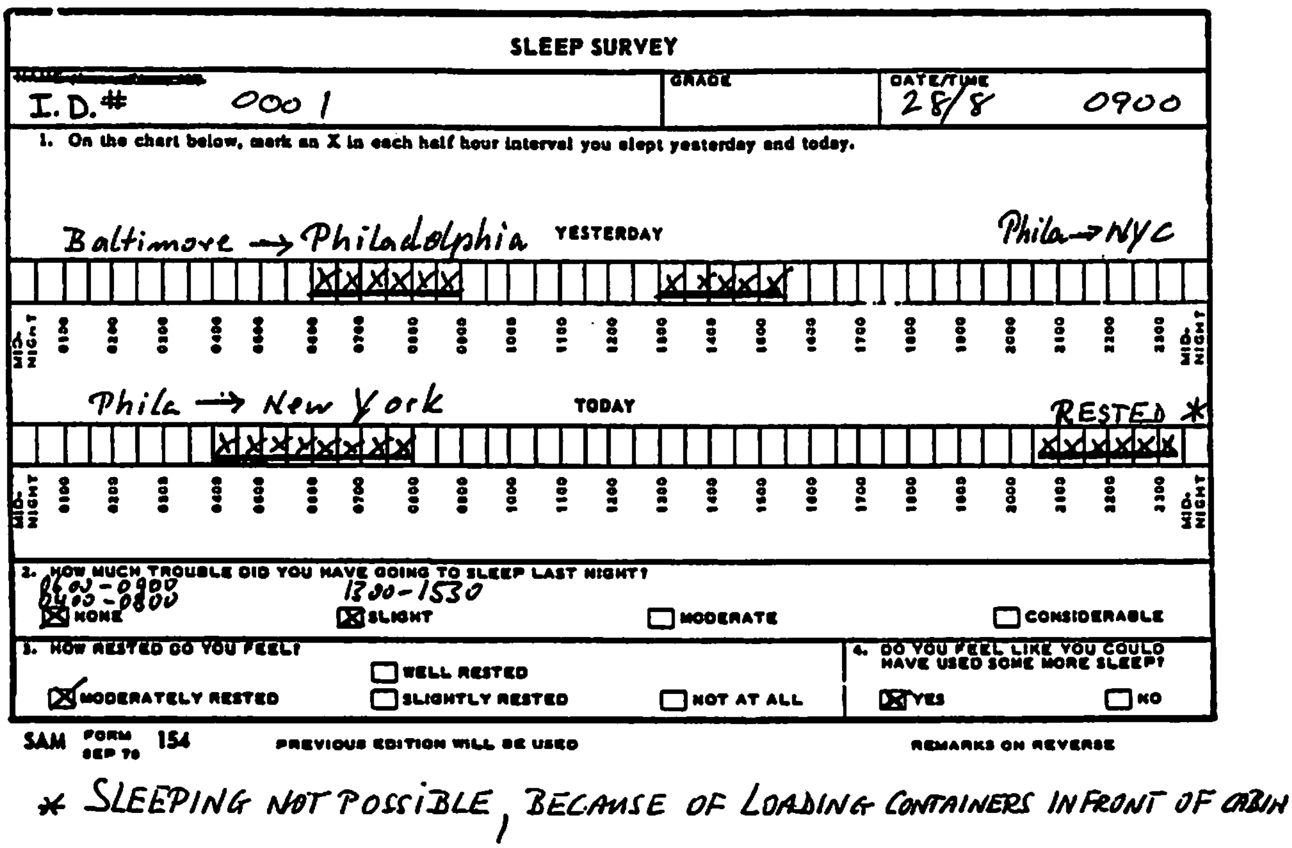
5.2 Surveys

Because of the various limitations of laboratory methods of fatigue assessment and because the scope of this project precluded non-self-administering tests, the surveys described in the following sections were the only research methods considered beyond the interviews.

5.2.1 Sleep and Fatigue Surveys

In considering what form of survey to use, it was recognized that military organizations, particularly the United States Air Force, have long been interested in assessing the fatigue levels of their pilots. More than a decade ago, the Air Force devised the sleep survey form shown in Figure 5.2.1-1 and the fatigue/workload scale reproduced in Figure 5.2.1-2. Because of their history of widespread use, these forms were tried first.

In administering the surveys, the first step after arriving on board was briefing the master. The masters had been informed in advance to expect a Department of Transportation researcher interested in fatigue, but knew little more about the study. After briefing the master and securing his approval, appointments were then made with various officers for briefings and interviews. Because of the workloads and irregular sleeping hours of the officers, it was not possible for a single researcher to get around to all of the officers until fairly late in the second day on board each vessel. All briefings and interviews were conducted one-on-one, chiefly because it would have been difficult to schedule two or more officers at the same time. In general, it was much easier to conduct interviews with deck officers than engineers, because the former had more free time during watches.



SLEEP SURVEY

[redacted] I.D.# 0001	GRADE	DATE/TIME 28/8 0900

1. On the chart below, mark an X in each half hour interval you slept yesterday and today.

Baltimore → Philadelphia YESTERDAY Phila → NYC

MID-NIGHT 0100 0200 0300 0400 0500 0600 0700 0800 0900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 MID-NIGHT

Phila → New York TODAY RESTED *

MID-NIGHT 0100 0200 0300 0400 0500 0600 0700 0800 0900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 MID-NIGHT

2. HOW MUCH TROUBLE DID YOU HAVE GOING TO SLEEP LAST NIGHT?
0600-0900
0400-0800
1300-1530
☒ NONE ☒ SLIGHT ☐ MODERATE ☐ CONSIDERABLE

3. HOW RESTED DO YOU FEEL?
☒ MODERATELY RESTED ☐ WELL RESTED ☐ SLIGHTLY RESTED ☐ NOT AT ALL

4. DO YOU FEEL LIKE YOU COULD HAVE USED SOME MORE SLEEP?
☒ YES ☐ NO

SAM FORM SEP 78 154 PREVIOUS EDITION WILL BE USED REMARKS ON REVERSE

* SLEEPING NOT POSSIBLE, BECAUSE OF LOADING CONTAINERS INFRONT OF CABIN

FIGURE 5.2.1-1. U.S. Air Force Form SAM154 Sleep Survey.

I.D. 0004

NAME

26/8/89 22:00

DATE AND TIME

SUBJECTIVE FATIGUE

(Circle the number of the statement which describes how you feel RIGHT NOW.)

1	Fully Alert; Wide Awake; Extremely Peppy
2	Very Lively; Responsive, But Not At Peak
3	Okay; Somewhat Fresh
4	A Little Tired; Less Than Fresh
5	Moderately Tired; Let Down
6	Extremely Tired; Very Difficult to Concentrate
7	Completely Exhausted; Unable to Function Effectively; Ready to Drop

COMMENTS

WORKLOAD ESTIMATE

(Circle the number of the statement which best describes the MAXIMUM workload you experienced during the PAST HOUR. Estimate and record the number of MINUTES during the past hour you spent at this workload level.)

		MINUTES
1	Nothing to do; No System Demands	
2	Little to do; Minimum System Demands	
3	Active Involvement Required, But Easy to Keep Up	15
4	Challenging, But Manageable	45
5	Extremely Busy; Barely Able to Keep Up	
6	Too Much to do; Overloaded; Postponing Some Tasks	
7	Unmanageable; Potentially Dangerous; Unacceptable	

COMMENTS

SAM FORM JUL 80 202

CREW STATUS CHECK

FIGURE 5.2.1-2. U.S. Air Force Form SAM202 Crew Status Check

Each session began with a description of the background and objectives of the study. Subjects were then invited to talk about any aspects of fatigue or stress they wished. These discussions generally lasted a half hour or more and were frequently continued at various times over the remainder of the voyage.

The survey forms were then explained and filled out for at least the current day, and sometimes for the previous day as well. Once it was clear that the subject was agreeable, a supply of forms was given to the subject covering the remainder of the voyage. They were collected from each participant shortly before the researcher left the vessel. On one voyage, forms covering an additional five days together with self-addressed, U.S. government prepaid-postage envelopes were left with several officers.

The response to these surveys is discussed in Section 6.1

5.2.2 Activity Surveys

Because of the aforementioned concerns about subjective fatigue ratings and because of the results obtained from the forms described in 5.1, alternative data were sought which might have some bearing on the issues of crew size and fatigue. The obvious measures are those of how much time is spent working.

In most industries, a forty-hour week is the norm and extra work requirements are accurately reflected in hours of overtime paid. A mariner's life is quite radically different in that he or she is at the job site round the clock, seven days a week for the duration of the tour of duty. Freed from all the usual burdens of shopping, commuting, cooking, household maintenance and denied the opportunity to spend off-duty hours with friends, family and other shore-side interests, sailors routinely work about twelve hours a day, seven days a week. Because there is little else to do, many merchant seamen seem to prefer to work upwards of twelve hours per day, or 80-100 hours per week. Compensation arrangements in the industry are such that mariners expect to derive a large portion of their total pay from overtime. Seamen who decline opportunities to put in a substantial amount of overtime are unusual and not likely to be well regarded by their superiors or peers.

Overtime records for the previous pay period were reviewed at length with the master and chief engineer of one of the vessels visited. These showed paid overtime for various crew members varied from two to 72 hours per week, with an average of 34. The senior officers felt that these numbers gave a good relative indication of which members of the crew were doing the most work, but that they overstated actual work because of union work rules which establish minimum numbers of paid hours for jobs performed on overtime regardless of how long the task takes.

The use of overtime records as a means of measuring workload was discussed with various shipping company managers and Coast Guard officials. The consensus was that analyzing overtime records would require extensive and detailed knowledge of work rules and practices, understanding of how those rules are interpreted by different senior officers and union officials, etc. Such an approach could not be applied uniformly across different shipping companies because of the substantial differences in their labor agreements or policies. Hence, this approach was rejected.

Self reporting was the method selected, which suited the time and budget constraints of this exploratory phase. The model for the activity survey forms used was taken from the "Job Functional

Analysis" (JFA) developed by Hendricks and Grabowski (1990) developed in support of the National Academy of Sciences Marine Board Study on Reduced Manning. The JFA is a detailed listing of all of the discrete functions each merchant ship's officer must perform in the course of his or her duties.

In order to reduce the length of the forms given to each subject, separate subsets of tasks were developed for each type of officer. In the first trial of these forms (on the third research voyage), an attempt was made to record the amount of time consumed by each type of activity down to the minute during each four-hour period. These forms are reproduced in Appendix D.1.

Subjects were introduced to these forms in the course of the initial interview, and asked to fill out one or more of them at that time. They were instructed to report actual working time, not hours paid and were assured of confidentiality. They were asked to complete additional forms as time permitted during the remainder of that brief voyage. Some of the forms were filled out by the TSC investigator during the navigation watches of various subjects.

For the fourth voyage, the activity survey forms were shortened slightly and changed to a once-a-day format rather than every four hours. Times were reported in hours or fractions thereof rather than minutes. Completed forms were collected from all participants near the end of the voyage. Additional forms for the next five days were left with five officers and two unlicensed crew members who volunteered to complete them. Examples of these forms are reproduced in Appendix D.2.

6. Findings from Surveys

6.1 Subjective Fatigue and Sleep Surveys

On the first two ships visited for this project, the products tanker and the foreign-flag containership, volunteers were sought to complete the fatigue and sleep survey forms from the deck department only. (See Figures 5.2.1-1 and 5.2.1-2 for examples of these forms.) The masters of both ships took considerable interest in the study and gave freely of their time to discuss a broad range of topics related to fatigue. Both encouraged their mates to volunteer.

On the tanker, the captain felt it would be pointless to participate himself since, he said, he was not experiencing significant fatigue and expected nothing to interfere with getting a good night's sleep every night on that voyage. Everything about his appearance, behavior and schedule supported that statement. The first mate was very busy with tank-cleaning operations and was not standing watches. He declined to participate because of he was pressed for time and not operating on anything like his normal schedule. The other two mates stood six-on/six-off watches for most of the three-and-a-half-day voyage. The second mate was not particularly busy and said he did not feel fatigued, nor did he appear so. He did, however, detest paperwork, especially government-imposed paperwork, and refused to complete any forms. The third mate completed all forms and seemed to enjoy the lengthy interviews about fatigue during his watches. Despite spending almost twelve hours a day on watch, he consistently reported his fatigue level as "O.K." or "A Little Tired" (level 3 or 4 on the form shown in Figure 5.2.1-1). He reported averaging eight hours sleep per day, generally broken into a five- hour major period and a three-hour nap.

All three mates on the foreign containership took considerable interest in the fatigue study and completed survey forms along with the master. One of these mates felt that the sleep survey constituted an invasion of privacy and omitted that portion of his questionnaires however. All four of these officers reported minimal fatigue, never more than "A Little Tired." The captain reported averaging only a little more than four hours sleep per day during this series of port calls, but said he slept much more in open seas. The other officers averaged closer to seven hours per day. Such sleep loss as occurred was the result not of lack of time to sleep, but rather of schedule disruption from moving the ship at night and the constant banging of containers during loading and unloading during the days in port.

Because so little fatigue was reported aboard the first two ships visited, it was decided to try out the activity survey on the next voyage. Since that voyage turned out to be quite brief, the sleep and fatigue surveys were suspended. However, they were used again aboard a VLCC on a voyage to Valdez. Again, the master and chief engineer were highly supportive of the study and spent many hours discussing fatigue issues with the two TSC staff members on the voyage. Three mates, two assistant engineers, the bosun and the pumpman participated in the surveys and interviews. Of the seven sets of forms left with subjects for completion after the TSC investigators left, three were returned.

Despite its 25-person crew size, this vessel seemed to have a higher average fatigue level than any of the three visited previously. Subjective fatigue ratings of 5 (moderately tired) or 6 (extremely tired) were reported at least once by two of the participants, which had not occurred in the earlier surveys.

The fatigue observed during this voyage resulted primarily from sleep loss rather than physical exertion. The chief mate and pumpman were normally up for more than 24 hours during loading and unloading. Sleep was also disrupted by relatively unpredictable sailing times and rough seas. On the particular voyage during which the survey was conducted, seas never rose above 12-15 feet, which caused relatively little sleep disruption. However, seas of 40 feet or greater are commonly encountered in the Alaska trade, which could and did produce severe sleep loss, sometimes for several days consecutively.

Several crew members on this vessel reported that severe fatigue from physical exertion occurred occasionally. Deck work in arctic conditions (wind chill factors of -50°- F. and worse) was frequently cited. Preparing the ship for inspections or yard work, mainly tank cleaning, was also a source of extreme physical fatigue.

In summary, the subjective fatigue ratings seemed to correlate reasonably well with the comments made in the interviews and the personal impressions of the author, at least so far as conditions during the voyages in question. There was no indication that any participant made untruthful claims about his or her sleep time or fatigue state. However, on the products tanker, crew members reported that they occasionally experienced much more fatiguing conditions. The VLCC's crew said they frequently experienced much worse conditions. Only the crew of the foreign containership said that they hardly ever experienced any conditions more stressful than those observed during the VNTSC visit. There was general agreement that in order to be meaningful, any survey of sleep and fatigue should include every crew member on board, extend for at least one entire round-trip voyage and include the heaviest sea conditions routinely encountered. Achieving these conditions, particularly the last one, would substantially complicate scheduling and conducting this sort of research.

6.2 Workload Surveys

Because so little fatigue was reported by the crew members of the first two ships visited, workload measurement was considered as an alternative and perhaps more sensitive means of measuring the effects of changes in crew size and other variables of interest. For the third research trip, it was the only technique employed because the brevity of the trip -- only one and a half days. Since it took each participant about an hour to work through the forms the first (and only) time, only five of the vessel's crew could be surveyed, although there were additional volunteers. Those included were the master, two mates, the chief engineer and a technician who performed electrical and refrigeration maintenance. The vessel was an American-flag containership.

As discussed in Section 5.2, slightly different versions of the workload survey were prepared for masters, engineers, and mates corresponding to the differences in their respective duties. (Survey forms for each of the five categories are reproduced in Appendix D.) In the first test of these forms, it was hoped that each participant would fill out one set of forms every four hours, providing an estimate of the number of minutes in that period devoted to each task category. However in the space of less than two days on the vessel, it was not possible to schedule more than about one hour of time to interview and instruct each survey participant. During these interviews, crew members filled in several sets of forms, reconstructing their days as best they could recall. The dominant reaction was that they could not see the point of trying to break their time into such fine detail.

In any given period, deck officers performed many different tasks, often simultaneously. Accounting for each type of activity accurately would require an observer with a battery of timers for each crew member being surveyed. Many of the survey forms were simply marked "Stood watch" for 240 minutes with brackets embracing all of the navigation activities.

Since the ship had a fully automated engine room, there was no need for routine monitoring of engine-room functions. Engineers were usually able to concentrate on one task at a time, such as preparation of a specific report or repairs to a specific piece of hardware. Thus they could generally be more specific as to how they spent their time than the deck officers.

At the conclusion of the third voyage, nothing had occurred to support the need for minute-by-minute accounting of how mariners spent their time, and the activity forms were modified accordingly.

For the fourth voyage, survey participants were requested to fill out only one set of forms per day, with time for each activity expressed in hours or fractions thereof rather than minutes. This drastically reduced the reporting burden and most of those surveyed felt they completed this task in less than five minutes per day. Again however the deck officers were often unable to disaggregate their time on watch into time on specific tasks and could not see any point in trying to do so.

In summary, the activity surveys were found to be workable, but required a good deal of explanation and one-on-one briefing. The reported working and sleeping times were in all cases consistent with the authors' personal observations of the subjects. There were almost universal questions about the point of trying to disaggregate time spent into so many categories and what possible relevance such information could have. In any given hour, most officers work on several different tasks and could not accurately account for exactly how much time was devoted to each without having an observer standing by keeping track with a battery of stopwatches.

6.3 Combined Survey Form

Because of the substantial time required to fill out the separate forms previously tested and the lack of any identified need for highly disaggregated data regarding time on specific tasks, a much simplified form combining both activity and fatigue/sleep data was prepared, as illustrated in Figure 6.3-1 with an accompanying instruction sheet in Figure 6.3-2. Only eight categories of activities are included. In most cases, crew members should require under two minutes to complete one of these forms.

These forms were tested with nine crew members during the last research voyage. Everyone asked to participate completed and submitted all forms, which was not the case with any of the previous versions. The respondents reported that they could complete these forms in two or three minutes and had no complaints about them whatsoever.

1. Vessel Name XXXX 2. I.D. # 03 3. Date - 3/27/90

EXAMPLE

Time	4. Watch Standing	5. Maintenance Scheduled	5. Maintenance Unscheduled	6. Supervision/ Training	7. Other Operations	8. Off-Watch PaperWk	9. Leisure eating & personal	10. Sleeping	11. Unusual Conditions
00:00-00:59									
01:00-01:59									
02:00-02:59									
03:00-03:59									
04:00-04:59									
05:00-05:59									
06:00-06:59									
07:00-07:59									
08:00-08:59									
09:00-09:59									
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16:00-16:59									
17:00-17:59									
18:00-18:59									
19:00-19:59									
20:00-20:59									
21:00-21:59									
22:00-22:59									
23:00-23:59									
24:00-24:59									

12. Total number of hours worked today 11
13. Number of undesired hours worked today 0
14. Number of days on duty 36
15. Activities today: Open-water sailing ✓; Pilot-water sailing ✓;
Anchored/Adrift______; Berthed ✓

16. How much trouble did you have going to sleep?
- [x] None
- [ ] Slight
- [ ] Moderate
- [ ] Considerable

17. How well rested did you feel when you awoke from your last sleep period?
- [ ] Well rested
- [x] Moderately rested
- [ ] Slightly rested
- [ ] Not at all rested

18. Check box which describes how you feel right now.
- [ ] Fully alert, wide awake, extremely peppy
- [ ] Very lively, responsive, but not at peak
- [ ] OK, somewhat fresh
- [x] A little tired, less than fresh
- [ ] moderately tired, let down
- [ ] Extremely tired, very difficult to concentrate
- [ ] Completely exhausted, ready to drop

19. Comments:

FIGURE 6.3-1: Example of Mariners' Fatigue Survey Form

INSTRUCTIONS FOR MARINERS' FATIGUE STUDY

Please fill in one sheet in this booklet on each day of the survey period for your ship.

Items 1-3: Please enter the vessel name, your ID number and the date. If the forms are securely bound together, it is not necessary to write the vessel name on every sheet. Your ID number will be assigned to you by the person aboard your ship who is administering this survey.

Items 4-10: For each of the types of activities listed in the column headings, please draw a vertical line (pencil or pen) starting at the time that activity began and ending where it stopped. See attached example. Every period of time should have some line corresponding to it and the total length of all the lines should add up to 24 hours, except when you cross time-zone boundaries. If you cross a boundary, continue keeping your log for that day according to the time in the zone where you began your day, using the 25th hour when necessary. Please note whether you gained or lost hours in Item 19.

Item 11: For the last column, labelled "Unusual Conditions," draw a vertical line for periods of time in which some out-of-the-ordinary situation produced high fatigue or disrupted sleep. Examples would include storms, tank-cleaning operations, fires, etc. Identify the cause in Item 19.

Item 12: Please enter the actual number of hours worked.

Item 13: If you felt compelled to work more overtime hours than you wanted to, whether as a result of a request or order from a superior, peer pressure, or simply your own desire get the job done, please enter the number of undesired hours of overtime here, regardless of whether you were paid for those hours.

Item 14: Enter the number of days you have been working since your last vacation, starting with "1" for the first day back and so forth.

Item 15: Check one or more boxes describing what your vessel was doing on this day. Check all that apply.

Items 16-18: Please check the appropriate boxes for these items.

Item 19: Please use this space to enter any comments you would like to make or explain unusual conditions. Use the back of the sheet to extend your comments if necessary.

FIGURE 6.3-2: Instructions For Mariners' Fatigue Study

7. Findings from Interviews

In the course of the numerous and extensive conversations aboard various vessels, dozens of issues were raised in connection with stress, fatigue and boredom. Some of these issues were of concern on every vessel, while others were mentioned by only a single individual. In the sections that follow, they are grouped in five headings: (1) those which are affected by company and/or union policies and work rules or practices; (2) those which are characteristics of a given ship; (3) those which are characteristics of the particular personnel aboard a given ship; (4) those determined by the nature of the voyage or trade route; and (5) those influenced by the particular port being visited.

7.1 Company and/or Union Variables

7.1.1 Compensation System

There were striking differences in work styles between the crew of the German ship and those of the U.S.-flag vessels. On the American vessels there was much more conversation on the job. Some of it was occasioned by the need to ask questions about how to do a job or where to find something, but much of it purely social. Distractions and diversions were much more common on the American ships. The result was that a given job tended to take longer on the U.S. vessels.

Undoubtedly some of this difference in working style is due to cultural differences between Germans and Americans, but it was also clear that the behavior of the Americans served to boost earnings. Virtually all of them, except the captains and chief engineers, reported that overtime pay was an important part of their total compensation. Several stated that unless they collected pay for 50 or more hours of overtime per week, they would not find it worthwhile to remain in the merchant marine.

Heavy overtime was once the norm on German ships. A decade ago, the average was about 200 overtime hours per person-month. Out of concern for the fatigue generated by these very long work hours, the German government brought regulatory pressure to bear, which resulted in a phased-in cap on overtime hours. The limit was eventually reduced to 90 overtime hours per person-month, with no more than 30 in any given week.

This reduction in overtime was achieved at the same time crew sizes were being reduced. Base pay was also raised so that the total compensation being received by sailors remained about the same.

7.1.2 Organization of Work and Work Rules

Complaints about the organization of work or lack thereof were heard fairly commonly, more often in the context of psychological stress than fatigue *per se*. The complainers were mostly younger officers who had rotated among several vessels and had noted substantial differences in the organization of their work aboard different ships.

Some of the concerns related to ambiguities in the organization of work, i.e., lack of clear directions as to who was supposed to do what under which conditions and what supervision was required. Such questions tended to resolve themselves the longer an individual served under a given superior.

Another group of criticisms under this topic had to do with union work rules which effectively required extra persons to be present at certain tasks even though their presence was unnecessary and often counter-productive. A licensed engineer cited a work rule stating that he was forbidden to move his tools while performing a welding job, (He had to summon an unlicensed engineer each time he wanted his hose moved.) Another complained about union rules requiring six engineers to be up and on-duty during departures and arrivals. His vessel is highly automated and fitted with complete bridge control of all engine functions. Even if its bridge controls failed, no more than two or three engineers are needed to control the engine manually. The result of this work rule is that several engineers have their normal rest periods disrupted unnecessarily at every night departure or arrival.

7.1.3 Proportion of Work Performed by Relief and Riding Crews

As the complexity of mechanical and especially electronic systems aboard merchant ships has increased, there has been a world-wide tendency toward increasing the proportion of maintenance performed by shore-based specialists. Conversely, there is less work for the regular crew to do. Continued increases in technological complexity and economic pressures seem likely to continue this redistribution of work. Even when the work does not require a high degree of skill, e.g., chipping and painting, more of it is being performed by riding crews staffed with temporary workers because it is cheaper than maintaining a year-round crew large enough to handle work which can be done only in good weather.

Port-relief crews also permit reductions in the size of permanent crews without increasing their fatigue levels. Port-relief crews can be particularly effective as a fatigue mitigation strategy in ports like Valdez because the major cause of fatigue is the sleep loss caused by the heavy seas frequently encountered by vessels bound for such ports. The shore-based relief crew, who are not subject to the sleep loss experienced by the regular crew, can handle a portion of the unloading and loading tasks while some of the regulars catch up on lost sleep.

Port relief in home port is especially valuable because it affords an opportunity for mariners to visit their families, which provides a host of psychological benefits.

7.1.4 Assignment Duration

On the two vessels visited on which minimal fatigue was reported, no one served more than 60 days without a vacation of at least four weeks. On the other vessels, company policy was to limit tours of duty to 70 days whenever possible, but difficulties in securing qualified personnel from the rotaries frequently prevented the achievement of that objective. Thus many officers reported serving three and occasionally four months at a stretch. All of the officers who had served these extended tours felt their productivity began to fall off significantly somewhere between 60 and 75 days on duty. They were unanimous in recommending that tours should be limited to about 60 days in order to minimize both fatigue and the psychological stress associated with prolonged separation from families.

Several interviewees expressed the view that expectations about length of tour are more important than the actual length of the tour. They maintained that a seaman who finds himself still on duty after 80 days, when he had expected a 60-day job, will experience more stress and fatigue than one who has worked 90 days, but expected to do so when he first came aboard.

Managers report that as continuity of employment has increased, the problem of unexpected extension of duty tends to diminish, since the alternating crews guarantee each other timely relief. However, the high average age of A/B's in the U.S. merchant marine may lead to further problems as a large number reach retirement in the next few years.

7.1.5 Scheduling

For vessels engaged in container liner service, maintenance of a reliable schedule is vital to successful competition. Hence, a few days of slack are built into the schedule so that the inevitable breakdowns and weather delays will not throw the ship behind schedule. Most of the time, however, there are no such problems, so much of the slack can be taken in home port, allowing some shore leave for much of the crew to visit their families. Schedules with some slack are much preferred by crewman both because of the extra port leave and because they permit mariners to schedule personal activities, such as vacations, with reasonable certainty.

In contrast to liner services, most other mariners find that their vessels are operated for maximum productivity, with no slack time. Their home port visits often last less than day and there is much uncertainty as to when their tours will end.

7.1.6 Standardization of Tasks Across the Fleet

Complaints about the lack of standardization of tasks across the fleet of vessels operated by the same company were most frequently heard from watch officers who worked on rotation. They described numerous examples in which different masters or chief engineers had developed their own ways of doing certain tasks and insisted that the rotating watch officers learn their particular approaches. These learning requirements often added hours of work each day, especially during the first few days under a new arrangement.

The most commonly cited example of lack of standardization was that of using different software packages to generate the same report. In most fleets, choices about which commercial software packages to use were left to individual masters and chiefs, with no attempt to coordinate them.

Although efforts are now underway in several firms to standardize software for specific tasks, the number of computerized tasks is constantly expanding with the result that the backlog of non-standardized tasks does not appear to be shrinking much.

7.1.7 Paperwork Requirements

Deck officers spend several hours a day tending to various paperwork requirements; where fatigue occurs, paperwork requirements must be judged a major contributor to the problem. Many officers complained about having to complete several different reports containing duplicative information for different elements of their firm and for various regulatory agencies. They were painfully aware of how much time they were wasting. One group of masters for a major containership line organized to demand that all of the recipients of these reports in their firm justify in writing the need for these reports. The result of this tactic was an 80% reduction in the paperwork burden for the masters as well as significant reductions for other officers.

Substantial differences were observed in the amount of paperwork required in different fleets. Some firms are far ahead of others in terms of installing net-worked computers and appropriate software on board to automate the generation and transmission of required reports. There appears to be great opportunity for further improvement in this area in most fleets, with concomitant elimination of a few hours of work per day for most officers.

7.1.8 Psychological Stress

Conflicts generating psychological stress among officers and crew were not much in evidence aboard any of the vessels visited. However, several of the officers interviewed described experiences earlier in their careers which were highly stressful.

Most of these revolved around superior officers who lacked "people management" skills. One mate described a master of his previous employer's who deliberately set up situations in which he could write up disciplinary citations, with which he could then threaten his subordinates in future conflicts. In one instance this captain invited all of the officers to his stateroom for a New Year's celebration and poured drinks for everyone but himself (company policy approved moderate consumption of alcohol off duty). He then proceeded to write up citations for drinking against everyone present, which he said would not be forwarded to the Coast Guard unless some future behavior displeased him.

Conflicts with union officials were reported by one mate, who felt that his union's pension fund was being seriously mismanaged and that the senior officials of his union were very much out of touch with the situation aboard modern vessels, inasmuch as none of them had been to sea for more than a decade.

Several respondents felt that the best way to detect and deal with personality problems was for managers and union officials to spend more time aboard. More opportunities to discuss problem situations with managers and union officials in private and without fear of recriminations were widely recommended by both officers and unlicensed seamen.

Finally, it should be noted that camaraderie among officers and crew was much more apparent on some vessels than others. In general, there was more socialization after dinner on the vessels on which the same individuals had served together longer. The friendships developed certainly helped relieve the loneliness characteristic of so many mariners' lives.

7.2 Ship Variables

7.2.1 Level of Automation

Thus far, shipboard automation has had its greatest impact in the engineering department. Virtually all of the routine monitoring tasks can be taken over by automation so that unattended engine rooms have become the norm on new vessels. Engineers spend their days performing maintenance, improvements and managerial tasks. The work of two or three unlicensed ratings has been permanently eliminated.

Further automation opportunities in the engineering department mainly involve such tasks as report generation, inventory control, stores ordering and maintenance scheduling. These may be sufficient to justify the elimination of at least one licensed assistant engineer, but maintenance workload (discussed in 7.1.2 and 7.1.3) is likely to be the dominant factor in such decisions.

Many of the deck officers' tasks have been automated, but only in the case of the radio officer has enough work been eliminated that the position is being eliminated. Other deck officers consistently report that their workloads are lower and that they experience less fatigue than they did a decade ago because of the automation that has been implemented. Automated tracking of many targets by modern radars was often cited as the single most valuable improvement, but the many improvements in navigation and weather monitoring instruments are also credited.

7.2.2 Level of Redundancy

Among the most frequently expressed concerns about crew-size reductions is that of how to deal with breakdowns in one or more critical systems. Coping with such an emergency could be much more difficult than on a vessel with a larger crew. There are multiple, complementary approaches to reducing the probability that a crew will have to deal with critical-system failure(s) at sea: improved reliability, inspection and maintenance (discussed in 7.1.3) and increased redundancy.

Redundancy in critical systems, sometimes doubled or even tripled, has been established practice on aircraft because of the impracticality of making repairs in flight and the need for almost instant substitution for any failed critical component. Some degree of redundancy is present in many modern merchant ships, but it falls far short of the norm for airliners. As crew size is further reduced, it is reasonable to expect the introduction of additional redundancy in critical navigation, communication and control systems.

7.2.3 Reliability, Inspection and Maintenance

Among the vessels visited, the frequency of occurrence of main-engine breakdowns varied from not once in eleven years to four or five times per year. These huge differences in reliability (probability of failure per unit of time differing by more than a factor of one hundred), must bear heavily in any decisions about crew-size reductions. Mechanical failures impact fatigue in a number ways: they can require extended duty hours, disrupt sleep, and require extra-ordinary efforts from the crew. Ships with highly reliable systems are far better suited to reduced-crew operation than those with a history of frequent breakdowns. The achievement of high reliability depends upon the quality of the original design of each component, quality of workmanship and adequate scheduled maintenance, inspection and testing.

7.2.4 Age of Vessel

Even in a well-designed and well-built vessel, there are likely to be quite a few problems to be remedied during her first year or two of service, particularly if she is among the first of a new class. Thus initially such a vessel may need extra troubleshooters on board whose jobs will disappear when all the design problems have been eliminated. These extra engineering positions might be filled by increasing the size of the crew temporarily, but more commonly, riding technicians employed by the builder or component vendors will perform such work. The vessel is then likely to enter a period of a decade or more when her needs for repairs will be at a minimum and her crew may be sized accordingly.

At some point in her second decade of service, a vessel is likely to experience an increase in component-failure rates as wear, corrosion, metal fatigue, and related factors take their toll. Thus the amount of maintenance labor will increase. By its nature, however, much of this additional maintenance must be performed in shipyards and has no effect on labor on board. At the discretion of the operator, other portions of this increased maintenance may be performed by shore personnel in port, by riding contractors or by an increased permanent crew.

7.2.5 Motion Characteristics

Excessive rolling and pitching were widely acknowledged to cause major sleep loss and severe fatigue. Some vessel designs have more desirable motion characteristics than others, but the weather and sea conditions of a particular trade route and the vessel's loading condition were felt to be far more significant than vessel design.

Away from heavy seas, some vessels were acknowledged to have more desirable motion characteristics than others, but the issue did not seem to be of great importance. It was suggested that by a process of self-selection, mariners who were made uncomfortable by the characteristics of some ships tended to leave those ships.

7.2.6 Vibration and Noise Levels

Vibration and noise levels under way varied substantially among vessels, but did not provoke much complaint, even from crew members working under extremely noisy conditions, for example those working in the engine room of the steam-turbine-powered VLCC tanker. All but one of the mariners interviewed maintained that they adapted to the noise (which was constant) and did not lose any sleep because of it. Whether the high level of acoustic noise contributed to feelings of physical fatigue was not clear.

In-port noise and irregularly occurring noise resulting from cargo operations seemed to cause more sleep loss than the ship's own machinery. Several respondents mentioned being kept awake by the banging of containers and hold covers.

7.2.7 Interior Comfort

Malfunctioning cabin temperature controls were reported to be a fairly common problem. Improvised dampers made of cardboard and duct tape were noted on several occasions. Minor repairs to air conditioning systems are apparently not accorded a very high priority, despite their potential for disturbing sleep. One of the vessels visited was consistently overheated due to problems with thermostats.

7.2.8 Air Quality

Fumes from auxiliary engines and from products carried on tankers were a source of worry about adverse health effects for a few of the crewmen interviewed. None of the interviewed mariners reported loss of sleep, although several had become light-headed or dizzy at various times, mainly during tank-cleaning operations.

7.2.9 Cargo Requirements

Peak fatigue levels were associated with two infrequent events --major storms and breakdowns-- and one that occurred regularly-- tank cleaning. The hard physical labor involved in tank cleaning, often performed while wearing a cumbersome breathing apparatus, produced more reports of fatigue than any other common cause. On most vessels, it was done only when required for inspections or yard work, and temporary riders are the most efficient means to minimize fatigue for the permenant crew. However in some trades, cleaning is required on every voyage, in which case extra crewmen may be necessary.

Loading and unloading cargo generated moderately high levels of fatigue among those members who were involved in the operations, especially the cargo officer and (on tankers) the pumpman. Though there is not much physical labor entailed, the unload/load cycle often takes the better part of a day and sometimes extends to 30 hours. Cargo officers are rarely in any condition to stand watch after such a port call. Several approaches may be used to mitigate the fatigue created. On some vessels, the master takes the cargo officer's first watch; on others the other mates stand six-and-six watches until the cargo officer has had a chance to get some sleep. Port-relief crewmen can rarely be found who are competent to assume the duties of the cargo officer because too much specific knowledge of the particular ship and cargo is required. At best the relief crew could stand watches for the other mates so that they would be better rested for taking six-and-six watches.

One other cargo problem can easily generate high crew workloads resulting in the need for one or two additional crew members or riding technicians. The rapid growth in shipments of refrigerated cargos is resulting in situations in which containerships may be carrying more than two hundred reefers. (Additional generators and electrical distribution facilities are being added to containerships to accommodate this growth.) Checking hundreds of refrigeration systems and making necessary repairs is rapidly turning into a full-time job for one or two additional crew members on many ships. Further increases in the requirement for this type of labor may ensue, especially if barriers to trade in foodstuffs are lowered.

7.3 Personnel Characteristics

Among the several vessels visited, there were striking differences observed in the amount of time which was required to be spent by the senior officers supervising and teaching lower ratings how specific tasks were done on the ship in question. In ships with relatively little crew continuity, the supervising and teaching activities became a significant part of the duties of the senior officers.

The kinds of specific information that had to be imparted ranged from where certain spare parts were stored to how a report should be formatted to who was authorized to approve some action to what software package was to be used to accomplish some task (and why not some other software package). On some vessels, the senior officers find that the need for this informal training made it necessary for them to be available for 14 or 16 hours a day so that their subordinates will be able to get immediate answers to whatever questions arise. Although this is certainly not hard physical work, it clearly extends the work day and can interfere with sleep.

On vessels with high crew continuity, the amount of time devoted to supervision and instruction was much smaller. Senior officers were rarely interrupted by subordinates because the later usually knew every detail of how to carry out their assigned tasks.

Achievement of the ideal state in which every crew member knows every detail of every task to be performed and can be trusted to do them with little or no supervision can be pursued through several approaches, generally in combination. These include careful selection of personnel and elimination of those who fail to perform well, proper training (academic, continuing education and on-the-job), and standardization of tasks and functions across the fleet. Continuity of employment aboard a particular vessel is probably the most significant contributor toward the development of detailed knowledge of procedures. These variables are discussed individually in the following section.

7.3.1 Personnel Turnover

Marked differences in the continuity of employment of crews were apparent on the various vessels visited. At one extreme was the foreign containership whose crew members had served for an average of eight years aboard that vessel. The non-union U.S. tanker operator managed to achieve an average of a few years of employment continuity under its system involving A and B crews for each of its vessels.

Among the U.S.-flag union operators, only the master and chief engineer were always permanent, although steps to make chief mates and first assistant engineers permanent were apparently in progress and second mates are now permanent on at least one U.S. line. The operator with an independent union was somewhat better off in that its non-permanent personnel mostly rotated among different ships within the company. Though the ships were not identical, there were many important similarities.

By far the worst case was that of the operator with a new, high-technology ship drawing most of its crew members from union-hall rotaries. This frequently resulted in situations in which the ship was being conned by a mate who had no previous experience on the vessel or indeed any vessel with similar technology. Whenever such personnel were on duty, their workloads were effectively much higher than that of experienced crew members because they had to spend so much time asking questions. This behavior also increased the workload of other crew members who answered the questions. Several crew members reported having been wakened to answer questions or give instruction to inexperienced individuals.

7.3.2 Training

Fatigue levels tended to be lower where officers and crew were fully knowledgeable of all details of how to carry out their tasks. Such knowledge not only enabled them to complete their jobs faster, but also eliminated their having to ask other crew members for information. Ultimately it makes little difference whether this knowledge is acquired through on-the-job experience or formal training. However proper training before undertaking a tour of duty can certainly reduce fatigue as compared with the situation in which the mariner is trained on the job.

7.3.3 Substance-Abuse Problems

Although substance-abuse problems were not evident aboard any of the vessels visited, many of the interviewees recalled individuals with drinking problems on other ships. These persons were regarded as "deadwood," who could not be relied upon to do a normal amount of work and thus increased the workload on other members of the crew. One master with 25 years experience remarked that, prior to his present employment, he had expected to find two or three members on the crew of an average ship who did very little useful work because of substance-abuse and related personality problems.

Everyone interviewed was emphatic in declaring that persons with substance-abuse problems could not be tolerated on a vessel with minimum crew size. Some sailors criticized management for reluctance to fire such individuals. Managers retorted that when they attempted to investigate such complaints, they were often frustrated by a pervasive "you don't turn in your shipmate" attitude.

7.3.4 Morale

Morale was raised as an issue by most of the interviewees. Ships with good morale seemed to have lower fatigue they said. Several mechanisms were suggested including: (1) elimination of stress from interpersonal conflict, (2) better organization of work, (3) better motivation leading to jobs being completed in less time, and (4) perception of fatigue influenced by one's morale, i.e., happier crews feel less tired than unhappy ones even when the amount of work and hours of rest are the same. There was no agreement as to which mechanisms were more important, nor, for that matter, how best to improve morale.

7.4 Voyage Variables

For the same crew on the same ship operated by the same company, there can be enormous differences in fatigue levels depending on scheduling, where she is bound, and the weather and sea conditions at the time. The differences between companies may be even greater. For example the U.S. Coast Guard's *Report of the Tanker Safety Study Group* (1989) discusses the intense pressure to minimze at-sea and port time under which the masters of some tankers must operate. In particular, the authors cite the tight scheduling as a prime cause for the failure of the ships officers' to get enough rest.

7.4.1 Weather and Sea Conditions of the Trade Route

The most severe instances of fatigue and prolonged sleep disruption were reported by the interviewees in the Alaskan oil trade. Most of their winter voyages were rough. Occasionally, they were subjected to wave heights of more than forty feet for several days at a stretch. Few persons sleep well under such conditions and many are unable to eat normally. Anti-seasickness medications may induce further drowsiness. In such operations not only is sleep disrupted but any activity, physical or mental becomes much more difficult. Loss of energy may also be experienced due to reduced food intake resulting from loss of appetite.

In contrast to the Alaska trade, most other vessels are able to sail clear of storms. The crews of the containerships said they had not sailed through severe storms in years. They credited the improvements in weather forecasting technology with a significant reduction in stress and fatigue.

7.4.2 Traffic Density

Among the most stressful situations commonly faced by mariners is maneuvering a large vessel in a restricted channel when substantial numbers of other vessels are present in the same area. Operators of pleasure craft and small fishing vessels, who seem to lack any conception of the danger in which they place themselves, were cited as the principal source of this stress.

Trying to keep track of the courses of a large number of other vessels and estimate which ones are subject to possible collision can be extremely taxing. Fortunately, in recent years, radar systems have been developed with the capability to track and display the courses of large numbers of targets automatically. These units also generate warnings regarding possible collisions. The deck officers interviewed were unanimous in their praise of these new radars, and said that these units had done more to mitigate stress on watch than anything else. Some radars were described as substantially better than others, particularly in regards to their ability to discriminate between real targets and sea-scatter artifacts. That is to say, the better radar units made the officer's job significantly less stressful and tiring than the lesser units.

7.4.3 Number and Spacing of Port Calls

Getting the ship in and out of port is universally agreed to be much more tiring than open-water sailing regardless of vessel type or size. Everyone expects to get less-than-normal sleep on arrival and departure days. They also count on making up that sleep loss as soon as they get to open water.

In trans-oceanic container trade, however, economics dictate making several port calls at either side, while sailing time between most of the major port cities is a day or less. Masters and chief cargo officers are therefore prone to loss of sleep due to extended work hours and disruption of sleep patterns. This can result in the development of significant sleep deficits during periods of frequent port calls. Again, this situation is viewed as inherent in some types of trade.

7.5 Port-Business Factors

Upon arrival in home port, it is common for dozens of visitors to board a ship. These can include wives and other family members, girlfriends, marine-equipment salesmen, technicians, marine inspectors, clergymen, public-health officials, customs officials, pollution-control officials, brokers, stevedores, delivery men, vendors of personal goods, and representatives of almost every department in the operating company. Even in ports other than home, quite substantial numbers of visitors may appear. Each of these visitors can often take up an hour or more of the time of one or more of the crew. Thus a mariner, especially a senior officer, is often unable to rest or sleep in port even though he/she may be theoretically at leisure.

On two of the containerships visited, the officers are expected to assist the sales force and brokers by hosting ship tours, lunches and cocktail parties for customers and prospective customers.

The result of all of these visits is that the crew may get no sleep at all during the day, despite having brought the ship into port in the early morning hours one day and having to take it out the following night. The longer stays in home port, usually two or three days, ease the problem considerably.

Complaints about the sleep loss caused by visitors were not very strong. The crewmen enjoyed some of the visits and certainly did not wish to give those up. The rest (inspectors, government officials, etc.) were viewed as an unavoidable nuisance. The only suggestions for change were that the shipping company coordinate these visits in order to keep unusually large numbers of them from occurring at one time. The deckhouse designs of the newest vessels have taken the visitor problem into consideration explicitly by separating ship offices from sleeping quarters and providing additional meeting rooms.

7.5.1 Government Regulations and Inspections

Almost every officer interviewed had anecdotes about unproductive work required to comply with the regulations and inspections of various governments. A large number of these revolved around the themes of inappropriate attention to details and failure to apply elementary common sense.

Among the most frequently cited examples was the failure of various governments to standardize requirements so that the same report or inspection preparation could be used everywhere. Many of the purported problems that brought various inspectors on board during the authors' visits (pollution-control, customs, public-health, etc.) were trivial questions, or misunderstandings on the part of the inspectors, that could have been resolved with a phone call or radio call. It appeared that the excellent hospitality offered to visitors on these vessels may have been counter-productive from the point of view of fatigue mitigation.

Overall, this government business in port was not considered a major contributor to fatigue, but very definitely a source of frequent nap interruptions.

7.5.2 Maintenance, Stores and Company Business

The workload imposed on the ship's crew by in-port maintenance work and provisioning varied greatly between ports and companies. From the point of view of fatigue mitigation, having shore-based personnel perform as much of these jobs as possible would be desirable. In fact, a substantial amount of such labor was so performed. However, in some ports, especially smaller ones, the full array of needed services was either not available or sufficiently expensive that management declined to purchase them. In these situations, members of the regular crew turned out to load provisions, maintenance stores, etc. Giving the delivery men a hand was not a major burden, just another nap-interrupter.

For the engineers, working with the shore-based maintenance technicians often meant very long, hard days. Because jobs like main-engine maintenance had to be finished by scheduled sailing time, the engineers had to sacrifice sleep whenever necessary to make sure that objective was achieved. Some companies provided a substantial number of port-relief crew to help, but these workers invariably had questions that only the regular crew could answer.

7.6 Summary Of Effects Of Fatigue Factors

The interviews and observations made in this study reveal that there is no simple formula for determining the impact of crew size on fatigue. However there are circumstances and factors which exacerbate or mitigate fatigue.

Where a particular shipping operation combines a preponderance of mitigating factors, reduced manning is less likely to result in increased fatigue; where the operation includes a preponderance of exacerbating factors, the possibility that reduced manning will result in increased fatigue becomes stronger. It must be recognized that even a single exacerbating factor, if it is present to a strong degree, can offset a large number of mitigating factors.

To summarize the results of approximately three dozen interviews conducted and the observations made during the voyages and port visits, the following table lists those factors which contribute to increasing fatigue and psychological stress and those which help reduce them.

TABLE 7.1. Clustered Fatigue Factors

Factors Contributing to Increased Fatigue and Stress	Factors Tending to Reduce Fatigue and Stress
Organizational Factors	
inflexible work-rules creating imbalanced workloads; work-rules requiring unnecessary time on duty	flexible work-rules allowing workloads to be shared equitably; elimination of unnecessary duty hours
lack of port-relief crews and/or incompetent relief	provision of relief crews and/or contractor personnel in port sufficient to allow permanent crew adequate rest
lack of standardization of procedures and tasks requiring retraining during voyage	common procedures, formats, equipment, software, etc. across the fleet
burdensome and unnecessary paperwork	low level of paperwork (few unnecessary items and productive use of automation to accomplish the remainder)
officers with poor "people management" skills; tolerance for unfit personnel; encouragement of interpersonal conflict	officers trained to manage effectively, resulting in socially cohesive crew
tolerance of substance-abuse problems	effective crew selection process and substance-abuse programs resulting in few substance abuse problems
poor morale	socially cohesive crew with strong self-motivation
high personnel turnover; crew does not stay with ship, must be "trained at sea" in procedures used on particular ship	voyage-to-voyage continuity, i.e., crews relatively permanent, know ship procedures
insufficient training to perform all required tasks	personnel selected and trained to be competent in every aspect of their jobs
large numbers of inspectors and other visitors on board in port	relatively few visitors allowing more time to sleep in port
inadequate inspection and maintenance programs increasing the likelihood of equipment failure	established inspection and scheduled maintenance programs sufficient to achieve a low rate of in-service failures

TABLE 7.1. Clustered Fatigue Factors (cont.)

Factors Contributing to Increased Fatigue and Stress	Factors Tending to Reduce Fatigue and Stress
Voyage Scheduling Factors	
long tours of duty of unpredictable duration	tours of duty of known length and of less than 75 days duration
short port-to-port durations (less than 24 hours)	sufficient time between port stops to make up sleep deficit
unpredictable sailing schedule	reliable sailing schedule
extremely long periods of duty for personnel involved with cargo operations	adequate relief for cargo personnel
sailing in congested and restricted waters	open-water sailing
Ship Design	
lack of automation and labor-saving devices; failure of such devices and systems to perform effectively	well-designed, smoothly functioning devices to eliminate as much labor as possible, both mental and physical
lack of ship-system reliability and/or redundancy; frequent false alarms	all critical systems highly reliable and/or backed by redundant components
ship design which results in excessive rolling, pitching, vibration or noise	absence of rolling, pitching, vibration or noise sufficient to interfere with sleep
overheated or overcooled deckhouse and engine room	air-conditioning system well maintained
Physical Environment	
frequent deck work under extreme weather conditions	majority of work performed in protected environment
foul weather routinely encountered particularly when ship is in ballast	weather routing and other measures to avoid storms

8. Conclusions

This study has not revealed any simple method, procedure, or technique for measuring or predicting the extent to which crew fatigue will increase, if at all, as ship manning levels decrease. This is only in part due to a lack of agreement on accurate and unequivocal measures of fatigue. A more important reason is that different shipping operations place widely differing demands on crew members, thereby generating very different levels of fatigue.

While parametric predictors of the relationship between crew size and fatigue were not found, clusters of factors which were likely to impact fatigue due to their effects on workload, sleep, circadian rhythm, and stress were identified. These clusters of factors should be useful in the evaluation of the relative likelihood that proposed crew reductions will or will not engender fatigue in particular shipping operations.

The study also indicated that brief and well constructed self-report workload and sleep forms hold promise for determining the level of workload, fatigue, and stress actually experienced by crew members.

In summary, while two of the clusters of factors identified (voyage-scheduling and physical-environment) are inherent in the requirements of particular types of trade, the other two clusters (organizational and ship-design) are not. These provide opportunities, under some circumstances, for the design of advanced merchant ships which can be operated safely and efficiently by well-rested crews which are smaller than are common today.

9. Recommendations

This study has identified clusters of factors which are likely to impact the development of fatigue in ships operating with smaller crews. The relevance and validity of these factors must be evaluated to develop better methods for determining under what conditions crew-size reductions will impact fatigue.

It is recommended that case studies be conducted of ships now operating with crews which are greatly reduced as compared to current American-flag practice. These case studies should provide information and data which will be very valuable to agencies, such as, the U.S. Coast Guard, which are charged with passing on proposed crew reductions. Compliance with the Oil Pollution Act of 1990 is likely to stimulate a variety of responses from various operators. Studies of alternative approaches to meeting the limits on working hours imposed by this law and evaluations of those which are most successful are also suggested.

Self-report techniques have been used successfully to detect, gauge, and evaluate the presence of excess workload, fatigue, and stress in military personnel. The results of this study indicate that self-report fatigue/stress/workload instruments could be adapted, developed, and refined for use in merchant-marine operations.

Finally, while no objective, performance-based, fatigue measure suitable for shipboard use was identified in the research review conducted for this study, the use of one or more techniques currently in development or testing might yield valuable results. Further evaluation is recommended.

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Appendix A. Drug Effects

A.1 Opiates

Opiates (i.e. Codeine, Heroin, and Methadone) are among the drugs having the highest potential for abuse. The general effects of the opiates are to dull the perception of external and internal stimuli (particularly pain) and to induce a feeling of pleasant lethargy.

Heroin originally was developed as a "safe" (non-addictive) substitute for opium, which represented a major addiction problem in the nineteenth century. Similarly, methadone has been promoted as a substitute for heroin that has a lower abuse potential.

Codeine finds therapeutic use as an analgesic in prescription cough medicines and pain relievers. Perhaps because of its relatively greater legal availability (as compared to other opiates), it is believed to be frequently abused. The use of these drugs by operating personnel will reduce their attentiveness to critical signals. Codeine's most frequent side effects are light-headedness, dizziness, sleepiness, and nausea. Other possible affects are euphoria, headache, agitation, incoordination, faintness, hallucination, disorientation, and visual disturbances (Silverman and Simon, 1978).

The opiates are related to a new group of drugs sometimes referred to as "designer" drugs. The term designer drug derives from the concept that slight changes to the molecular structure of such drugs can result in new and different psychological effects. Because such drugs have new formulae, they cannot be classified as illicit, until their abuse potential has been demonstrated.

A.2 Central Nervous System (CNS) Depressants

As a class, the CNS depressants tend to depress the function of the central nervous system, reducing the ability of the user to concentrate or focus attention, reducing sensitivity to stimuli, and slowing the processing of information. While all of the CNS depressants tend to make the user drowsy, it is the main therapeutic function of those drugs in the sedative hypnotics subgroup (i.e., Chloral hydrate, Meprobamate, Methaqualone (Quaalude), Pentobarbital, Phenobarbital, and Secobarbital) to induce sleep, and use of these agents is likely to result in relatively profound reductions in alertness including: drowsiness, lethargy, dizziness, hangover, and the slowing down of physical and mental reflexes (Silverman and Simon, 1978).

Antihistamines (i.e., Chlorpheniramine), as a class, are widely used in non-prescription over-the-counter medications to reduce allergic symptoms, particularly those associated with hay fever and colds. The use of antihistamines characteristically results in drowsiness.

Drowsiness is also a side effect of tranquilizers (i.e.,Chlorpromazine Chlordiazepoxide (Librium), Diazepam (Valium, and Flurazepam), but the major desired effect of these agents is reduced response to anxiety-producing situations. The reduction in response to threatening situations undoubtedly is of value in reducing stress-related symptoms, but may be highly undesirable when the user must deal with an emergency. The drugs in this subgroup are among the most widely prescribed drugs. The use of these drugs may produce unwanted effects, such as hangovers. One of the tranquilizers listed, chlorpromazine, is far more powerful than the others. It finds use in the treatment of severely disturbed institutionalized patients.

A.3 Central Nervous System (CNS) Stimulants

The CNS stimulants as a class, tend to increase mental activity, responsiveness to external stimuli, and in some cases restore concentration to fatigued individuals.

The first subgroup of CNS stimulants, the Amphetamines (i.e.Amphetamine, Dextroamphetamine, and Methamphetamine), are prescribed for the treatment of narcolepsy, depression, hyperactivity in children, and as antidote for certain CNS depressant poisons.

Amphetamines have been used to extend and improve the performance of fatigued individuals. They have been used under controlled conditions by pilots returning from extended night missions and it is believed they frequently find illicit use in uncontrolled circumstances such as truck driving.

The following material is abstracted from Wiener's (1985) overview of the pharmacological effects of amphetamines. The most striking impact of amphetamines is in the reversal of the effects of fatigue on performance. While use of this class of drugs is not likely to improve the performance of rested, motivated individuals, it can aid individuals who are fatigued and/or suffering from lack of sleep. However Wiener notes that "beneficial effects of the drug have to be repaid in the coin of fatigue". After heavy use, sleep patterns may take up to two months to return to normal. Another property of the amphetamines, which may be related to illicit use, is their ability to increase the threshold at which individuals react to pain, particularly when used in combination with drugs such as morphine.

Although a number of laboratory studies have revealed potentially beneficial short-term effects, the use of these drugs in uncontrolled, real-world situations is likely to have serious negative side effects. Under uncontrolled conditions, the operators of motor vehicles, vessels, and heavy equipment may rely on such drugs to sustain alertness and concentration for periods that go beyond the period of effectiveness of the drugs. As the effects of fatigue and lack of sleep increase, the operator may increase the dosage resulting in the build-up and finally predominance of the negative side effects of the drug. These include blurred vision, dizziness, loss of coordination, paranoia, and irregular heartbeat followed ultimately by physical collapse.

Of the drugs covered here, cocaine probably represents the most serious current public health hazard. Cocaine combines the euphoric effects of the opiates and the sensory disruption of hallucinogens with an increase in mental activity similar to that provided by amphetamines in fatigued individuals. Although laboratory studies of cocaine use may not reveal conclusive evidence of physiological or physical dependence in the form of severe withdrawal symptoms, it has a high abuse potential. This is because it provides an immediate and strong positive reinforcement. The cessation of this positive reinforcement is believed to result in psychological dependence. This is particularly true when "crack," a purified form of the drug, is used.

Blume (1985) indicates the distinctions between psychological and physiological aspects of drug dependence is to some extent artificial. Most investigators would concede that psychological dependence certainly is a consequence of repeated cocaine use."

A.4 Anti-Depressants

Tricyclic antidepressants (i.e., Imipramine and Amitriptyline) are prescribed therapeutically to combat mental depression, and their effect is to impede the user's ability to form thoughts.

Treatment with these drugs over a period of weeks can yield a reduction in depression. When administered to normal individuals, they cause a feeling of unpleasant dullness, lightheadedness, and/or sleepiness. In general they interfere with thought processes and have a number of unpleasant physical side effects such as a drying of the mouth.

This method of depression reduction is in contrast to the action of drugs that appear to elevate the user's mood such as 3,4-Methylenedioxyamphetamine (MDA). MDA, sometimes referred to as "Ecstasy," is classed as an LSD-like drug with other properties. In the case of MDA, it is LSD-like in that it produces vivid and organized hallucinations, but its other properties include a marked euphoria or feeling of well being.

A.5 Hallucinogens

Although they differ widely in their specific effects, the hallucinogenic drugs (i.e., Marijuana, Phencyclidine (PCP), and Mescaline) have common features that are detrimental to safety. Rather than reducing or increasing the user's responsiveness to external or internal physical stimuli, they tend to distort the perception of internal and external stimuli. More significantly, they permit the user to disassociate himself or herself from external events, particularly the consequences of actions taken by the user.

Marijuana, which is believed to be the most widely used illicit drug, is relatively mild (as compared to other hallucinogens) in its effects. It combines the distortion of sensory information with a mild euphoric state.

Small doses of marijuana produce euphoria, relaxation, a shortened attention span, and distortion of the sense of time and space. Larger doses impair motor response, motion coordination, and logical thinking, as well as producing illusions, hallucinations, and transient psychotic reactions (Benjamin, 1972).

The effect of PCP is to allow the user to achieve a profound disassociation from external reality. Under the influence of this drug, individuals are often totally incapable of perceiving even the most direct consequences of their actions, making them extremely dangerous to themselves as well as others. Mescaline severely distorts the cognitive processes and induces powerful, relatively long-lasting and vivid hallucinations.

A.6 Other Drugs

The anti-hypertensive drugs (i.e., Dyazide and Propranolol) are of major therapeutic importance in controlling high blood pressure. While they have the relatively mild side effect of depression and drowsiness), their widespread use by older individuals increases the chance that their use may result in decrements in safety-critical performance.

Appendix B. Physiological Tests for Fatigue

B.1 Brain Electrical Activity

In laboratory studies, certain component frequencies of the electroencephalogram (EEG) have been found to be useful markers of a subject's transition from an alert to a sleeping stage (Erwin, Volow, and Gray, 1973). Typically, increased appearance of alpha frequencies (8-13 Hz) is considered to be a signal of inattention, relaxation, and transition to a drowsy state. Theta (5-7 Hz) and delta (0.5-4 Hz) activity are found to replace alpha activity as the subject continues to relax and fall asleep.

The results of relevant past research have commonly shown increased appearance of EEG components indicative of reduced arousal and correlated changes in subject performance after prolonged periods in a low demand task (Mackie and Miller, 1978), (Storm, 1984), (Erwin, *et al.*, 1973). Alpha activity has been observed often in the records obtained during periods of extended driving, and rarely, delta activity has been observed (O'Hanlon and Kelley, 1977). Sussman *et al.* *(op.cit.)*, in a study of simulated long term driving, found that the failure to make lane position corrections was directly correlated with the occurrence of bursts of alpha waves. More recently, Lemke (1982) found similar changes in EEG indicative of reduced arousal and correlated changes in the coarseness of driver-control performance during long periods of driving in a simulator.

Some measures of brain electrical activity obtained through EEG analysis appear to be good indicators of drowsiness when they are present. The appearance of theta and delta activity, for example, is usually taken as a sign of a transition to, or actual sleep, and indicates a driver state incompatible with adequate attention performance (O'Hanlon and Kelley, 1974).

In recent years, investigators have had some success in relating Evoked Cortical-response Potentials (ECP), particularly the P-300 attribute, as a measure of mental workload and attention. In his review of physiological measures of mental workload, Wierwille (1979) recalls that ECPs tend to change as attention is directed to a stimulus source. He also notes that they change with operator attitude and understanding of instructions.

In addition, as Israel, Wickens, Chesney, Gregory, and Donchin, (1980) point out, the magnitude and latencies of the components of the ECP vary with the physical and informational properties of the stimulus event as well as the subject's expectancy and cognitive response to the stimulus. The research of Wickens (1980) and Wickens, Kramer, Heffley, and Donahin (1980), as well as that of Israel *et al.* (1980) and others, suggest the ECP is definitely, but complexly, related to the attentional state of an operator. However, considerable research will be required to clarify the relationship of ECP components to attentional state.

B.2 Heart Rate and Heart Rate-Variability

Heart rate has often been found to decrease, and heart rate variability to increase, during extended periods of low workload under uneventful conditions. These two measures are indicative of long-term trends of driver physiological arousal (Mackie and Miller, 1978, Harris and Mackie, 1972; Mackie *et al.*, 1974; Riemersma *et al.*, 1977).

Laurel and Lisper (1976) found that driver heart rate decreased during two-hour highway driving periods on each of three days. The change was greatest during the first, and least during the third periods of driving. Watanabe *et al.* (1982) also observed decreased heart-rate levels in operators of high speed electric trains during the second and later hours of a 260-minute high speed, monotonous driving period. Kazuyoshi *et al.* (1976), however, found no changes in driver heart rate during seven to ten hours of on-road driving. In a recent study using a driving simulator, Wierwille and Muto (1981) observed increased driver-heart-rate variability with driver time up to 150 minutes. Conversely, Sekiguchi *et al.* (1979) have observed that heart rate variability tends to decrease with increased workload and presumably with increased attention.

Investigators have used many different measures of heart activity, and the conclusions drawn from a study may depend on the measures used. This problem was illustrated recently by Egelund (1982), who re-analyzed data obtained by earlier researchers. These reserachers had obtained heart-activity measures on eight relatively inexperienced drivers during four-hour, 350 kilometer trips. All subjects reported high levels of fatigue, although none accepted rest stops for fear of appearing weak. No significant changes in heart rate or standard deviation of heart rate were observed, however. Egelund performed a detailed spectral analysis of their heart-activity data and found a small, but statistically significant change in the 0.1 Hz component of the heart-rate variability. In general, it was low at the beginning of the trip, increased during the trip, and then decreased toward the last part of the drive.

Heart rate and heart-rate variability are often, although not consistently, observed to be correlated with time on task. In part, inconsistencies in the results of different studies reflect the complexity of the factors affecting heart activity. Opmeer (1973) and Erikson (1975) have noted the large number of measures of variability and the lack of high correlation between them. Recent investigators have focussed their attention mostly on heart-rate variability and the attempt to find a reliable measure. As Hyndman and Gregory (1975) observe, the 0.1 Hz activity has been found to have the highest correlation with measures of workload, and light physical activity, *per se*, does not affect it. Considering this finding and the results of the analysis by Egelund mentioned above, it is possible that this measure may have some potential as a secondary indicator of inattention.

Great care must be used in the interpretation of changes in heart rate because there is evidence that such changes are learned, and therefore idiosyncratic responses to stimuli such as stress and fatigue. may occur. Changes in heart rate in response fatigue might be consistent within individuals but inconsistent between them.

B.3 Core-Body Temperature

One of the most reliable indicators of an individual's position with respect to his or her circadian cycle is core-body temperature. (Moses, J., Lubin, A., Naitoh, P.L., and Johnson, L.C.) Rectal temperature is often a better indicator of sleepiness (as measured by sleep latency tests) than is self report. Normally troughs in core temperature correspond to the two periods of maximum sleepiness (1530 to 1700 and 0400 to 0600). Measurements of core-body temperature has been used to great advantage in studies of airline-pilot crew fatigue, circadian disruption, and sleep loss, such as that of Gander, Mhyre, Graeber, Anderson, and Lauber (1985) and Graeber *et al.* (1987).

B.4 Other Physiological Indicators

Several other measures of physiological activity have been used by investigators of fatigue, inattention, or increased attentional demand. These measures include, for example, muscle and skin electrical activity, catecholamine (hormone) secretions, respiratory patterns, critical flicker frequency (a measure of the ability of the brain to discriminate flickering images), pupil size, eye blinks, and gross body movement. In the past, investigators have found these measures to be inconsistently correlated with fatigue or length of time of driving.

In a study of locomotive engineers, Kazuyoshi (1976) found that during trips of seven to ten hours, operator critical flicker frequency, number of galvanic skin responses, and inspiratory number and volume decreased with time into task. Watanabe (1982), also observing locomotive engineers, noted that critical flicker frequency was depressed and gross bodily movement increased after 200 minutes of driving. Wierwille and Muto (1981) also reported increased gross bodily movement of subjects after extended periods of driving a simulator.

Electrodermal response and skin resistance have been found to be quite ambiguous as indicators of attentional state. Erwin *et al.* (1973), in a study of the electro-physiological correlates of drowsiness, found that skin resistance decreased and skin potential became less negative with time into task. Skin potential changes were not consistently correlated with changes in EEG components, however. Helander (1978) has suggested that increased electrodermal voltage is a relatively slow response to changes in mental demands in a driving situation. His data suggest the possibility of the use of changes as an indicator of changes in attentional demand, but not as an indicator of inattention.

Mackie *et al.* (1978) found higher adrenaline-excretion rates, indicating physiological stress, associated with relay truck drivers on late-night and early-morning trips and higher adrenaline and noradrenalin output for regular schedule truck drivers after five days of operations. Evaluating these catecholamine data, however, is difficult due to a basic inability to accurately define the underlying conditions which affect the secretions. There is a large affective component resulting from the effects of circadian dysrhythmia, and a further confounding effect attributable to a moderate to heavy workload required of the test drivers.

Other research that has included studies of changes in subjects' pupil size has been mostly focussed on the problem of measuring relative workload. Wierwille (1979) reviewed a number of studies that confirm a general conclusion that subjects' pupils dilate with increases in mental workload and tend to constrict under conditions of overload. Pupil constriction, thus, may indicate inattention related to excessive attention demand.

In past research, blink rate has been typically found to increase with increased driver fatigue. Watanabe (1982) reported that blink rates of train drivers increased during long-duration, monotonous trips. Wierwille (1979) noted that blink rate tends to decrease with increased mental workload, and Rockwell *et al.* (1973) have reported differences in blink rate related to driving task. Rockwell found, for example, that the blink rate for drivers on a freeway approach ramp was somewhat higher than that for drivers on the freeway approaching the ramp.

These indicators of operator physiological state have not been found consistently correlated with subjective fatigue, length of time of activity, or other indicators of attentional state. They are strongly affected by many personal and situational variables, and evidence for correlation with operator attention is so weak that they appear to have little potential for use as detectors of inattention.

Appendix C. Behavioral Tests for Fatigue

C.1 Looking Behavior

Looking behavior is possibly one of the most direct indicators of attentional performance, although fixation does not necessarily indicate attention and the lack of fixation does not necessarily indicate lack of attention. Mourant and Rockwell (1971), for example, have emphasized operators' use of peripheral vision to obtain guidance information.

In past investigations, it has been found that eye movements change under conditions resulting in reduced driver arousal, such as the development of driver fatigue due to sleep debt, demanding visual performance, and alcohol intoxication. With fatigue, the number of pursuit movements has been found to increase, but the lateral velocity of eye movements decreases. Fatigue has also been found to result in narrowing and changing of the field of visual search. Similar changes in the field of search have been found with alcohol-intoxicated drivers, who also showed a tendency to fixate on passing cars less frequently than sober drivers.

Research has also shown changes in the focus of driver attention and apparent selective narrowing of the attentional field as the result of task demands, as well as of alcohol intoxication. As noted in the review by Zaidel (1978), Mourant and Rockwell (1970) found that in straight-ahead driving, drivers tend to concentrate their fixations near the focus of expansion (the farthest visible point on the roadway as projected from the movement of the vehicle). In comparison, Shinar *et al.* (1977) found that drivers negotiating curves concentrated their fixations intermittently on the position of the road ahead and on the road edge or lane markers. Curve scanning was begun two to three seconds prior to entering the curve. Fixation durations were similar during approach and curve negotiation, but durations tended to be longer for dangerous curves. Williams (1982) found that reaction time to peripherally presented stimuli increased when the cognitive difficulty of a foveally presented visual task was increased. Moskowitz *et al.* (1976) also found that alcohol intoxication resulted in increased driver reaction time to visual stimuli requiring decisions.

Ziedman *et al.* (1980) noted a shift in attention from roadway-position control to speed control, and both Ziedman and Moskowitz (1976) indicated that the distribution of horizontal dwells (visual fixations in the horizontal plane) did not change with increased driver blood-alcohol concentration (BAC). They also reported that marijuana had no effect on any measure of looking behavior. In his discussion, Moskowitz noted that data obtained in previous on-road studies were inconsistent. Shinar (1978) review cites Belt's 1969 work, which found drivers' horizontal fields to be constricted with increased driver BAC. In contrast, Mortimer and Jorgeson (1972) did not find a visual field constriction. Both Belt and Mortimer reported that visual-fixation duration increased with BAC, although Belt found this to occur only in open-road driving and not in car-following situations.

A similar restructuring of the attentional field was shown in a study of pilot workload by Tole *et al.* (1982). Both experienced and inexperienced pilots decreased the number of looks at secondary instruments and increased dwell times on primary instruments as mental workload was increased. The shift in the pattern of looking was most pronounced for inexperienced pilots. Wierwille (1978) also noted that large eye movements decreased as pilot workload increased.

Ziedman *et al.* (1980) and Moskowitz *et al.* (1976) also analyzed in detail the eye movement patterns of drivers under the influence of alcohol or marijuana while driving a simulator. They found that with increased driver BAC, mean dwell time and variability increased, dwell frequency decreased, and pursuit frequency increased. Pursuit dwell time was variable and saccade (small involuntary eye movements) durations increased. These results are consistent with those obtained under conditions designed to induce driver fatigue. Considering the several studies together, it is apparent that the general pattern of sluggish eye movements is always found with drivers influenced by conditions designed to result in low arousal, but some differences in details may reflect an interaction of subject and specific situational factors.

The strong interaction of attentional effort and eye movements is seen in the results obtained by Gopher (1973) in a laboratory experiment. In this study, subjects listening to an auditory message showed reduced spontaneous eye movements, and selective monitoring of messages in one ear resulted in a pattern of large saccades with long fixations in the direction of the critical ear.

Eye movements are perhaps the most direct indicators of attentional performance. Eye movements and fixations are necessary for the acquisition of required information. They can be used as indicators for each of the dimensions of attentional performance, and changes in movement patterns have been found to be correlated with changes in attentional state related to task demands or to changes in physiological states, such as intoxication or the existence of a sleep deficit. The absence of nominally appropriate eye movements, however, does not indicate inattention. Acquiring and processing eye movement data requires relatively elaborate equipment, and their utility as a basis for an inattention detector is limited. However, eye movements seem to have excellent potential for use in research and development efforts.

C.2 Subsidiary-Task Performance

Little use has been made of extraneous secondary or subsidiary task performance as an indicator of inattention. Subsidiary-task performance is an ambiguous indicator, since a failure to respond to the secondary task indicates only a failure to allocate effort to the secondary task and attentional performance may be adequate or inadequate. Similarly, good performance on a subsidiary task implies nothing about driving-related attentional performance. The additional task may, in fact, result in inadequate attentional performance related to driving.

Brown (1965) maintains that negative results in field studies are highly probable where measurement is restricted to the task of driving itself, since the driver is capable of drawing on "reserve capacity" for brief periods, in order to eliminate driving errors. He further asserts that driving may indeed be a "fatiguing" endeavor, but driving behavior itself, is not as sensitive as other measures of fatigue. He compared two subsidiary auditory tasks as measures of fatigue in car drivers: one involving memory spans of three seconds (Attention Task) and the other requiring a memory span of up to 55 seconds (Memory Task). His results indicated that memory tasks interfere more with driving performance (the primary task) than do the attention tasks, but performance of either of the subsidiary tasks did not interfere with driving performance to any meaningful degree. However, Brown points out that the "arousing" effect of the subsidiary task may have influenced driving behavior and that under the more usual "de-arousing" conditions such as on a freeway, with no subsidiary task, driving behavior might be expected to be worse.

In another study Brown *et al.* (1967) used the subsidiary-task method of measuring driver fatigue. He found no performance decrement in either driving or task performance over 12 hours of almost continuous driving. Again, however, as Brown admits, these results may be highly influenced by the arousing effect of the subsidiary task and does not reflect more common driving experiences.

Laurell and Lisper (1976) measured driver reaction time to auditory stimuli during extended periods of on-road driving. They found driver reaction time increased during the period, but no changes were found in the reaction times of passengers or subjects seated in a stationary vehicle for the same period of time. Since the same task time was used for all subjects, the authors suggest that the increased driver reaction times were due to perceptual-motor requirements of driving rather than changes in attention with time. Related to this interpretation are the results of a study by Nobel and Sanders (1970). They found that searching for critical signs imbedded in groups of signs interfered with performance on a tracking task, and tracking errors increased with search difficulty. Similarly, McDonald and Ellis (1975) and McDonald and Hoffman (1977) found the demand of a secondary task resulted in an increase in steering-wheel-reversal rate of on-road drivers.

A possibly more useful approach to the application of the concept of subsidiary-task performance is to consider measures on different component tasks in driving rather than including extraneous tasks. For example, Moskowitz *et al.* (1976), Ziedman *et al.* (1980) and Buikhuisen and Jongman (1972) found that subjects driving simulators while under the influence of alcohol shifted their attention from the roadway to speed control. Reaction time to detection of information signs was inconsistent, but greater time was required to respond to the information, and subjects observed fewer critical incidents. Regina *et al.* (1974) observed that drivers given caffeine (presumably increasing arousal level) were faster in responding to high-beam signals and missed fewer signals than control subjects in an extended duration simulation driving task. Putz (1979), investigating reaction times to peripherally presented visual stimuli when subjects were exposed to carbon monoxide gas, found that the reaction times increased after two hours of exposure, and the increase was faster and greater with higher levels of the gas.

As indicators of inattention, driving-related signal errors and increased reaction time to these signals, for example, are reasonably direct. However, they are not unambiguous and their usefulness as a basis for an inattention detector is limited by the requirement for independent indication of the critical signal. Technically, there are no obstacles to the development of the required signal system. One concept of a system for use in railroad locomotives, for example, requires the engineer to respond correctly to a signal inside the cab when it is triggered by a signal transmitted from a source, such as a critical speed signal.

C.3 Control Movements

The results of past research indicate that during long periods of driving, a driver's steering movements become coarse, i.e., the number of large steering movements increases and the number of small movements decreases. It can be hypothesized that as attention decreases the operator makes less frequent course corrections (steering-wheel movements) and those corrections which are made must be of greater amplitude (coarser) to maintain position.

In recent investigations, this change in driver control behavior has been followed by investigators using a variety of specific steering control measures in both simulator and on-road studies. In addition, recent studies have shown that short-term changes in driver's attention state may be reflected in changes in steering movements, for example, increased steering-wheel reversal rate with imposition of a secondary task.

Reporting in general terms, Lemke (1980) noted that during extended periods of driving in a simulator, driver control activity became more coarse, Allen *et al.* (1978) observed that the number of critical movements decreased for licensed drivers with repeated showing of a six-minute driving scenario. No such changes were observed in the control behavior of subjects who were non-drivers.

Steering-wheel reversal rate has been used in a number of studies. MacDonald *et al.* (1980) present a good review of the results obtained with this measure. As they indicate, steering-wheel-reversal rate has been found to increase with increased traffic density (Greenshields, 1963), encounters with oncoming vehicles (Rockwell and Lindsey, 1968), decreased lane width and decreased preview distance (McLean and Hoffman, 1972, 1973), increased workload (Hecks and Wierwille, 1978), and drug-induced high-arousal states (Safford and Rockwell, 1970). Generally, these studies suggest a correlation of greater steering-wheel-reversal rate with higher workload and high levels of arousal or attention. Completing these results, Mortimer and Sturgis (1979) found the reversal rate was lower for drivers on roads with double center lines. Possibly, this was related to a reduced attentional demand due to the better definition of the center line.

The complexity of the relationship between steering-wheel-reversal rate and the attentional state of the driver is suggested in two studies by MacDonald and Hoffman (1977, 1978). In the first, conducted on a test track, they found the reversal rate increased with task demand due to extremely narrow lanes, but it decreased with task demands imposed by a secondary task. In the second, on-road, test they found the reversal rate increased with imposition of a secondary task, but was lowest on those sections of the road with the greatest number of events. Considered together, the results of these experiments suggest that the drivers changed their attention state (re-allocated available capacity) during the most severe test conditions. Thus, reversal rate appears to be sensitive to changes in attentional state and may have potential for indicating transitory changes in the attentional state.

In other analyses of steering behavior, Wierwille (1981) found that during long-duration driving periods in a simulator, the number of large steering-wheel reversals greater than 72 degrees increased; the number of small reversals from 0.5 to 2.0 degrees decreased; and the mean steering-reversals amplitude increased. The standard deviation of the steering-wheel position also increased. Ziedman *et al.* (1980) found that increased driver BAC also resulted in increased steering error and RMS steering error. In detailed analyses of steering performance, McLean and Hoffman (1971, 1972, 1973) found a high correlation between the steering-wheel-reversal rate and the power in the high-frequency (greater than 0.4 Hz) area of the steering spectral-density curve. Of general interest, they noted that most drivers exhibit a primary dominant frequency of less than 0.3 Hz in their steering frequency spectrum, and they suggest that the number of reversals between five and seven degrees might be a most useful measure. They also noted the ambiguity in interpreting reversal rate (and other indicators) since, for example, a fatigued driver might tolerate greater steering or vehicle position errors and thus show a low reversal rate; or the fatigue might be shown as a higher rate of reversals because of increased difficulty in maintaining the desired accuracy of steering input.

In related laboratory studies, tracking error has been used by a number of investigators. As would be expected, error has been found to increase during long task periods and with the use of depressants.

Putz (1979) scored his subjects on a compensatory tracking task during four hours of continuous exposure at three level of carbon monoxide: 5, 35, and 75 ppm. He found tracking error for the high-frequency input increased in a positively accelerated manner during the exposure period, and the increase was most pronounced with the highest level of the gas. Tracking error for the low-frequency input increased only after three hours of exposure. Noble and Sanders (1980) had their subjects search for critical traffic signs imbedded in dense and distributed groups of signs. They found tracking error was the greatest when subjects had to search through distributed groups of signs and increased with the number of critical signs to be detected. As might be expected from classical work on displays, tracking error was least when critical signs were uniquely color coded.

Zaidel *et al.* (1978) review the work of Sussman and Morris (1970), and Sugarman and Cozad (1972) on road-position steering movements, as well as that of Riemersma *et al.* (1977), Mackie and O'Hanlon (1977), and O'Hanlon and Kelly (1977) on speed variability. As a result of their review, Zaidel *et al.* concluded that studies of driver/vehicle performance have indicated that vehicle-lateral-road position, steering movements, and vehicle-speed increase in variability with alertness decrements and time-at-the-wheel.

Lemke (1982) reported that pedal activity of drivers decreased during extended periods of driving. Zaidel *et al.* also reviewed work by Riermesa *et al.* (1977), Mackie and O'Hanlon (1977), O'Hanlon and Kelly (1977), and Sugarman and Cozald (1972), which showed that in on-road studies, speed variability increases with time in monotonous driving.

Steering movements have been used by many investigators as indicators of inattention. They are directly related to attentional performance, but are ambiguous since "coarse" steering performance, for example, may indicate a decision to allocate attention to another task or large-amplitude corrections required because of inadequate attentional performance. The available data suggest that it may be possible to reduce this ambiguity with the use of complex analysis of scores on several measures of steering-wheel activity. These measures have good potential utility as a basis for an inattention detector.

In contrast, both accelerator and brake-pedal activity appear to be affected by so many personal and environmental factors that they seem to have limited potential for such use. It should be noted, however, that accelerator-pedal activity has been used successfully as an element in a statistically-derived complex signature used to identify sleepy drivers.

C.4 Vehicle Dynamics

Measures of vehicle position and heading reflect and complement measures of driver control behavior. In general, the same comments apply to both sets of measures.

C.4.1 Lateral Position

Zaidel (op.cit), reviewed the work of Sussman and Morris *(op.cit.)*, and Sugarman and Cozad (1972). These investigators found, through simulator studies, that road-position error increased with driving time. On-road testing replicated their results. These findings have been confirmed in recent investigations. Wierwille (1981) found lateral-position variability to increase with time during extended periods of driving in a simulator. Blaauw (1982), comparing data obtained in simulator and on-road driving, found lateral-position error and variability greater in simulator driving than in on-road driving. MacDonald *et al.* (1980) found increased lateral drift and lateral acceleration when drivers were asked to perform a secondary task while driving.

Similar results have been obtained with drivers under the influence of depressant drugs. In a study by Ziedman *et al.* (1979), mean lane-position error and lane-position variability were increased for subjects driving a simulator under the affects of diazepam or secobarbital.

It appears that measures on lane-position error may indicate possible inattention, but they can, of course, also indicate driver reaction to traffic conditions. Triggs (1979), for example, made the observation that vehicles meeting on a two-lane highway systematically moved away from the road centerline.

C.4.2 Heading Error or Yaw

Wierwille and Muto (1981) found that both the number of yaw reversals greater than two degrees and the standard deviation of the yaw angle increased during extended periods of driving a simulator. In comparison of simulator and on-road driving, Blaauw (1982) found the variability of yaw rate was less in a simulator than in on-road driving for experienced, but not for inexperienced drivers.

Measures of driver-control activity and vehicle dynamics are perhaps among the most consistent and useful indicators of possible driver inattention. Measurement of lateral-position error is usually accomplished with a lane-sensing system. The possibility of inferring lane drift and change in relative lane position from measures of steering-wheel activity, lateral acceleration and yaw rate, for example, should be examined. Measures of vehicle position relative to other vehicles are strongly affected by personal and environmental variables. However, considering the rapid advances in micro-electronics and miniaturized radar systems, they should be considered for use as an element in combined-signature systems or for use in stand-alone proximity-warning systems.

Appendix D. Examples of Activity Log Sheets

D.1 Activities by Watch

D.1.1 Master's Activities

Form M-A   DATE: 11/7   TIME INTERVAL: 0400 -0800
ID. Number: 0001   WEATHER CONDITIONS: fair

DURING THIS WATCH HOW MANY MINUTES DID YOU SPEND ON:

NAVIGATION?	MINUTES	COMMENTS
Track Keeping		
Taking Action To Avoid Collisions		
Planning the Voyage		
Keeping Records and Charts including Bridge Logs		
Maintaining Navigation Equipment		
Performing Unscheduled Maintenance on Navigation Equipment		
Testing Vital Navigation Systems		
Bridge Housekeeping		
Monitoring Weather	10	
Monitoring, Maneuvering and Planning Relatedto Hull Performance		
Training on Equipment, Procedures and Standard Operations		
USING ELECTRONIC EQUIPMENT?		
VHF radio		
FAX machine		
ON DECK OPERATIONS?		
Carrying out docking or undocking		
Carrying out mooring or unmooring off-shore		
Doing anchoring or heaving-in		
Helicopter operations		
Carrying out underway lightering		
Using tugs and/or cranes		
Preparing for Going into Yard or Dry Dock		

Page 1

Master's Activities by Watch

Form M-A2 | DATE: | TIME INTERVAL:
ID. Number: | WEATHER CONDITIONS:

DURING THIS WATCH HOW MANY MINUTES DID YOU SPEND ON:

ON GENERAL OPERATIONS?	MINUTES	COMMENTS
Doing Maintenance of Vessel in terms of painting, chipping, grease, and coating		
Maintaining Deck equipment including the lights, structure, mooring equipment, anchor, bow transfer, gangway, capstans, and windlass		
Maintaining Line and Wire		
Handling Stores and Supplies		
Storing Stores and Supplies		
Ordering Stores and Supplies		
Training		
GENERAL ADMINISTRATION?		
Carrying out financial Administration		
Labor Relations		
Conducting Meetings about Shipboard Management		
Conducting Meetings About Safety		
Handling the Payroll		
Monitoring for Regulatory Requirements		
Inspections		
Walkaround with Regulatory Inspection Authorities		
Carrying Out Special Projects		
HOTEL FUNCTIONS?		
Supervising Catering Activities		
Supervising Accommodation and Space Cleaning		
Managing Operations		
Provisioning		
Supervising Maintenance of Galley Equipment		
Supervising Maintenance of Hotel Equipment		
Supervising Maintenance of Recreation Equipment		

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Master's Activities by Watch

Form M-A3

DATE:
ID. Number:

TIME INTERVAL:
WEATHER CONDITIONS:

DURING THIS WATCH HOW MANY MINUTES DID YOU SPEND ON:

	MINUTES	COMMENTS
OTHER RECORD KEEPING?		
PERSONAL TIME?		
Personal Housekeeping	30	
Eating		
Sleeping	120	
Leisure	20	

D.1.2 Cargo Officer's Activities

Form C-A

DATE: 11/6
ID. Number: 0002

TIME INTERVAL: 0800 - 1700 [illegible] US
WEATHER CONDITIONS: [illegible].

DURING THIS WATCH HOW MANY MINUTES DID YOU SPEND ON:

CARGO ACTIVITIES?	MINUTES	COMMENTS
On-loading		
Off-loading		
Maintaining Cargo Equipment		
Keeping Port Logs	20	
Maintaining the Reefer	15	
Inspecting	60	
Handling Ballast; Weight and Trim	60	[illegible] (1 [illegible] per day)

NAVIGATION?	MINUTES	COMMENTS
Track Keeping		
Taking Action To Avoid Collisions		
Planning the Voyage		
Keeping Records and Charts including Bridge Logs		
Maintaining Navigation Equipment		
Performing Unscheduled Maintenance on Navigation Equipment	30	
Testing Vital Navigation Systems	[illegible]	
Bridge Housekeeping		
Monitoring Weather		
Monitoring, Maneuvering and Planning Related to Hull Performance		
Training on Equipment, Procedures and Standard Operations		

USING ELECTRONIC EQUIPMENT?	MINUTES	COMMENTS
VHF radio		
FAX machine		

OTHER RECORD KEEPING?	MINUTES	COMMENTS
	60	[illegible] stability [illegible]

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Cargo Officer's Activities by Watch

Form C-A2

DATE:
ID. Number:

TIME INTERVAL:
WEATHER CONDITIONS:

DURING THIS WATCH HOW MANY MINUTES DID YOU SPEND ON:

DECK OPERATIONS	MINUTES	COMMENTS
Carrying out docking or undocking		
Carrying out mooring or unmooring off-shore		
Doing anchoring or heaving-in		
Helicopter operations		
Carrying out underway lightering		
Using tugs and/or cranes		
Preparing for Going into Yard or Dry Dock		

GENERAL OPERATIONS	MINUTES	COMMENTS
Doing Maintenance of Vessel in terms of painting, chipping, grease, and coating		
Maintaining Deck equipment including the lights, structure, mooring equipment, anchor, bow transfer, gangway, capstans, and windlass		
Maintaining Line and Wire		
Handling Stores and Supplies		
Storing Stores and Supplies		
Ordering Stores and Supplies		
Training		
Cleaning and Washing Down the Deck		
Engine Room Housekeeping		
Supervising Shore Personnel and Work Gangs	180	[illegible]
Planning for Cargo and Stability	30	

PERSONAL TIME?	MINUTES	COMMENTS
Personal Housekeeping		
Eating	30	
Sleeping		
Leisure		

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D.1.3 Navigation Officer's Activities

Form N-A | **DATE:** 11/7/89 | **TIME INTERVAL:** 12:00 - 16:00
ID. Number: 0003 | **WEATHER CONDITIONS:** fair, 42 2-3 M

DURING THIS WATCH HOW MANY MINUTES DID YOU SPEND ON: on watch

NAVIGATION?	MINUTES	COMMENTS
Track Keeping		continuous
Maneuvering		"
Making Chart Corrections		done in port, usually
Taking Action To Avoid Collisions		cont.
Planning the Voyage	15	main planning done by Ocean R
Keeping Records and Charts including Bridge Logs	30+	
Maintaining Navigation Equipment		
Performing Unscheduled Maintenance on Navigation Equipment	15	troubleshooting bell logger
Testing Vital Navigation Systems		
Bridge Housekeeping	.	
Monitoring the Weather	30	
Monitoring, Maneuvering and Planning Related to Hull Performance		only in heavy weather
Training on Equipment, Procedures and Standard Operations		not today

USING ELECTRONIC EQUIPMENT?		
VHF radio		
FAX machine		

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Navigation Officer's Activities by Watch

Form N-A2	DATE:	TIME INTERVAL:
	ID. Number:	WEATHER CONDITIONS:

DURING THIS WATCH HOW MANY MINUTES DID YOU SPEND ON:

DECK OPERATIONS

Carrying out docking or undocking	______	____________________
Carrying out mooring or unmooring off-shore	______	____________________
Doing anchoring or heaving-in	______	____________________
Helicopter operations	______	____________________
Carrying out underway lightering	______	____________________
Using tugs and/or cranes	______	____________________
Preparing for Going into Yard or Dry Dock	______	____________________

GENERAL OPERATIONS?

Doing Maintenance of Vessel in terms of painting, chipping, grease, and coating	______	____________________
Maintaining Deck equipment including the lights, structure, mooring equipment, anchor, bow transfer, gangway, capstans, and windlass	______	____________________
Maintaining Line and Wire	______	____________________
Handling Stores and Supplies	______	____________________
Storing Stores and Supplies	______	____________________
Ordering Stores and Supplies	______	____________________
Training	______	____________________
Bunkering	______	____________________
Maintaining the Vessel Structure	______	____________________
Repairing the Vessel Structure	______	____________________

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Navigation Officer's Activities by Watch

Form N-A3 **DATE:** **TIME INTERVAL:**
ID. Number: **WEATHER CONDITIONS:**

DURING THIS WATCH HOW MANY MINUTES DID YOU SPEND ON:

	MINUTES	COMMENTS
ADMINISTRATION?		
Record-keeping	______	______
Monitoring for Regulatory Requiirements	______	______
Inspections	______	______
Walkarounds with Inspection Regulatory Authorities	______	______
Special Projects	______	______
OTHER RECORD KEEPING?	______	______
PERSONAL TIME?		
Personal Housekeeping	______	______
Eating	______	______
Sleeping	______	______
Leisure	______	______

D.1.4 Safety Officer's Activities

Form S-A

DATE: 11/7/87

ID. Number: 0004

TIME INTERVAL: 0400-0800

WEATHER CONDITIONS:

DURING THIS WATCH HOW MANY MINUTES DID YOU SPEND ON:

NAVIGATION?	MINUTES	COMMENTS
Track Keeping		
Maneuvering		
Making Chart Corrections		
Taking Action To Avoid Collisions		
Planning the Voyage	15	relaying info from previous
Keeping Records and Charts including Bridge Logs		
Maintaining Navigation Equipment		
Performing Unscheduled Maintenance on Navigation Equipment		
Testing Vital Navigation Systems		
Bridge Housekeeping		
Monitoring the Weather		
Monitoring, Maneuvering and Planning Related to Hull Performance		
Training on Equipment, Procedures and Standard Operations		

DECK OPERATIONS?		
Carrying out docking or undocking		
Carrying out mooring or unmooring off-shore		
Doing anchoring or heaving-in		
Helicopter operations		
Carrying out underway lightering		
Using tugs and/or cranes		
Preparing for going into yard or dry dock		

Page 1

Safety Officer's Activities by Watch

Form S-A2 | DATE: | TIME INTERVAL:
ID. Number: | WEATHER CONDITIONS:

DURING THIS WATCH HOW MANY MINUTES DID YOU SPEND ON:

GENERAL OPERATIONS?	MINUTES	COMMENTS
Conducting Lifeboat and Firefighting Drills		
Maintaining the Lifeboats		
Conducting safety Tours		
Maintaining the Vessel in terms of painting, chipping, grease, and coating		
Maintaining Deck equipment including the lights, structure, mooring equipment, anchor, bow transfer, gangway, capstans, and windlass		
Maintaining Line and Wire		
Handling Stores and Supplies		
Storing Stores and Supplies		
Ordering Stores and Supplies		
Training		
Medical Situations		
Maintaining Safety Equipment, Testing Gas Meters, Gauging Equipment		

GENERAL ADMINISTRATION?		
Carrying out financial Administration		
Labor Relations		
Conducting Meetings about Shipboard Management		
Conducting Meetings About Safety		
Handling the Payroll		
Monitoring for Regulatory Requirements		
Inspections		
Walkaround with Regulatory Inspection Authorities		
Carrying Out Special Projects		

Page 2

Safety Officer's Activities by Watch

Form S-A3 **DATE:** **TIME INTERVAL:**
ID. Number: **WEATHER CONDITIONS:**

DURING THIS WATCH HOW MANY MINUTES DID YOU SPEND ON:

	MINUTES	COMMENTS
OTHER RECORD KEEPING?		
PERSONAL TIME?		
Personal Housekeeping	20	
Eating	15 ~~30~~	
Sleeping	180	
Leisure		

D.1.5 Engineering Officers' Activities

Form E-A

DATE: ~~0013~~ 11/7
ID. Number: 0013

TIME INTERVAL: 12 · 1600
WEATHER CONDITIONS:

DURING THIS WATCH HOW MANY MINUTES DID YOU SPEND ON:

	MINUTES	COMMENTS
THE ENGINES?		
Routine Engine Operations		
Engine Room Watch Standing		
Scheduled Engine Maintenance		
Unscheduled Engine Maintenance		
Keeping Records of Engine Operation		
Taking Engine Soundings		
THE GENERATORS?		
Operating the Generators		
Maintaining the Generators		
Unscheduled Maintenance of the Generators		
THE FUEL OIL SYSTEMS?		
Operating the Fuel Oil System	30	planning fuel moves
Maintaining the Fuel Oil System		
Unscheduled Maintenance of the Fuel Oil System		
THE BOILERS?		
Operating the Boilers		
Maintaining the Boilers		
Unscheduled Maintenance of the Boilers		
THE EVAPORATORS?		
Operating the Evaporators		
Maintaining the Evaporators		
Unscheduled Maintenance of the Evaporators		

Page 1

Engineering Officers' Activities by Watch

Form E-A	DATE: ID. Number:	TIME INTERVAL: WEATHER CONDITIONS:

DURING THIS WATCH HOW MANY MINUTES DID YOU SPEND ON:

THE REFRIGERATOR/AIR CONDITIONING?	MINUTES	COMMENTS
Operating the Refrigerator/Air Conditioner	______	______
Maintaining the Refrigerator/Air Conditioner	______	______
Unscheduled Maintenance of Refrigerator/Air Conditioner	______	______
THE SEWAGE SYSTEMS?		
Operating the Sewage Systems	______	______
Maintaining the Sewage Systems	______	______
Unscheduled Maintenance of the Sewage Systems	______	______
THE INERT GAS SYSTEMS?		
Operating the Inert Gas Systems	______	______
Maintaining the Inert Gas Systems	______	______
Unscheduled Maintenance of the Inert Gas Systems	______	______
THE ELECTRICAL/ELECTRICAL CONTROL SYSTEMS?		
Operating the Electrical/Electrical Control Systems	______	______
Maintaining the Electrical/Electrical Control Systems	______	______
Unscheduled Maintenance of Electrical/Electrical Control Systems	______	______
TOOLS AND TEST EQUIPMENT?		
Operating tools and test equipment	______	______
Maintaining tools and test equipment	______	______
Unscheduled maintenance of tools and test equipment	______	______
PUMPS?		
Operating pumps	______	______
Maintaining pumps	______	______
Unscheduled maintenance of pumps	______	______

Page 2

Engineering Officers' Activities by Watch

Form E-A

DATE:
ID. Number:

TIME INTERVAL:
WEATHER CONDITIONS:

DURING THIS WATCH HOW MANY MINUTES DID YOU SPEND ON:

	MINUTES	COMMENTS
FUEL TRANSFER / BUNKERING?		
Performing fuel transfer		
Doing maintenance of fuel transfer		
Unscheduled maintenance of fuel transfer		
WORKING ON THE VESSEL STRUCTURE?		
Maintaining the vessel structure		
Repairing the vessel structure		
WORKING ON THE STEERING GEAR?		
Maintaining the steering gear		
Repairing the steering gear		
Govt Inspections,	10	me.
OTHER RECORD KEEPING?		
Gen Adm	120 ~~10~~	office, reports, phone calls.
PERSONAL TIME?		
Personal Housekeeping		
Eating	30	
Sleeping		
Leisure	20	
Prepare for Inspection	30	

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D.2 Activities by Day

D.2.1 Master's Activities

Form . .-A DATE: 11/16 TIME INTERVAL: 16 Nov Th

ID. Number: 0001 WEATHER CONDITIONS: in port, drizzle

DURING THIS ~~WATCH~~ DAY HOW MANY ~~MINUTES~~ HRS DID YOU SPEND ON:

NAVIGATION?	~~MINUTES~~ HRS	COMMENTS
Track Keeping		
Taking Action To Avoid Collisions		
Planning the Voyage		
Keeping Records and Charts including Bridge Logs		
Maintaining Navigation Equipment		
Performing Unscheduled Maintenance on Navigation Equipment		
Testing Vital Navigation Systems		
Bridge Housekeeping		
Monitoring Weather		
Monitoring, Maneuvering and Planning Relatedto Hull Performance		
Training on Equipment, Procedures and Standard Operations		
USING ELECTRONIC EQUIPMENT?		
VHF radio		
FAX machine	1 ~~60~~	
supervision of repairs to Loran + radar	1 ~~60~~	
ON DECK OPERATIONS?		
Carrying out docking or undocking	3 ~~180~~	
Carrying out mooring or unmooring off-shore		
Doing anchoring or heaving-in		
Helicopter operations		
Carrying out underway lightering		
Using tugs and/or cranes		included above
Preparing for Going into Yard or Dry Dock		

300

Page 1

Master's Activities by Day

DATE: 11/16 | TIME INTERVAL: 10 NOV
ID. Number: 0001 | WEATHER CONDITIONS:

DURING THIS ~~WATCH~~ DAY HOW MANY ~~MINUTES~~ HRS DID YOU SPEND ON:

ON GENERAL OPERATIONS?	~~MINUTES~~ HRS	COMMENTS
Doing Maintenance of Vessel in terms of painting, chipping, grease, and coating		
Maintaining Deck equipment including the lights, structure, mooring equipment, anchor, bow transfer, gangway, capstans, and windlass		
Maintaining Line and Wire		
Handling Stores and Supplies		
Storing Stores and Supplies		
Ordering Stores and Supplies		
Training	1 ~~60~~	
GENERAL ADMINISTRATION?		
Carrying out financial Administration		
Labor Relations		
Conducting Meetings about Shipboard Management		
Conducting Meetings About Safety		
Handling the Payroll		
Monitoring for Regulatory Requirements		
Inspections		
Walkaround with Regulatory Inspection Authorities		
Carrying Out Special Projects		
HOTEL FUNCTIONS?		
Supervising Catering Activities		
Supervising Accommodation and Space Cleaning		
Managing Operations		
Provisioning		
Supervising Maintenance of Galley Equipment		
Supervising Maintenance of Hotel Equipment		
Supervising Maintenance of Recreation Equipment		

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Master's Activities by Day

DATE: 11/16
ID. Number: 0001

TIME INTERVAL: 10 NOV
WEATHER CONDITIONS:

DURING THIS WATCH HOW MANY MINUTES DID YOU SPEND ON:

	~~MINUTES~~	COMMENTS
OTHER RECORD KEEPING?	2 ~~110~~	crew list, articles, etc.
MBWA (some cargo related)		
PERSONAL TIME?	4½ ~~300~~	
Personal Housekeeping	½ ~~30~~	
Eating	1 ~~40~~	
Sleeping	8 ~~480~~	
Leisure	2 120	

480
~~600~~
1080
60
300
1440

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D.2.2 Cargo Officer's Activities

Form

DATE: 11/18 Sat
ID. Number: 0003

TIME INTERVAL:
WEATHER CONDITIONS:

DURING THIS D ~~WEEK~~ HOW MANY HRS ~~MINUTES~~ DID YOU SPEND ON:

NAVIGATION?	HRS ~~MINUTES~~	COMMENTS
Track Keeping	7½ hrs	
Maneuvering	½ hr	
Making Chart Corrections	2½ hr	
Taking Action To Avoid Collisions		
Planning the Voyage		
Keeping Records and Charts including Bridge Logs	½ h.	
Maintaining Navigation Equipment		
Performing Unscheduled Maintenance on Navigation Equipment		
Testing Vital Navigation Systems		
Bridge Housekeeping		
Monitoring the Weather		
Monitoring, Maneuvering and Planning Related to Hull Performance		
Training on Equipment, Procedures and Standard Operations		

USING ELECTRONIC EQUIPMENT?		
VHF radio		
FAX machine		

Page 1

Cargo Officer's Activities by Day

DATE: 11/1 Y
ID. Number: 0003

TIME INTERVAL:
WEATHER CONDITIONS:

DURING THIS ~~WATCH~~ DAY HOW MANY ~~MINUTES~~ HRS DID YOU SPEND ON:

DECK OPERATIONS

Carrying out docking or undocking	______	______________
Carrying out mooring or unmooring off-shore	______	______________
Doing anchoring or heaving-in	______	______________
Helicopter operations	______	______________
Carrying out underway lightering	______	______________
Using tugs and/or cranes	______	______________
Preparing for Going into Yard or Dry Dock	______	______________

GENERAL OPERATIONS?

Doing Maintenance of Vessel in terms of painting, chipping, grease, and coating	______	______________
Maintaining Deck equipment including the lights, structure, mooring equipment, anchor, bow transfer, gangway, capstans, and windlass	______	______________
Maintaining Line and Wire	______	______________
Handling Stores and Supplies	______	______________
Storing Stores and Supplies	______	______________
Ordering Stores and Supplies	______	______________
Training	______	______________
Bunkering	______	______________
Maintaining the Vessel Structure	______	______________
Repairing the Vessel Structure	______	______________

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Cargo Officer's Activities by Day

DATE: 11/18 **TIME INTERVAL:**
ID. Number: 0003 **WEATHER CONDITIONS:**

DURING THIS ~~WATCH~~ DAY HOW MANY ~~MINUTES~~ HRS DID YOU SPEND ON:

	~~MINUTES~~ HRS	COMMENTS
ADMINISTRATION?		
Record-keeping		
Monitoring for Regulatory Requiirements		
Inspections		
Walkarounds with Inspection Regulatory Authorities		
Special Projects		
OTHER RECORD KEEPING?		
PERSONAL TIME?		
Personal Housekeeping	½ h	
Eating	¾ h	
Sleeping	6½ h	
Leisure	5½ h	

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D.2.3 Navigation Officer's Activities

Form | **DATE:** 11/21 ~~Tues~~ | **TIME INTERVAL:**
ID. Number: 2/ | **WEATHER CONDITIONS:**

DURING THIS ~~WATCH~~ DAY HOW MANY ~~MINUTES~~ HRS DID YOU SPEND ON:

NAVIGATION?	**~~MINUTES~~ HRS**	**COMMENTS**
Track Keeping	3+2 5	1) Position Keeping in Anchor, 2) Monitoring Calls on Channel [illegible]
Maneuvering		
Making Chart Corrections		
Taking Action To Avoid Collisions		
Planning the Voyage		
Keeping Records and Charts including Bridge Logs	1/2	
Maintaining Navigation Equipment		
Performing Unscheduled Maintenance on Navigation Equipment		
Testing Vital Navigation Systems	1/2	
Bridge Housekeeping		
Monitoring the Weather		
Monitoring, Maneuvering and Planning Related to Hull Performance		
Training on Equipment, Procedures and Standard Operations		

USING ELECTRONIC EQUIPMENT?		
VHF radio		
FAX machine		

Page 1

Navigation Officer's Activities by Day

DATE: 11/21 **TIME INTERVAL:**
ID. Number: **WEATHER CONDITIONS:**

DURING THIS ~~WATCH~~ DAY HOW MANY ~~MINUTES~~ HRS DID YOU SPEND ON:

DECK OPERATIONS		
Carrying out docking or undocking		
Carrying out mooring or unmooring off-shore		
Doing anchoring or heaving-in	1	
Helicopter operations		
Carrying out underway lightering		
Using tugs and/or cranes	½	
Preparing for Going into Yard or Dry Dock		
Start Ballast + Load Cargo, [illegible]	2½	
GENERAL OPERATIONS?		
Doing Maintenance of Vessel in terms of painting, chipping, grease, and coating		
Maintaining Deck equipment including the lights, structure, mooring equipment, anchor, bow transfer, gangway, capstans, and windlass		
Maintaining Line and Wire		
Handling Stores and Supplies		
Storing Stores and Supplies		
Ordering Stores and Supplies		
Training		
Bunkering		
Maintaining the Vessel Structure		
Repairing the Vessel Structure		

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Navigation Officer's Activities by Day

DATE: 11/21 **TIME INTERVAL:**
ID. Number: **WEATHER CONDITIONS:**

DURING THIS ~~WATCH~~ DAY HOW MANY ~~MINUTES~~ HRS DID YOU SPEND ON:

	~~MINUTES~~ HRS	COMMENTS
ADMINISTRATION?		
Record-keeping	[illegible]	
Monitoring for Regulatory Requiirements	1	
Inspections	1	
Walkarounds with Inspection Regulatory Authorities	1/2	Environment, DEC, Personnel on Board
Special Projects	1/4	DOT
OTHER RECORD KEEPING?		
PERSONAL TIME?		
Personal Housekeeping	1/2	
Eating	1	
Sleeping	6	
Leisure	3	

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D.2.4 Safety Officer's Activities

Form S-A

DATE: 11/17/89
ID. Number: 0004

TIME INTERVAL: [illegible]
WEATHER CONDITIONS:

DURING THIS ~~WATCH~~ DAY HOW MANY ~~MINUTES~~ HOURS DID YOU SPEND ON:

NAVIGATION?	~~MINUTES~~ HOURS	COMMENTS
Track Keeping		
Maneuvering		
Making Chart Corrections		
Taking Action To Avoid Collisions	1.00	relieve chief for supper
Planning the Voyage		
Keeping Records and Charts including Bridge Logs		
Maintaining Navigation Equipment		
Performing Unscheduled Maintenance on Navigation Equipment		
Testing Vital Navigation Systems		
Bridge Housekeeping		
Monitoring the Weather		
Monitoring, Maneuvering and Planning Related to Hull Performance		
Training on Equipment, Procedures and Standard Operations		

DECK OPERATIONS?		
Carrying out docking or undocking		
Carrying out mooring or unmooring off-shore		
Doing anchoring or heaving-in		
Helicopter operations		
Carrying out underway lightering		
Using tugs and/or cranes		
Preparing for going into yard or dry dock		

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Safety Officer's Activities by Day

DATE: **TIME INTERVAL:**
ID. Number: **WEATHER CONDITIONS:**

DURING THIS ~~WATCH~~ DAY HOW MANY ~~MINUTES~~ HOURS DID YOU SPEND ON:

GENERAL OPERATIONS?	**~~MINUTES~~ HRS**	**COMMENTS**
Conducting Lifeboat and Firefighting Drills		
Maintaining the Lifeboats		
Conducting safety Tours		
Maintaining the Vessel in terms of painting, chipping, grease, and coating		
Maintaining Deck equipment including the lights, structure, mooring equipment, anchor, bow transfer, gangway, capstans, and windlass		
Maintaining Line and Wire		
Handling Stores and Supplies		
Storing Stores and Supplies		
Ordering Stores and Supplies		
Training		
Medical Situations		
Maintaining Safety Equipment, Testing Gas Meters, Gauging Equipment		

GENERAL ADMINISTRATION?		
Carrying out financial Administration		
Labor Relations		
Conducting Meetings about Shipboard Management		
Conducting Meetings About Safety		
Handling the Payroll		
Monitoring for Regulatory Requirements		
Inspections		
Walkaround with Regulatory Inspection Authorities		
Carrying Out Special Projects		

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Safety Officer's Activities by Day

DATE: **TIME INTERVAL:**
ID. Number: **WEATHER CONDITIONS:**

DURING THIS ~~WATCH~~ DAY HOW MANY ~~MINUTES~~ HRS DID YOU SPEND ON:

	~~MINUTES~~ HRS	COMMENTS
OTHER RECORD KEEPING?		
PERSONAL TIME?		
Personal Housekeeping		
Eating		
Sleeping		
Leisure		

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D.2.5 Engineering Officers' Activities

Form E-A **Date** 11/26 **Time Interval** 26 NOV Sunday
ID. Number 17 **Weather Conditions** SLIGHT ROLL

HOW MANY MINUTES DID YOU SPEND ON EACH ACTIVITY TODAY:

OPERATIONS?	**MINUTES**	**COMMENTS**
Routine Engine Operations?		
Engine room watch standing	8hrs.	
Taking engine soundings		
Fuel transfer / bunkering		

MAINTENANCE - SCHEDULED?		
Engines		
Generators		
Fuel Oil systems		
Boilers		
Evaporators		
Refrigeration / Air-conditioning		
Sewage systems		
Inert gas systems		
Electrical / control systems		
Tools and Test Equipment		
Pumps		
Fuel transfer / bunkering		
Vessel structure	4hrs.	INSTALLED POTABLE WATER PIPING IN PUMPROOM.
Steering Gear		

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Engineering Officers' Activities by Day

DATE 11/26
ID. NUMBER 17

TIME INTERVAL 26 NOV
WEATHER CONDITIONS SLIGHT ROLL CLOUDY. WET.

HOW MANY MINUTES DID YOU SPEND ON EACH ACTIVITY TODAY:

MAINTENANCE - UNSCHEDULED?	MINUTES	COMMENTS
Engines		
Generators		
Fuel Oil systems		
Boilers		
Evaporators		
Refrigeration / Air-conditioning		
Sewage systems		
Inert gas systems		
Electrical / control systems		
Tools and Test Equipment		
Pumps		
Fuel transfer / bunkering		
Vessel structure		
Steering Gear		
CONTRACTUALLY REQUIRED ACTIVITIES		
e.g. monitoring ship's systems		
RECORD KEEPING		
PERSONAL TIME		
Personal House keeping	1	
Eating	1	
Sleeping	5	
Leisure	5	BAD NIGHT FOR SLEEPING 2-3 HRS. LOST DUE TO OVERTIRED AND SHIPS HOUSE WAS TOO OVERLY HEATED COULD NOT GET TO SLEEP

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