FATIGUE, WATCHKEEPING AND ACCIDENTS: A CONTENT ANALYSIS OF INCIDENTS AT SEA REPORTS

By

Richard Phillips B.Ed., Dip.Teach.

SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR
THE DEGREE OF MASTERS OF BIOMEDICAL SCIENCE (RESEARCH)

School of Human Life Sciences, University of Tasmania.

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CANDIDATE DECLARATION

I certify that the thesis entitled

"Fatigue, watchkeeping and accidents: a content analysis of Incidents at Sea reports"

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The conceptualisation, data acquisition and analysis, and writing of this thesis occurred concurrently with many changes in my personal and working life.

My interest in shift work and sleep deprivation comes from almost twenty years of working shifts as a paramedic with the Tasmanian Ambulance Service.

My interest in the maritime industry comes from teaching the ship's masters medical course at the Australian Maritime College, where I gained some insight to the unique nature of the challenges facing members of the seafaring profession.

The scientific basis for my research and my understanding of both the potential and the limitations of the human body are based on my last eight years work as a teacher with the School of Human Life Sciences at the University of Tasmania.

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ABBREVIATIONS USED IN THIS THESIS

AMSA	Australian Maritime Safety Authority
ANTA	Australian National Training Authority
ARPA	Automatic radar plotting aids
ATSB	Australian Transportation Safety Bureau (Federal department responsible for transport accident investigation from June 1999)
BAC	Blood alcohol concentration
BRAC	Basic rest activity cycle
CFF	Critical flicker fusion
COPE test	Choice of Probability and Effort test
EEG	Electroencephalogram/encephalography
EMG	Electromyogram
EOG	Electrooculogram
FFT	Fast Fourier transformation
FTP	File transfer protocol
GEMS	Generic error modelling system
HRV	Heart rate variability
IMO	International Maritime Organisation
KSS	Karolinska sleepiness scale
MIIU	Marine Incident Investigation Unit (Federal department responsible for marine investigation to June 1999)
MSLT	Multiple sleep latency test
Non-REM sleep	Non rapid eye movement sleep
NUDIST®	Non-numerical unstructured data indexing, searching and theorising (software used in data analysis)
REM Sleep	Rapid eye movement sleep

SSS	Stanford sleepiness scale
STCW	Standards for Training, Certification of Watchkeepers. (International Convention and Code on Standards)
SWS	Slow wave sleep
VTS	Vessel Traffic Services
WWW	World-wide web (the internet)

ABSTRACT

The profession of seafaring involves rest and sleep in a 24-hour-a-day work environment; obtaining sufficient sleep under such conditions is often difficult, and sleep loss and the need for sleep is often related to fatigue and contributory to accidents. Maritime incident reports form a rich source of human performance data with high face validity, however fatigue as contributory to human error is elusive, and direct evidence of accident causation is hard to come by. In Australia, the Australian Transportation Safety Board has responsibility to investigate incidents at sea.

The present study aimed to identify evidence of time of day and sleep deprivation as factors that appear contributory to fatigue in "Incidents at Sea" reports. Both quantitative and qualitative analyses of the text of these reports were conducted using NUDIST®, categories were developed and patterns identified.

The effect of time of day was identified from analysis of the conclusions of 100 consecutive reports to determine the nature and distribution of behaviours associated with fatigue. Collisions and groundings were more prevalent during the early morning watches. Behaviours consistent with fatigue were identified, categorised and described for different times of the day with deficits in alertness predominating in the early morning watches and deficits in information processing predominating in the afternoon watches.

The contribution of sleep deprivation and its relationship with fatigue and accidents was identified from analysis of the full text of 44 reports, which incorporated three levels of association of sleep with accident causation. The highest level establishes either being asleep, or being sleep deprived as causal to an accident. At an intermediate level, reference to the conflicting pressures of work and sleep suggests a work environment that is not conducive to obtaining sufficient sleep, and accident investigators were usually unable to link the watchkeeping environment with fatigue as a contributing factor. At the lowest level of association, reference is made to the integrated nature of sleeping and work on board.

Finally a model illustrating the relationships between sleep deprivation, time of day and fatigue behaviours in the maritime setting was proposed, providing accident investigators with a tool to assist with the identification of fatigue in their analyses of maritime incidents. In addition, this model would be useful in the education of maritime administrators and policy developers, shipping companies and seafarers.

CHAPTER 1 – INTRODUCTION

1.1. Purpose and introduction

In Australia, the Marine Investigation Unit of the Australian Transportation Safety Board has statutory responsibility to investigate incidents at sea[1] as defined in the Navigation (Marine Casualty) Regulations and specified in the Navigation Act of 1912. Since 1991, this unit has published 152 Incidents at Sea reports and made available another 26 previously published reports. Full text of these reports is available from the Marine Incident Investigation's web site at <http://www.atsb.gov.au/marine/incident/index.cfm>. An example of an Incident at Sea report is given in Appendix 1.

The Incidents at Sea reports have high ecological validity, being documentation of actual incidents but are, naturally enough, not designed as scientific experiments. The scientific literature, on the other hand, contains much evidence of the effects of fatigue under experimental conditions, but lacks ecological validity.

The study addresses the literature relating to the concept of relevant competence in watchkeepers, human factors and human error in a maritime and transport setting and the general nature of fatigue, its measurement and its effect on performance.

The role of the ship's watchkeeper is introduced using the National Maritime Industry Competency Standards as a benchmark for the industry-accepted role of ship watchkeeper, supported by the International Convention and Code on Standards of Training, Certification and Watchkeeping of Seafarers (STCW).

Content analysis of selected Incidents at Sea reports, using a non-numerical text analysis computer software package, was used to correlate fatigue

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[1] The term incidents at sea will be used in this thesis to refer to any maritime incident or accident, whereas the (capitalised) Incidents at Sea will refer specifically to those incidents investigated and reported under statute by the Australian Marine Investigation Unit.

characteristics obtained from the scientific literature with the watch-keeping activities. Possible relationships between fatigue behaviours, competence and human errors leading to incidents at sea were established using a theory-building approach.

Time-of-day factors and sleep-loss factors are the two fatigue-related variables that appear to be most contributory to accidents, based on the results of this study and supported by the literature. These two variables were subject to separate analyses. First, the conclusions of 100 reports were analysed in order to determine the nature of human error demonstrated on each watch (conventional ship's watches consist of six four-hour periods over a 24-hour day). Second, 44 complete reports were analysed to determine the accident investigators reference to sleep and to develop a model relating sleep factors and time-of-day factors with accidents.

Descriptors of fatigue behaviours may well be of use to marine incident investigations in determining the extent to which fatigue contributes to accidents. The outcomes of this research may be used in further quantitative studies. For example, descriptors of fatigue that are identified as contributing to accidents, could be used as experimental dependent variables in simulation studies, possibly using a marine simulator such as the Australian Maritime College's Ship Simulator. These further studies should allow the manipulation of independent variables that are hypothesised to be causally related to Incidents at Sea identified in this study with observation of dependent performance variables.

1.2. Research Questions

A study into shipping casualties in the United Kingdom identified that although the human element has been identified in 90% of collisions and 75% of fires and explosions (Bryant 1991), "... there is so little detailed information and inability to determine the relationship between hours worked and frequency of accidents to men at sea - direct evidence of fatigue as a cause of collisions is hard to come by" (Brown 1989).

The central question in any analysis of fatigue and accidents is ***does fatigue contribute to incidents at sea, and if so to what extent and in what***

manner? With the advent of decreased manning levels and increased automation within the maritime industry, this problem has increasing relevance. The challenge lies in attempting to reconstruct and understand the reality of fatigue-induced incidents from retrospective analyses, given the difficulty that human actors exhibit in describing and interpreting such an indefinite concept as fatigue.

The relationships between these events could be represented as follows:

1. Factors contributing to fatigue

↓

2. The watchkeeper experiencing fatigue

↓

3. The watchkeeper exhibiting behaviours resulting from fatigue

↓

4. Fatigue behaviours affecting the safe navigation of the vessel

5. An incident at sea

↓

6. A marine inquiry/incident investigation

↓

7. Reconstruction of the incident by accident investigators

↓

8. Interpretation of the description of fatigue by the investigator

↓

9. Establishment of causality (i.e. a series of conclusions) resulting from the investigation process

Figure 1: Sequence of events leading to an incident investigation

In this sequence of events, the actual phenomenon of fatigue and the establishment of causality by an investigator involve quite complex communication processes, both written and verbal, during the process of a formal investigation. The indeterminate nature of fatigue and the complexity and formality of the communication process all contribute to potentially compromising the establishment of a relationship between fatigue and the incident.

In this study, the latter four events of the above chain were explored - those events that related to the description and interpretation of fatigue. In addition, this study explored the nature of fatigue as described in the scientific literature and related this knowledge to fatigue as possibly experienced by ship's watchkeepers.

In addressing this problem therefore, the following research questions were raised:

- Within maritime accident investigation, what are the potential manifestations of fatigue experienced by watchkeepers and interpreted by accident investigators?
- What are the factors that contribute to fatigue in a maritime setting?
- How do these factors interact and what is their contribution to accidents?
- How does the fatigue experienced by watchkeepers in the maritime industry compare with the phenomenon that is described by cognitive psychologists, human factors and human error researchers?

And finally, in general terms:

- Within the maritime context, what is this phenomenon known as fatigue?

Captain Kit Filor of the Australian Transportation Safety Board (1996, pers. comm.) identifies the difficulty accident investigators have in determining the extent to which fatigue contributes to accidents due to the indeterminate nature of fatigue in the real world. The problem facing marine investigators is establishing what is meant by fatigue and differentiating between various manifestations of fatigue as contributing causes of accidents. The STCW Code of 1995 indirectly describes fatigue as a consequence of time on task, "... provisions made to prevent fatigue should ensure that excessive or unreasonable overall working hours are not undertaken." This latter statement may also be construed to take into account time-of-day influences if the term "unreasonable" is interpreted to include night work. The Code

(1995) also states that "...there is no universally accepted technical definition of fatigue" but refers readers to the International Maritime Resolution (IMO Resolution A772 (18), paragraphs 2 to 4.4.1.) which identifies factors which could contribute to fatigue.

Though fatigue may be ill defined, its causal relationship with performance is well documented and the subsequent physiological, behavioural and subjective manifestations are well documented - the difficulty lies in different people having differing interpretations of fatigue in its various contexts. Specifically, those presenting evidence at a Departmental Investigation or a Marine Court of Inquiry may consider fatigue differently from each other and from the point of view of an investigator. Those presenting evidence may hold popular or simplistic views on the nature of fatigue whereas the investigator may have an understanding of fatigue based on previous experiences in accident analysis. It is desirable that there is a common currency of understanding as to the contributing factors, nature, manifestations and consequences of fatigue in the maritime environment. This requires translating the subjective nature of fatigue from the language of the seafarer to an objective interpretation by the accident investigator.

Much of the literature defines fatigue from the perspective of particular disciplines or based on a specific research methodology. In order that previous studies in the area could be contextualised, a common understanding of fatigue needed to be found, or conversely, the limitation of definitions from various disciplines or using particular methods needed to be established. Subsequent chapters of this thesis will describe various interpretations of the effects of fatigue from a behaviourist, physiological and subjective viewpoint; perspectives which will form the basis of interpreting the nature of fatigue, independent of any specific context.

Finally, given that fatigue is also a subjective phenomenon, what is the essence of this phenomenon? This question is beyond the scope of this study but could be addressed using phenomenological methods allowing learning and understanding of peoples' subjective experiences. Such qualitative methods could involve interviewing those directly experiencing the phenomenon - namely ship watchkeepers affected by fatigue inducing stressors.

Much work has already been done in quantifying the effects of fatiguing stressors on subjective, behavioural and physiological variables, and there is little doubt that there are decrements in performance resultant from variables such as time of day, time on task and arousal. The critical issue for accident investigators is establishing the relationship between these possible causes and the resultant changes in behaviour of the operative that results in the incident.

According to the Tavistock Report on the Human Element in Shipping Casualties (Bryant 1991) "... direct evidence on fatigue as a cause of collisions is hard to come by". The contribution of fatigue to incidents at sea is not established outside the anecdotal evidence detailed in reports of such incidents. Bryant (1991) does, however, note that lack of supporting documentary evidence on the work patterns and watchkeeping system on board hampers the investigator's ability to determine the extent to which fatigue may have been a factor. This position does demonstrate a limited view of the nature of fatigue on the part of the Tavistock Institute whereby fatigue is described only in terms of a consequence of previous work.

There are many factors that contribute to the phenomenon of fatigue that may present as a number of critical behaviours other than lapses of attention, awareness or vigilance as described by the Tavistock team (Bryant 1991). This issue is pursued by Brown (1989) who questions the Tavistock team's [earlier and preliminary] finding of

> "... no direct evidence of the presence of fatigue... in the Marine Surveyors' files' in the light of findings of carelessness, over-confidence and other risky behaviour, with errors of judgement and excessive speed in poor visibility being plausibly associated with the mental exhaustion associated with fatigue".

It may appear that unless fatigue, manifest as a loss of alertness, is explicitly presented as evidence in an inquiry, behaviours may be unable to be attributed to fatigue, or alternatively, the incident may be attributed to some other mechanism.

CHAPTER 2 - LITERATURE REVIEW

2.1. The role of the ship's watchkeeper

Introduction

Seafaring has been described as the original 24-hour society (Filor 1996). Commercial vessels employ a ship's crew of a master and two or three deck officers, engineering officers and a complement of integrated ratings. These personnel may be engaged in navigation, cargo handling, communication, emergency response, maintenance, catering, administration and human resource management in a closed community that is isolated physically and socially from other vessels and from shore-based life (ANTA; Maritime Competency Standards 2001). These activities take place 24 hours a day, for every day that the vessel is in commission.

Watchkeeping is the responsibility of deck officers, who comprise the master and first and second mate (and perhaps a third mate), typically operating a three-watch system. The first mate takes responsibility for the 4 to 8[2] watch, the second mate the 12 to 4 watch and the third mate and/or the master the 8 to 12 watch. Ships' officers therefore have two four-hour watches per 24-hour period. In addition to watchkeeping, officers have other duties; the first mate manages mooring and unmooring operations and cargo handling, and the master has overall responsibility for command of the vessel and the safety of crew, specific manoeuvring operations, monitoring, budget, information control and security.

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[2] Each officer generally undertakes two watches during each 24-hour period, hence the first mate, for example, would take the early morning 0400 to 0800 watch, and the evening watch of 1600 to 2000. Watches are numbered following the evening meal, hence the first watch is from 2000 to 0000, the middle watch is from 0000 to 0400, the morning watch from 0400 to 0800, the forenoon watch from 0800 to 0000 and the afternoon watch from 1200 to 1600. The evening watch is from 1600 to 2000, and may be broken into two two-hour watches known as the first and last dog watch, however this is rarely done in Australian vessels.

Smaller vessels such as fishing boats typically have a skipper and one or two deck hands, who operate a watchkeeping system based around fishing activities. For example, prawn trawling is a night-time activity with the crew sleeping during the day. Travelling to and from the fishing grounds, cleaning and stowing the catch and getting the catch to markets frequently involves extended periods of wakefulness and it is common for the entire ship's complement to sleep at anchor or to lie ahull (i.e. engine off and not underway, but not at anchor) between fishing activities.

The human need for regular and extended periods of sleep is often at odds with the ongoing nature of shipboard activities. Just as "time and tide wait for no man", ship operations must continue around the clock due to economic (time) and navigational (tide) pressures and the physiological needs of the crew are frequently left wanting.

Definition of roles and competence

The role of the ship's watchkeeper is defined by two documents; the 1995 Revised International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (known as STCW) and the National Maritime Competency Standards. The former document is an international convention of deliberations and resolutions agreed to by parties to the convention, namely representatives of 71 sovereign states and numerous inter-governmental organisations and non-government organisations. The latter document has been endorsed by the National Training Board (the national body responsible within Australia for industry standards endorsement) and is a reflection of the Australian Maritime Industry's position following major structural reforms and is in complete accord with relevant industrial awards. In addition, the watchkeepers role is specified in the various training documents, employers' job specifications, and operational manuals and procedures guides used within the maritime industry.

As the National Competency Standards for the Maritime Industry (referred to hereafter as Maritime Competency Standards) contain specific performance requirements (known as performance criteria) for the role of deck watchkeeper, this document was used as the primary specification for determining watchkeeping tasks and in extracting the subset of tasks that may be affected by fatigue. In addition, the STCW Code was used as a means of validating watch-keeping competencies extracted from the Competency Standards as they apply to both watchkeeping tasks and the Australian context. The STCW Code also contains some general guidance regarding watchkeeping. (Chapter VIII, STCW Code)

For the purpose of this study, the role of deck watchkeeper was defined by the Units of Competency for the occupational group Deck Watchkeeper with the exception of the Units relating to administrative and lower management functions that have no direct relation to the safe operation of a watch.

The Master and Chief Mate are involved in both the supervision of deck watchkeepers and frequently participate in watchkeeping activities according to Tony Boyle of the Australian Maritime College (1996, pers. comm.). Many of the competency units performed by the Chief Mate and Master were closely related to the watchkeeping role and involve both the monitoring and controlling of watchkeeping functions.

2.2. The concept of stress and fatigue

Introduction

This section will explore the relationship between stress, boredom, vigilance and fatigue and consider both historical and contemporary neurological and humoral models. Fatigue is a difficult construct as it behaves as both an independent and dependent variable and is unlikely to operate in a purely linear fashion (Finkelman 1994). In addition Finkelman (1994) states "fatigue remains an elusive variable because of the inability to extrapolate laboratory research into real-world settings and because of the great variety of moderating variables that alter fatigue's relationship with performance."

Fatigue stress and strain

Stress, strain, fatigue and boredom are interrelated subjective states, though there may be objective components of each state.

In popular use, the term fatigue infers tiredness, exhaustion, loss of energy and inability to carry on. This thesis considers fatigue in the cognitive sense -

the decrement in cognitive (and often physical) performance following some stress or activity.

Fatigue has been described by Cameron (1974) as "... a generalised response to stress experienced over a period of time, with effects which may be acute or chronic, or both, confined to the subjective state of the individual, or extending into measurable aspects of individual performance." Hockey (1986) adopts the position that boredom results from the requirement to maintain attention in the absence of relevant task information whereas fatigue is the consequence of continuously high levels of information load. Hockey's (1986) discussion on fatigue maintains the core concept of prolonged work as contributory to fatigue and differentiates between physical, and cognitive or perceptual work.

Finkelman (1994) views fatigue as both an independent and a dependent variable that is unlikely to operate in a purely linear fashion, but rather as a variable in a limited-channel capacity model that only becomes manifest after no more reserve capacity is available to offset its input. Finkelman (1994) acknowledges motivational factors may serve to moderate the effect of fatigue on performance.

Bartley and Chute's (1947) classic publication on fatigue makes a distinction between the subjective experience of symptoms and the physiological impairment of performance. McFarland (1971) describes both physiological factors such as energy requirements, muscle fatigue and oxygen consumption, and psychological aspects such as time on task that result in attention loss and error. In addition, he proposes stress and anxiety as contributory to fatigue and the modern industrial environment and an increasing utilisation of shiftwork having significant influence. Finally, McFarland (1971) cites fear and apprehension as well as boredom as contributory to fatigue, particularly in the context of aviation where selection and training have mitigated against the effects of these common but extreme contributing factors.

Hockey (1986) classifies fatigue contributing to stress as either skill fatigue or the after effects of prolonged work; the former characterised by undertaking complex and/or simultaneous tasks (overloading). The latter effect has been particularly difficult to demonstrate due to individuals' ability to compensate over long periods of time (Hockey 1986).

Johns (2000), in consideration of driver fatigue, prefers to use the term sleepiness and avoids the use of the term fatigue, reserving that term for the "... process that occurs typically in many ... muscles, whereby their strength of contraction decreases with continuing use and is usually restored by rest." Johns (2000) does not accept the use of the term fatigue in any context other than muscular, a view that is in conflict with a considerable body of literature on cognitive fatigue. As will be evident later in this thesis, where fatigue is simply reduced to a decrease in alertness, or as argued by Johns (2000), decreased muscular strength following exertion, the varied manifestations of work, at different times of the day and often under conditions of deficient sleep may be missed.

Stress was first discussed by Selye in 1936 as an endocrinological phenomenon and became a common term in the performance/efficiency literature in the 1960s (Hockey 1986). Contemporary stress models include both information-processing models, characterised by a limited system information processor approach, and an arousal theory characterised by drive, stress and arousal (Hockey 1986). The latter theory incorporates Selye's general adaptation syndrome and the inverted-U relation between performance and arousal (Hockey 1986). Arousal is defined as a general state varying from coma and drowsiness to alertness and frantic excitement (Parasuraman 1986). This latter relationship between performance and arousal provides an explanation of selectivity of cues such that performance is optimised at high levels of arousal by restricting the range of environmental events that could be processed and at low levels of arousal by reducing attention to irrelevant cues (Hockey 1986).

The dependence relationship between stress and fatigue is unclear. In a model proposed by Hockey (1986), fatigue is cited as a primary contributory variable of stress, along with cyclical changes, physical stressors, drugs and cognitive factors. Hockey (1986) describes fatigue as an internal stressor, which in conjunction with cyclical changes (another internal stressor) and external stressors, contributes to performance changes and subjective states following the closely related functions of information-processing resources and cognitive appraisal respectively. He adds that effects of the social environment (social stressors) normally influence cognitive appraisal, which in turn affects subjective reactions. This model categorises fatigue as a hypothetical construct, which like memory, is not observable but has observable effects on situations and behaviours (Haworth et al. 1988).

Conversely, some authors have described fatigue as the dependent variable (such as Bartlett 1943). Cook and Shipley (1980) describe fatigue as "...the result of high stress activity, whereas ... the term 'loss of alertness' [is used to] describe the effects of continued work under low stress conditions" (Fitts & Posner 1967). The term fatigue is frequently used therefore to cover the effects of both high stress and low stress activities. This is particularly relevant in studies where both high stress (e.g. time on task, high information density and adverse environmental factors) and low stress (e.g. the requirement for vigilance in low stimulation environments) are encountered.

In summary, fatigue can be considered a response to stress and the consequence of fatigue may be subjective, behavioural or physiological. The stressors most frequently considered in the literature are sleep deprivation and its interaction with time of day. Environmental stressors such as noise, heat and cold, the nature and duration of work appear to be less influential stressors contributing to fatigue (Hockey, 1986).

Adaptive and protective aspects of stress and fatigue

Mendelson (1990) describes the emotional effects of occupational stress as being affective disturbances, behavioural manifestations and psychiatric disorders. He cites alcoholism, smoking and drug abuse as well as emotional and psychiatric disorders as possible sequelae to occupational stress and proposes that feelings of tension, apprehension and nervousness associated with emotional arousal contribute to the anxiety response, the first step in a pathway, which may lead to adaptive anxiety. Such adaptive anxiety could either be beneficial in allowing mastery of a stressful situation or alternatively lead to decompensation and development of some psychopathology (Mendelson 1990).

Grandjean and Kogi (1971) refer to discrimination between acceptable and unacceptable (e.g. overwork, overloading, exhaustion) fatigue situations. In that paper they determine criteria for evaluation of fatigue rather than developing an argument for adaptive aspects of fatigue. However in introducing the concept of fatigue, Grandjean and Kogi (1971) described the sensations of fatigue as biological signs of the necessity to recover.

Bartley and Chute (1947) had previously "...interpreted the subjective feelings of fatigue as a warning to the body that its resources were being overtaxed and expected that the subjective feelings would be the first effects of fatigue to be manifest." Bartlett (1951) thought that the warnings generally arrived too late however. Comparison can be made between the adaptive aspects of stress such as adaptive anxiety (which allows mastery and control of the stressful situation) as described by Mendelson (1990) and the protective role of fatigue symptomatology as described by Bartley and Chute (1947) and by Grandjean and Kogi (1971).

Fatigue and alertness

Grandjean and Kogi (1971) discuss fatigue in terms of central inhibition, however such discussion alone risks reducing fatigue to manifestations of reduced alertness, omitting the more complex manifestations such as changes in long and short term memory, information processing and higher cognitive functions.

The role of the reticular activating system in maintaining wakefulness and alerting the cortex was first documented by Moruzzi and Magoun (1949, as reviewed by Berlucchi 1997). As part of the non-specific sensory system, the reticular formation extends from sensory receptors through the brain stem in a multisynaptic network terminating in the cerebral cortex, particularly the association cortex. The reticular activating system arouses cortical cells and determines how responsive they are to incoming signals. Grandjean and Kogi (1971) also refer to a descending corticofugal pathway descending on the reticular system from the cortex, responsible for stimulating the reticular activating system, which in turn maintains the cortex and behaviour in a state of arousal and alertness.

Bills (1931) introduced the concept of blocks (i.e. periods of time in which no responses were made in a laboratory alertness test) as rests which allow the individual to maintain efficiency in spite of the changes which fatigue has wrought on his nervous system. He speculated that the neural mechanism involved was a "...cumulative refractory phase, a periodic breakdown in the central facilitative mechanism..." Hockey (1986) later refers to blocks as brief interruptions in performance; "... prolonged work may be associated with a general increase in mean reaction time, as well as an increase in choice errors." Subsequent authors such as Harrison and Horne (1996) associate "microsleeps" with excessive daytime sleepiness and a marked reduction in behavioural responses. There are serious implications of such periods of cognitive absence such as during the operation of machinery, driving and monitoring equipment. Incidents may result from the operator either failing to remain vigilant or failing to recognise a visual or other cue required for safe operation.

Humoral and pharmacological models of fatigue

It is tempting to postulate that sleep is the consequence of some humoral entity, however early research to determine the presence of such a factor is conflicting. Though humoral sleep theories pre-date neurological theories, it was the advances in neurophysiology in the 1950's that helped explain the role of chemical neurotransmitters in sleep and activation studies. Studies giving credence to the involvement of humoral factors in the regulation of sleep and alertness include those undertaken by Elmadjian et al. (1956), Pappenheimer et al. (1967) and Monnier, (1963). It was the technical advances of the 1950's and 1960's, however, that resulted in these "humoral" factors being best explained in terms of "wet" pharmacology, or the study of neurotransmitters. More recent reviewers (Nicholson & Pascoe 1989; Nicholson 1989; Mendelson 2001) note the involvement of a variety of neurotransmitters in the regulation of alertness.

Secretion of melatonin by the pineal gland was thought to be associated with hypnotic and zietgeber (German for time-giving) properties at least in animal studies (Arendt et al. 1985). Described as a functional third eye, the mammalian pineal responds to changes in light via the suprachiasmatic nucleus of the hypothalamus (Klein 1985) Melatonin is synthesised rhythmically on a 24-hour basis, with a nocturnal increase in synthesis (Klein 1985). Arendt et al. (1985) observes that "... melatonin may have zeitgeber properties with respect to fatigue and alertness..." In a study by Lieberman et al. (1984) oral administration of melatonin decreased alertness and increased sleepiness in environmentally-isolated subjects. Lieberman et al. (1984) also showed that melatonin slowed choice reaction time but decreased errors of commission, concluding that melatonin had short-acting, sedative-like properties. Its role as a possible synchroniser of circadian rhythm forms the basis of melatonin being used in overcoming the adverse effects associated with jet lag (Reiter 1985; Lieberman et al. 1984; Arendt et al. 1985; Comperatore et al. 1996).

2.3. Assessment of fatigue and vigilance

Introduction

Fatigue exists as a hypothetical construct - in the real world it may only exist in terms of its consequences - the subjective experience and its effects on performance. The assessment of fatigue may then, be reflected by the measurement of its effects. The measurement of fatigue in the real world is difficult due to the great variety of moderating variables (Finkelman 1994). In experimental situations, specific dependent variables have been measured following manipulation of the independent variables such as time on task, time of day and sleep.

Muscio (1921) in asking the question "Is a fatigue test possible ?" argued that fatigue is an undefined entity and therefore directly unmeasurable. He proposes a performance-based definition:

> "Fatigue is a condition caused by activity, in which the output produced by that activity tends to be relatively poor, and the degree of fatigue tends to vary directly with the poorness of the output" (Muscio 1921).

He argues that though fatigue *per se* is unmeasurable, the subsequent diminished capacity is measurable, and he proposes a battery of performance and non-performance tests, the latter being measures of physiological variables such as pulse rate, blood pressure and muscle tone thought to be affected by fatigue.

In contrast to fatigue, consumed alcohol can be measured, as can the subsequent physiological, performance and subjective effects. Folkard et al. (1977), in a memory study involving 130 school children, found significant differences in retention of material presented at 0900 compared with 1500 and highlighted the magnitude of this difference by equating it to the performance difference one finds following sleep reduction to three hours, or alternatively being given the legal limit of alcohol for driving. In a recent study undertaken by Dawson and Reid (1997), performance following sleep deprivation was compared with performance following alcohol consumption. Dawson and Reid (1997) found that "... after 17 hours of sustained wakefulness, cognitive psychomotor performance decreased to a level equivalent to the performance impairment observed at a blood alcohol concentration of 0.05%, and after 24 hours of sustained wakefulness, cognitive psychomotor performance decreased to a level observed at a blood alcohol concentration of roughly 0.10%."

Human performance has been measured in laboratory performance tests, workplace tests and by simulations. Subjective measures of fatigue have utilised various rating scales, checklists and questionnaires. In addition, researchers have utilised a battery of experimental performance tests that attempt to establish a relationship to the subjective fatigue state or the performance differential or both. These latter tests have been used as both predictive and reactive to fatigue effects.

Much of the discussion in chapter 5 of this thesis is based on evidence from studies that have determined the amount of sleep that seafarers receive, their ability to subjectively assess their fatigue state and the decrements in performance associated with being fatigued. The following section outlines how fatigue is assessed from both an experimental viewpoint and in real world situations and comments on how fatigue may manifest. Finally, the behaviours associated with being fatigued are extracted and summarised in Table 1.

Subjective assessment of fatigue

Fatigue and sleep rating scales

Sleepiness has been quantified by at least two separate rating scales, the Stanford Sleepiness Scale (SSS), developed by Hoddes et al. (1973) and the later Karolinska Sleepiness Scale (KSS), developed by Åkerstedt and Gilberg (Åkerstedt & Folkard 1995). Such rating scales are designed to provide descriptors of sleepiness at equal-appearing intervals that allow sensitive ratings of sleepiness. Such scales are also validated by comparison with EEG and other physiological variables (Hoddes et al. 1973). Although the Stanford Sleepiness Scale has been independently validated as a predictor of performance following partial sleep deprivation (Broughton 1988), it does not predict individual performance efficiency and cannot be used as a substitute for performance measures in studies involving chronic sleep loss (Herscovitch & Broughton 1981). The Stanford Sleepiness Scale was, however, shown to correlate with performance in most cases in a total sleep deprivation study involving 290 naval seamen by How et al. (1994).

Daily records (diaries) and logs

In the study of watchkeeping by Colquhoun et al. (1988), subjects maintained daily records on a standardised 24-hour chart to record watchkeeping or other activities, the record incorporating a visual analogue scale to record sleep quality. Stampi (1988) reviews the use of interviews, questionnaires and sleep logs in his studies on the effects of ultrashort sleep patterns during singlehanded yacht races.

Parker and Hubinger (1998) utilised on-tour logbooks to record pilotage times, stress, sleep and fatigue ratings plus work schedules in a study of 176 work assignments undertaken by 23 Great Barrier Reef (Australia) pilots over a two-month period. These logbooks were similar to those used by a US Coast Guard Study conducted by Sanquist et al. (1996) involving 148 mariners from 8 commercial ships. Both studies identified a significant fatigue problem within their occupational group, and by inference, internationally.

Actigraphic devices may be used to record movement as an adjunct to written records, and be thereby used to objectively determine sleep periods. For example, Stampi (1988) utilised ambulatory wrist movement recorders to study polyphasic sleep strategies of solo sailors, allowing analysis of data on sleep duration.

Workplace reporting systems

Finkelman (1994) utilised a large database (n=100,000) to survey employees who reported job fatigue during their assignments. The results of this survey are discussed elsewhere, however the author cites lack of controlled and manipulated experimental design as limiting the ability to extrapolate from correlational data.

Behavioural (Performance) tests

Perceptual, cognitive and motor tests

Shingledecker (1989) outlines a group of available physiological and behavioural assessment methods that could be used as meaningful indicators of aircrew performance. These were not intended as a research tool but as a biocybernetic measure to provide the aircraft with feedback on pilot performance, an issue also raised by O'Donnell (1989).

Lamond and Dawson (1999) utilised a battery of neurobehavioural tests (simple sensory comparison task, unpredictable tracking task, vigilance task and grammatical reasoning task) in a study involving 22 participants. This study involved a comparison of performance decrement following a period of sustained wakefulness in comparison with performance decrement following alcohol consumption. Both variables resulted in a decrease in performance, allowing the authors to conclude that after only 20 hours of sustained wakefulness, performance impairment may be equivalent to that observed at a blood alcohol concentration of 0.10%.

Memory tests

Folkard et al. (1977) in a study involving 130 school children (mean age 12 years 11 months) investigated recall of a story presented at either 0900 or 1500 hours. The authors found that immediate recall was superior following the presentation of the story during the morning, whereas delayed recall was superior following the afternoon presentation of the same story. The authors demonstrated a time of day difference in both short-term and long-term memory. Interestingly, the authors found no significant difference between morning and afternoon recall (irrespective of the time of delivery of the story), suggesting that the time of day difference was related to encoding information rather than its recall.

Psychomotor tests

Colquhoun et al. (1988) utilised a vector test, a simple performance test involving an assessment of the risk of collision of two ships with given courses and speeds, represented by two lines of different angle and length. A similar test used by Craig and Condon (1984) required subjects to determine whether the risk of collision existed and also their confidence in their estimation.

Bohnen and Gaillard (1994) used a computer monitor to measure tracking, the ability to hold a cursor in the centre of a target. The dependent variables were the mean square error and the percentage oversteps (Bohnen & Gaillard 1994). In addition, Craig and Condon (1984) utilised a navigational plotting exercise whereby subjects plotted 50 pairs of coordinates on graph paper, the time taken being the measure. How et al. (1994) used a battery of neurobehavioural tests in a sleep deprivation study including the grooved peg board test, the digit span test and the digit symbol test. The authors also measured flicker fusion[3] and subjective variables (How et al. 1994). Craig and Condon (1984) have also used signal identification (similar but different discs) and visual search of a punctuation mark in an array of characters as a performance measure.

Sleep propensity

Lavie (1988) measured EEG, EOG and EMG in normal and sleep-deprived subjects who underwent 7-minute sleep, 13-minute awake schedules for 24

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[3] Flicker fusion (also known as critical flicker fusion, or CFF) is the frequency at which a flickering light appears as a constant image and is often used as an index of fatigue.

hours. Propensity to sleep and to resist sleep was determined using the physiological measures to determine onset and offset of sleep. The results of this study provided the author with evidence of sleep "gates" (periods of increased sleep propensity) and "forbidden zones" for sleep (whereby subjects have difficulty falling asleep). Sleep gates occurred in the afternoon and evening and were preceded by forbidden zones for sleep.

Simulations

How et al. (1994) used a set of known naval tasks in their studies on sleep deprivation, finding an improvement in performance over the first 30 hours, probably due to the effects of practice. There was, however, a drop in performance after 36 hours in all the subjects, followed by a partial recovery and finally a precipitous fall at 72 hours (How et al. 1994).

Physiological tests

Core temperature

Hockey (1986) claims that core body temperature is one of the most stable of all 24-hour rhythms and has attracted more study and attention than any other. Cook and Shipley (1980) note a relationship between body temperature and performance. Colquhoun et al. (1988) used the parameter of oral temperature in their study on sleep and circadian rhythms of ship's watchkeepers. In this study, the authors also monitored rectal temperature, however low social acceptance of this measure resulted in a small sample of results. The authors argue that by reducing environmental factors such as low ambient temperature, and by leaving specially designed oral thermometers under the subjects tongue for a five-minute period, oral approximations of core temperature were obtained (Colquhoun et al. 1988).

Hockey (1986) states that most researchers use body temperature as a reference point and a readily obtained physiological measure when studying the effects of time of day on performance. In Cook and Shipley's (1980) study, there was correlation between body temperature and pulse rates, subjective self-ratings and one measure of reaction time. However, the researchers noted an unexplained observation, that pre-pilotage temperatures were higher than post-pilotage temperatures irrespective of the time of day (Cook & Shipley 1980).

Heart Rate and ECG

Cook and Shipley (1980) measured the heart rate of ships' pilots using Medilog Recorders and found that in addition to the diurnal variation of heart rate there was a considerably higher heart rate when on pilotage duty than when off-duty. In addition they found that during monotonous and uneventful acts, the heart rate fell to a very low level, especially at night. Aasman et al. (1988) also found an increase in heart rate with dual task conditions compared to simple task conditions and that during a working day, the heart rate gradually decreased. Colquhoun et al. (1988) used heart rate as a physiological measure parallel to a continuous record of physical activity.

EEG

Cabon et al. (1993) used a combination of EEG, eye blink (electro-oculogram, EOG) and motor activity, the latter being measured by a small transducer placed on the subject's wrist, and provided a measure of the frequency and duration of sleep periods. Analysis of the EEG and EOG was conducted by Fast Fourier Transformation (FFT) which gave EEG spectrum power and eye blink frequency, measures of which were related to vigilance (Cabon et al. 1993). Broughton (1988) reviewed the use of EEG in determining the effect of microsleeps on performance, many authors claiming that they are the major cause of performance deficit in sleepy subjects.

Heart rate variability

Heart rate variability (HRV) decreases as workload increases (Shingledecker 1989). This is explained by Meshkati (1988) as "...heart rate was said to decrease in situations which required environmental intakes and accelerate in situations in which environmental rejection was involved." Thus a relationship is established between cardiac activity, cortical activity and behaviour (Meshkati 1988).

Critical Flicker Fusion Frequency

Critical flicker fusion frequency (CFF) has been used by Kogi and Saito (1971) to indicate the level of cortical activity. Grandjean et al. (1971) found that there was a significant correlation between CFF and self-rating test of subjective feelings of fatigue in addition to correlation between CFF and tapping tests. Therefore they concluded that all these above measures are indicative of a common state of fatigue.

Biochemical measures – blood, urinary and salivary assays

Measured in many studies, certain electrolytes and organic compounds show relationships with exercise and stress. Dukes-Dobos (1971) notes that these variations in electrolytes and metabolites are affected by nutritional status, climate and environmental conditions, and in the case of substances affected in opposite directions by exercise and stress, there will be a cancelling effect in conditions of both stress and exercise.

Selye (1950) proposed a general adaptation syndrome whereby activation of the pituitary-adrenal cortical axis results in a set of adaptive reactions including increased excretion of adrenaline, noradrenaline and cortisol. Dukes-Dobos (1971) noted contradictory results in studies where urinary metabolites of cortisol have been measured following various stressors. It is important that any measurements are taken at the same time of day to account for time of day variations due to sleep-wake cycles (Dukes-Dobos 1971). Measurement of 17 hydroxycorticosteroids (17-OHCS), which are metabolites of cortisol and cortisone, have shown variable results (Dukes-Dobos 1971).

In a study of ship's watchkeepers, Colquhoun et al. (1988) measured urinary adrenaline, noradrenaline, sodium and potassium and found levels of noradrenaline and adrenaline increased during the watchkeeping period, with levels of adrenaline remaining high during the whole of the waking day. Colquhoun's group found a more circadian rhythm with adrenaline excretion than noradrenaline excretion, noting that adrenaline excretion is more influenced by mental load than by changes in physical activity (reported by Plett et al. 1988).

Goh et al. (2000) studied circadian desynchronisation in 60 military personnel (20 day-work controls and 40 night-shift duties) onboard a naval ship. Salivary melatonin and cortisol profiles were obtained from 2-hourly samples. The authors found that day workers exhibited typical patterns of cortisol and melatonin, whereas 48% of night workers exhibited distortions, abnormal peaks and troughs and phase shifts in melatonin rhythm and erratic peaks and troughs in cortisol rhythm. The authors claim that salivary concentrations closely reflect serum concentrations of those hormones and are much more convenient and non-invasive.

Numerous authors refer to serum melatonin assays in laboratory studies of fatigue and alertness (e.g. Arendt et al. 1985; Lewy et al. 1985; Lieberman et al. 1984; Bitman 1985).

2.4. Performance variables - fatigue behaviours in the literature

In supporting the identification of performance variables associated with fatigue found during an analysis of Incidents at Sea reports presented in chapter 4, it is appropriate to summarise the performance variables obtained from the literature. In this chapter so far, the author has referred to the nature of fatigue and numerous assessments of fatigue, determined as being subjective, behavioural or physiological.

In comparing performance variables extracted from the literature with behaviours extracted from Incidents at Sea reports, the subjective and physiological measures of fatigue were largely omitted from further study. The conclusions of Incidents at Sea reports describe human behaviours (or human contributions in behavioural terms) that have resulted in the particular incident. There is infrequent reference to subjective measures of fatigue (such as where a watchkeeper admits to feeling tired or sleepy) and there is no opportunity to measure physiological variables (unlike the measure of blood alcohol used in motor vehicle accident investigation). There appears to be no appropriate physiological measure to assess fatigue in real world settings, nor would there be any more capacity to measure such a variable in maritime accident investigation.

Table 1: Fatigue Behaviours

Fatigue Behaviour	Reference
1. Activation problems	
Decreased vigilance (during a constant task)	Mackworth 1950; Krueger 1989.
Decreased alertness (to a possible problem)	Hockey 1986; Fitts & Posner 1967; Haworth et al. 1988; Stokes & Kite 1994; Broughton 1988; Vidacek 1993; Condon et al. 1988b; Folkard & Monk 1979.
Gaps, lapses or blocks	Haworth et al. 1988; Bills 1931; Hockey 1986; Brown 1989; Harrison & Horne, 1996.
2. Perception (and sensory input) limitations	
Reliance on visual (eyes and radar) inputs	Bryant 1991.
Decreased attention to peripheral instruments	Hockey 1986.
Uncertainty of observations	Bohnen & Gaillard 1994.
Decreased night-time communication	Ohashi & Morikiyo 1974; Graeber 1989b; Bryant 1991.
3. Information processing problems	
Decreased encoding/registration of recently acquired information	Hockey 1986.
Failure to interpret information as part of a single, integrated system	McFarland 1971.
Decreased ability to correlate dynamic processes	Luczac 1991.
Decreased ability to process lower and peripheral processes	Sablowski 1989; Gaillard & Steyvers 1988.
Information processing deficiencies in secondary task	Sablowski 1989.
4. Aversion to effort	
Low effort, low probability of success	Hockey 1986.
Easy, but risky alternatives	Hockey 1986.
Response latency/decreased speed of execution	Hockey 1986, Dawson & Reid 1997.
Lower standards of accuracy and performance	McFarland 1971, Colquhoun et al. 1988, Craig & Condon, 1984.
5. Differing effort	
Increased variability of timing of actions	Hockey 1986.
Decreased performance with lower/peripheral processes	Gaillard & Steyvers 1988.
General performance decrement	Grandjean 1970; Folkard & Monk 1979; Condon et al. 1988b; Haworth et al. 1988; Brown 1989; Stokes & Kite 1994; How et al. 1994; Parasuraman 1986; Hockey 1986; Cameron, 1974.

Behaviours associated with fatigue may serve as markers or identifiers of fatigue (among other things) in the absence of subjective or physiological measures. The classification of behavioural manifestations presented here (i.e. activation problems, perception limitations etc) were developed from the behaviours coded and classified in the analysis of Incidents at Sea reports and will be dealt with in the results and discussion chapters. The specific behaviours, however, are expressed in the terms that the various researchers have used in their studies (i.e. decreased vigilance, blocks, information processing deficiencies in a secondary task etc).

Table 1 summarises the behavioural or performance manifestations of fatigue as described in the scientific literature. Most of these behaviours have been discussed previously and have been extensively described in the literature. References attributed to the particular behaviour are exemplary and are not specific to a particular independent variable. The reference list includes studies using laboratory-based experimental models as well as occupational studies from maritime, aviation or industry settings.

2.5. Contributing factors: circadian desynchronisation and its consequences

Time of day - cyclical changes

The nature of circadian rhythms

The state of the body is able to adjust in anticipation to daily events - predictive homeostasis which presents as a series of daily cycles of body temperature, sleepiness, wakefulness, catecholamine and corticosteroid levels which have a direct influence on psychological, physiological and performance variables. The term circadian rhythm was coined by Halberg (Hockey 1986) and infers a rhythm of about one day. In addition, longer (infradian) and shorter (ultradian) rhythms have been identified (Broughton 1975; Lavie & Scherson 1981). Such rhythmic processes are said to have a period, a phase and an amplitude: studies of circadian rhythms tending to use a sinusoidal mathematical model (Hockey 1986). Endogenous rhythms are the body's innate rhythms resulting from some internal clock, whereas exogenous rhythms are those rhythms that are entrained by environmental factors such as light and dark, social behaviour and work patterns (Hockey 1986).

The internal clock and entrainment

In the absence of daily cues such as clocks, work commitments and meals, the body's internal clock usually has a period of approximately 25 hours (circadian means "about" one day). Mistleberger and Rusak (1989) note the existence of an internal biological clock mechanism with a 25-hour periodicity that is influenced by environmental cues. The internal clock is thereby entrained to a 24-hour cycle by such cues, which are called zeitgebers (German for "time givers").

The body's internal clock is thought to be located in the suprachiasmatic nucleus of the hypothalamus in association with other centres responsible for the control of body temperature and cortisol secretion (Mistleberger & Rusak 1989). Conn (1995) states that in all mammals, the cells of the suprachiasmatic nucleus receive retinohypothalamic input. Thompson (1993) states that these optic nerve fibres serve to entrain the suprachiasmatic nucleus rather than to control it, an argument he claims is supported by experimental studies where circadian rhythms remain intact on severing the optic nerve but are abolished by experimental lesions to the suprachiasmatic nucleus. Photic entrainment is the most significant cue, mediated by a neural pathway from the retina, via the lateral geniculate thalamic nucleus to the suprachiasmatic nucleus of the hypothalamus. Neural transmission from the suprachiasmatic nucleus mediates circadian variations in melatonin, produced by the pineal gland, via the sympathetic nervous system's superior cervical ganglion (Klein 1985). Mistleberger and Rusak (1989) also note the regulatory influences of periodic food availability, ambient temperature and social cues in animal models, however noting substantial interspecies variability. In humans, the biological clock is particularly robust with a very persistent phase that resists adjustment to non day-work patterns (Åkerstedt 1995a). The human internal clock forms the basis of a variety of daily variations in physiological activities.

Circadian rhythm in alertness and sleep propensity

Subjective alertness in humans increases during the waking day and reduces prior to sleep. Studies delving further into this phenomenon have identified an alertness rhythm coupled to physiological need for sleep. Objective alertness may be measured by sleep propensity as proposed by Lavie (1988) or multiple sleep latency as proposed by Dement, (Carskadon & Dement 1977). Circadian rhythms and sleep are intimately interrelated; "sleep gates" occurring at predictable times during the day, allowing the transition from the waking state to the sleeping state, in order to obtain the sleep necessary for tissue repair and restitution, as well as consolidation of memory (Horne 1978). Disruption of circadian rhythms due to shift work, jet lag or underlying sleep pathology will most likely be associated with sleep deprivation and its consequences. For example, Folkard (1996) notes that the decrease in sleep propensity between 0600 and 1200 corresponds to the time that night shift workers might try to get some sleep between shifts.

In a study of sleep propensity, Lavie (1988) proposed "gates of sleep", as the probability of falling asleep varies in a systematic way across the 24 hours. The author found that the probability of falling asleep was "... low during the morning-midday period increased during the afternoon, decreased again during the evening and gradually increased during the evening." Lavie (1988) also identified three peaks of sleepiness with sleep deprived subjects; a morning, a mid afternoon and a nocturnal peak. The nocturnal peak of increased probability of falling asleep (from 2300 hours and for 4.5 hours thereafter) was consistent in both normal and sleep-deprived subjects and was termed by Lavie as the nocturnal sleep "gate". The period just before the sleep "gate" has been termed the "forbidden zone for sleep" and is characterised by a large decline in the tendency to fall asleep, explained in terms of spontaneous activation of arousal related neural networks (Lavie 1988).

Ultradian rhythms

Ultradian rhythms include the 90-minute cycling between REM and non-REM sleep that occurs during normal sleep. Kleitman (1963) claimed the existence of a "basic rest activity cycle" (BRAC), also of 90-minutes duration, which has been supported by a number of studies. Broughton (1975), in his review of biorhythmic variations in consciousness and performance, notes that "normal" day work social and break activities incorporate the BRAC, and cites numerous studies supporting ultradian (predominantly 90 minute) rhythms during wakefulness such as gastric contractions, oral activity, heart rate and body temperature. The major implication of these rhythms is a propensity towards sleep, or at least reduced alertness that, in times of sleep loss or inadequate recovery, may lead to a critical performance breach and a possible accident.

Lavie and Scherson (1981) demonstrated rhythmic variations in subject's ability to fall asleep throughout the day and proposed that persons retiring at a somnolent phase of these daytime rhythms will exhibit a greater sleep propensity than those retiring nearer crests of arousal. Broughton (1988) does, however, state, "it appears that drowsiness enhances the daytime ultradian rhythm of vigilance, whereas high alertness suppresses it." Superimposed on the circadian rhythm, the basic rest activity cycle may influence alertness and sleepiness in some predictable manner, however confounding environmental factors are likely to render any measurement of this effect in real life situations impractical.

Time zone desynchronisation ("jet lag")

Adaptation to altered schedules either due to transmeridian flight (which results in "jet lag") or a change of work-sleep pattern (e.g. shiftwork) result in a phase shift of various rhythms depending on the ability of the individual to adjust to the new schedule (Hockey 1986). In the case of "jet lag" the new time zone is usually adopted for a longer period of time and social and day-night zeitgebers rapidly entrain the various rhythms, however in the case of shiftwork, there is usually alternation between the night shift state and more sociable day off schedules resulting in a compromise adjustment of body rhythms (Hockey 1986). Though not historically applicable to the maritime setting, modern high-speed vessels are capable of crossing time zones on a daily basis, and the use of air transport to transfer crew renders jet lag a potential fatigue-inducing factor.

There are two issues concerning so-called "jet lag". Firstly, the effect of time zone crossings and secondly, the opportunity for entrainment once the destination is reached. The latter issue depends largely on the amount of time spent at the destination time zone. "Jet lag" is a phenomenon of transmeridian flight and unlike shiftwork; the social and physical zeitgebers only allow adaptation over a long stay. Adaptation is relatively faster when the journey is east to west rather than vice versa. Hockey (1986) proposes that this is due to the phase delay of westward flight being more physiologically natural to the normal delay in the endogenous circadian rhythm.

In a study of adaptation of ship's watchkeepers conducted by Condon et al. (1988a) the authors found that there was full adjustment of phase to a change in time zone of 30 minutes per day. The study by Condon et al. (1988a) did, however, find that the normal body temperature waveform was distorted and that "...the peak of the daily curve occurred at a time that was earlier on westward journeys and later on eastward journeys, than is usual in ordinary circumstances." The authors propose that this distortion may be due to either an endogenous response of the rhythm to the shift in zeitgeber schedule or from alterations in sleep duration (Condon et al. 1988a).

The implications of this adjustment are particularly noteworthy in the aviation industry, both from the viewpoint of multiple time zone crossings and the shift schedules of airline pilots. Melton and Bartanowicz (1986) recommend phase delayed schedules (i.e. early shifts preceding afternoon shifts preceding night shifts) for air traffic controllers and the avoidance of long schedules of midshifts (midnight to morning) and extrapolate the dietary recommendations for travellers to the needs of night shift workers by advising high protein meals before going to work, high carbohydrate, low protein meals upon leaving work together with caffeine in coffee or tea during the first half of the night shift with abstinence during the latter half. The authors therefore note the similarity that exists between the issue of adjustment from jet lag (from moving time zones) and adaptation to a differing shift pattern (from moving work periods).

The adjustment from one time zone to another however is assisted by the presence of consistent zietgebers in the new time zone, and unless there is frequent moving between time zones (as in the case of airline crew), the subject has the opportunity to rapidly entrain to the new time zone, whereas the typical shift worker usually works in one "time zone" (the shift) but lives in another (the non-shiftwork world with all its daily cues). One might argue that shiftwork presents a chronic adjustment crises, in comparison with the once only adjustment associated with jet lag.

In addition to the slow time zone adjustment required on board a ship at sea, there is the increasing problem of jet lag associated with air travel associated with crew changes. There is a tendency to use air travel to redeploy ship crew, particularly in the offshore industry. Unless crewmembers have the opportunity to acclimatise to the new time zone before commencing duty, critical crewmembers (such as watchkeepers) risk being desynchronised in addition to being sleep deprived subsequent to their travel. There is at least one Incidents at Sea report citing jet lag as a contributing factor.

2.6. Contributing factors: sleep deprivation and its consequences

Sleep deprivation

Sleep

In a review of total sleep deprivation, Horne (1978) notes that sleep is governed by a requirement for tissue repair and restitution; non-rapid eye movement (non-REM) sleep, and a sleep mechanism directed towards protein synthesis and consolidation of memory; rapid eye movement (REM) sleep. Normal daily sleep duration is about 7.5 hours (with variability of about one hour) in the young adult with a slight decline in old age (Hockey 1986). Studies into sleep loss usually consider either the effects of total sleep loss (one night), partial sleep loss (several sleep cycles) or selective sleep loss (Hockey 1986). The latter usually involves the prevention of a particular type of sleep, usually REM sleep.

Sleep is characterised by changing levels of consciousness with alternation between two states - non REM sleep and REM sleep. Non-REM sleep, the first period after falling asleep, is characterised by a fall in heart rate and blood pressure and an alternating cycle of sleep depth over approximately 90 minute cycles throughout the night, deeper levels diminishing progressively over the period of sleep. Classically, there are four stages of non REM sleep described, the most deep (stage 4) characterised by sleepwalking, talking, tooth grinding and nightmares, particularly in the young. Stage 4 sleep is also called slow wave sleep (SWS) due to a characteristic electroencephalogram (EEG) pattern.

REM sleep, also called paradoxical sleep, is associated with rapid eye movements, dreaming, profound muscle relaxation and an increase in blood pressure, pulse and breathing. REM sleep occurs for a few minutes at a time, but the episodes lengthen as the night progresses with changes in body position and body movement in alternating between non-REM and REM states.

Total sleep loss

In most real-world work settings, total sleep loss is unlikely, however as a worst-case scenario it is relevant to identify the consequences of this extreme condition. Early studies on the effect of total sleep loss on performance have not yielded conclusive results, however it became apparent that the effects of total sleep loss varied depending on the particular task under investigation. Williams et al. (1959) deprived 50 volunteer subjects of sleep for 98 hours and found that lapses increase in frequency with hours of sleep deprivation during a reaction time task. The authors also found that speed was adversely affected in subject-paced tasks whereas errors were critical in event-paced tasks under prolonged sleep deprivation. The authors found an increase in variability of reaction time - by an increase in blocks or lapses, which are characteristic of many studies into total sleep loss (for example, as reviewed by Hockey 1986). Williams et al. (1959) termed these blocks "microsleeps", brief periods of reduced EEG alpha amplitude, which become more common with fatigue.

2.7. Other factors affecting human performance

Though time of day and sleep deprivation appear to be the major factors contributing to fatigue and affecting performance, there are also a variety of individual, environmental and work-related factors. Many of these factors have particular significance in the maritime industry with its unique shiftwork, technological and economic contexts.

Time on task

Grandjean and Kogi (1971) state that "fatigue appears to be the chief factor limiting a person's output... and that when the working day is lengthened, hourly productivity goes down...". Brown (1989) claims that if duty periods are extended for too long, there is a "...disinclination of the human brain to continue producing the same response over and over again to the same environmental stimulus..." - a term he called "reactive inhibition". Studies in which subjects are required to perform over long periods have identified changes in patterns of attention (Hockey 1986).

The effect of shift length is a significant predictor of performance decrements and accident propensity. Hanecke et al. (1998) analysed data on 1.4 million accidents looking at time of day and hours at work and noted an exponential increase in accident risk after the 9th hour of work. The researchers were limited in not having available the time of commencing work, however Folkard (2002) in his empirical review of work hours for the U.K. Civil Aviation Authority noted a 30% increase in relative risk of accidents for the night shift compared to the day shift. Time on task and time of day (i.e. shift commencement time) interact in a complex manner, however it is a reasonable simplification to state that accident risk increases with shifts commencing later in the day, and also increases with the shift duration.

The maritime setting is quite different from typical land-based eight-hour shift systems, as ship's watches are typically four hours in duration and the exponential rise in accident risk after nine hours work, as described by Hanecke et al. (1998), is therefore not able to be observed.

Performance over time is also significantly influenced by the nature of the task; Brown (1989) observes that few tasks are truly continuous and that many tasks permit voluntary rests at intervals during the task. Holding (1983) states that "... change *per se* appears to play a significant role in overcoming effects of fatigue ... and ... subjects may be able to compensate for a reduction in efficiency in meeting the demands of short tests." Most importantly, Holding (1983) states that "... tests have not examined the most central feature of the tonic fatigue state, that of aversion to effort...many of the effects of prolonged work may be seen in terms of less active control over behaviour and the selection of easy but risky alternatives" (Holding 1983).

This concept, referred to in terms of a speed-accuracy trade off is a well-documented phenomenon of prolonged work (Hockey 1986). Bartlett's (1951) cockpit studies experiments showed that when pilots became fatigued, "...they were willing to accept lower and lower standards of accuracy and performance." In addition, Bartlett (1951) found that they failed to interpret various instrument readings as part of a single integrated system and most significantly, there was a general tendency for an increase in errors at the end of a flight. Holding's (1983) Choice of Probability and Effort test (COPE) identified that after 24 - 32 hours on a multiple performance battery, subjects were found to be more likely to choose low effort/low probability of success strategies. Hockey (1989) summarises this phenomena in that "...a prolonged period of cognitive overloading may put an individual into a state where any further effort to meet task demands is aversive."

The classical view of fatigue proposed by Bartlett (1943) whereby there is a measurable deterioration in performance over time must be considered in association with other influencing factors. Stokes and Kite (1994) discuss the results of the Boeing Commercial Aircraft Company's study of fatigue-related accidents which indicate that the number of incidents peak in the middle of the duty period and decrease thereafter. Simon Folkard (1997) considered transport accident risk as a function of time of day and time on task and notes both circadian performance factors will reflect time on task for shifts commencing at certain times. Based on the work of both Pokorny and Wharf, Folkard (1997) makes the observation that relative risk of accidents increase over the first four hours of work, then decreases to a minimum at about 6-8 hours, only to rise exponentially thereafter. Folkard (1997) notes that the relative risk decreased by nearly 30% from the first four hours on duty to the second four hours on duty and explains the cause of the transient 2-4 hour period in terms of re-automisation of skills in the latter part of an eight-hour shift. Condon et al. (1988b), in studies of ship's watchkeepers, notes that alertness tends to decline when a spell of sleep is imminent.

Time-on-task usually parallels time-since-sleep, given that many working days or shift periods follow a period of sleep. Nicholson and Spencer (1988) propose that "...changes in performance during an irregular schedule of work and rest arise from both the endogenous circadian rhythm and the time that has elapsed since the end of the preceding rest period..."and have developed a mathematical model incorporating a sinusoidal component for time of day and a cubic trend in time since sleep. Nicholson and Spencer (1988) claim that this model could be used to predict changes in performance at different starting times and note in particular that performance of workers who commence duty in the evening will rapidly fall to very low levels due to the combination of time of day (circadian rhythm) and time since sleep. This model has been presented most elegantly by Åkerstedt and Folkard (1995) as the "Three Process Model of Alertness Regulation", where time since awakening, circadian influences and sleep inertia interact to affect alertness in a predictable manner.

Automation

Workload is an important human factors issue, in aviation as well as the maritime industry. In a study using the Airbus Industrie workload model where pilot error could be measured using line flights of varying workload and automation, Blomberg et al. (1989) suggest that there is a relationship between the severity and type of error and workload and that automation and workload are inversely related. The implication is that automation decreases workload and this decreased workload decreases errors and thereby increases safety. Though high workload could lead to errors, there is an optimum level of workload that provides optimum balance between boredom at one extreme, and overstimulation on the other. High workload could lead to a loss of spare capacity to attend to anything but the task in which the operator is engrossed (Blomberg et al. 1989). Automation allows the operator the capacity to concentrate on the critical task while concurrent non-critical or less critical tasks are executed. The issue of low workload has infrequently been addressed, there being need for further study as suggested by Blomberg et al. (1989).

An alternative case could be put whereby high levels of automation tend to encourage gross blunders rather than small errors (Blomberg et al. 1989). With the trend towards decreased crew size and increased automation in both the aviation and the maritime industry however, the relationship between workload, automation and errors/safety is pivotal. Roscoe (1989) notes that flight deck automation is associated with an increased probability of pilots experiencing underload and under arousal leading to reduced vigilance and even complacency.

The concern is expressed by Graeber (1989b) that low workload and the compromise of mental efficiency at night and after successive time zone crossings coupled to a decrease in (air) crew size may detrimentally affect decision making. Graeber (1989b) proposes that manufacturers capitalise on the power of on-board computers to generate high levels of attention and to monitor operator responses; to provide feedback to crewmembers about their alertness, and to provide stimulation to overcome boredom and sleepiness while on duty.

The decrease in workload associated with automated systems and the subsequent decrease in crew size may lead to changes in crew communication behaviours in both normal and emergency conditions. Graeber (1989b) notes that crews in advanced cockpit systems communicate less often with each other than do those in more traditional two-man cockpits and that this communication is even less frequent at night. Poor crew coordination has been identified as one of the prominent causes of aviation accidents and incidents (Lauber & Kayten 1988).

Crew size

Economic imperatives have pressured shipping companies and legal authorities to think about ways to save costs by increasing automation and reducing crew manning (Sablowski 1989). The Committee on the Effects of Smaller Crew Size on Maritime Safety (1990) note the interdependence of the four dimensions (technologies, people, organisational structures and the external environment) of the sociotechnical systems of ships. The introduction of new technologies, if managed in conjunction with the other three dimensions may result in improved health, safety, quality of work life and operating efficiency, however "... the extent to which technology, implementation, and associated crew reductions increase the risks of stress, fatigue and boredom is not precisely known, since little research has been devoted to stress in the shipboard environment" (Committee on the Effects of Smaller Crew Size on Maritime Safety 1990).

The two possible major effects of reduced crew size are overload, due to increased work hours and the more specialised nature of the work, (with reduced extra capacity in times of high work intensity), and underload and decreased vigilance due to the automation that invariably accompanied decreased crew size. Either extreme may result in fatigue and concomitant performance decrement with consequences for safety and efficiency.

Decreased crew size and automation present the risk that the navigator could become detached from the operation of the system by becoming a passive monitor in systems that remove much of the active content from the job, without decreasing the need for vigilance (Committee on the Effects of Smaller Crew Size on Maritime Safety 1990). Additional difficulties are encountered as a result of the non standard arrangement of ship bridges, lack of integration of navigational equipment and poor ergonomic bridge design without consideration for the ultimate user (Committee on the Effects of Smaller Crew Size on Maritime Safety 1990).

Decreased crew size has led to changes in the way modern vessels are manned, with the introduction of integrated bridge systems and single handed bridge operations, and integration of deck and engine room operation. In times where wages were not a major factor in vessel running costs, even small pilot vessels had manned engine rooms with separate engine and deck departments. In the modern ship's operation centre, routine navigational tasks, and controls for essential vessel functions are automated and centralised allowing a single operator control of all vital functions of the vessel. The Committee on the Effects of Smaller Crew Size on Maritime Safety (1990) note that "... when systems are working properly, this environment may be stimulating enough to keep the officer on the bridge awake and alert. On the other hand, it may be distracting enough to degrade performance on critical course keeping and collision-avoidance tasks." Studies that have evaluated the impact of automated bridge systems on performance have been inconclusive (Committee on the Effects of Smaller Crew Size on Maritime Safety 1990).

Single-handed bridges where the watchkeeper serves as helmsman operate either legally or without permission. The success of such an operation in simulation studies requires that ship control tasks change from active control actions to passive monitoring activities. There is the risk that operators may be reduced to a role of passive monitors of control systems. This issue is addressed in the section on human factors and automation and it is noteworthy that the argument in favour of automation in the aviation industry may be considered in quite a different light in the maritime industry. The control of a ship by a single fallible person may present a higher risk to life and property than the control of an aircraft by two-flight crew rather than three. In addition, the system redundancies, alarms and ground control requirements in aviation, coupled with "voyages" measured in hours rather than days and weeks may further require the maritime industry being considered in quite a different light.

The operation of a ship has been traditionally divided into a deck department and an engine department with lines of demarcation between the two areas of expertise. Both departments have operated separate, but around-the - clock watches with little if no integration. Automated engine rooms relieve the engine department of standing the traditional watch system and allow control of the engines to be conducted from the bridge. Most commercial shipping currently has capacity for unmanned engine rooms (unmanned machinery space) with implications in both automation (e.g. bridge monitoring of engine functions) and crew size. The US Coast Guard, Marine Safety Manual does, however, stipulate that vessels with automated engine departments carry sufficient crew to safeguard it if all the automated systems fail (Committee on the Effects of Smaller Crew Size on Maritime Safety 1990). In addition, engineers operating vessels in unmanned machinery space mode no longer stand watches and are on call outside their normal rostered hours (Committee on the Effects of Smaller Crew Size on Maritime Safety 1990). The effect of being on-call places this group of workers in a position where they may suffer additional anxiety and stress, sleep loss and performance decrements.

Medical conditions, sleep apnoea and minor illnesses

Though it is beyond the scope of this literature review to detail a health profile of the maritime industry, some picture can be painted of the health of seafarers and comments made on the possible consequences of health on performance. A number of disorders such as sleep apnoea do have a direct effect on sleepiness and therefore performance. Seafarers have higher than average incidence of specific diseases, some of which may be related to the seafaring lifestyle. In addition, some studies indicate a significantly higher incidence of personal accidents both at sea and ashore, a statistic which may indicate that seafarers exhibit risk-taking behaviour in addition to the occupational risks involved in seafaring.

Health profile of the maritime industry

In a series of three studies, Filikowski et al. (1992) examined the health of over 10,000 Polish seafarers over a ten year period from 1971 and found an increase in the incidence of neuroses, arterial hypertension, ulcers of the stomach and duodenum and renal calculi. The incidence of alcohol dependency decreased over that ten-year period.

Carel, Carmil and Keinan (1990) in a historical prospective study of a group of 144 ship captains and marine chief engineers found that though there were certain behavioural risk factors more dominant among seamen, there were only mild differences in biochemical and physiological health parameters as compared to a reference group of matched controls. The sample group, though not representative of the general seafaring population, reported higher levels of smoking, alcohol (>3 glasses per week) and coffee consumption, utilisation of medications and lack of physical activities, however only heavy smoking differed statistically significantly between the two groups. The specific sample group "...tended to show greater satisfaction at work and in life in general compared with the controls. They also indicated fewer complaints that could indicate depression, anxiety and burnout." The authors concede that though captains and chief engineers possess more behavioural and physiological risk factors than the control group, the slight differences in health indices may be attributable to the healthy worker effect, the self-selected nature of the group and the balancing effect of their high positions.

Rafnsson and Gunnarsdottir (1992 and 1993) investigated both fatal accidents at sea and fatal accidents occurring other than at sea among Icelandic Seamen and claim that "...fatal accidents at sea are about 36 to 50 times more frequent than occupational accidents ashore." In addition to occupational accidents, Rafnsson and Gunnarsdottir (1993) deduced that "...seamen seem to be a special group with a high risk of fatal accidents," based on the standardised mortality ratio of 1.83 for death due to accidents, poisoning and violence. They also found that "...length of employment was associated with higher risk of accidents unrelated to work indicating that seamen may have riskier lifestyles and that "... more experienced than inexperienced seamen died in accidents and drowned at sea" (Rafnsson & Gunnarsdottir 1993).

The effect of minor illnesses

Smith (1992) reviews the effects of minor illnesses such as the common cold on performance and notes that:

- Influenza impairs performance on tasks where a person is unsure of whether a signal will appear.
- Colds impair psychomotor performance slowing speed of response and reducing eye-hand coordination.
- Performance is impaired prior to the development of symptoms and can persist into convalescence.
- Minor illnesses make the individual more susceptible to the effects of other factors, such as prolonged work or noise.

Incidents at Sea rarely refer to the presence of minor illness as a factors contributing to accidents, however people living in close confinement are frequently susceptible to respiratory illnesses, which coupled to time of day and sleep factors may result in considerable performance deficits.

Sleeping disorders

Obstructive sleep apnoea is a likely factor contributing to excessive daytime sleepiness, fatigue and performance deficits. Gander et al. (1998), notes that while obstructive sleep apnoea affects up to 4% of the adult male population, some occupational groups exhibit a greater incidence, quoting one US study (n=156) claiming that 46% of commercial truck drivers suffered from moderate to severe sleep apnoea. Gander et al. (1998) notes that large neck size, age, regular snoring and excessive daytime sleepiness are risk factors for sleep apnoea. Parker and Hubinger (1998), in their on-tour analysis of 176 work assignments involving 23 Great Barrier Reef pilots note that a considerable number of pilots were classified as either overweight or obese as well as a considerable number reporting experiencing breathing difficulties while sleeping. A questionnaire survey of 263 Australian transport drivers found that 6% of drivers had a diagnosis of obstructive sleep apnoea, but a Multivariate Apnoea Prediction questionnaire and polysomnographic studies supported an obstructive sleep apnoea incidence of 18% (Howard et al. 2000). The authors' results mirrored those of other studies (such as Stepanski et al. 1984) in that sleep apnoea resulted in fragmented sleep, and excessive daytime sleepiness.

Johns (2000) notes that though sleep apnoea may increase an individual's instantaneous sleep propensity, subjects will avoid situations or modify their behaviour in situations where sleep onset may occur if they are required to perform tasks such as driving or operating machinery.

Drugs

Drugs could be considered from both the viewpoint of the intentional modification of behaviour, either stimulation for periods of activity or depression to facilitate sleep, or from the viewpoint of the side effects of recreational drugs such as caffeine, alcohol and marijuana.

The performance enhancing effects of amphetamines such as Benzedrine has been known and utilised in military applications since the Second World War (Mackworth 1950). Dopamine transmission acts to maintain wakefulness and amphetamines act to stimulate wakefulness by stimulating dopamine receptors in the reticular activating system (Nicholson & Pascoe 1988). Mackworth (1950) investigated these actions in post-war vigilance research, finding that Benzedrine (amphetamine) improved both speed and accuracy (particularly the latter) in a battery of vigilance tests. Buysse (1991) states that amphetamines increase sleep latency, decrease total sleep time and sleep efficiency, increase body movements, increase REM latency and decrease the amount of REM sleep. Krueger (1989) reviews the use of sedatives and hypnotics, ranging from tryptophan and benzodiazepines to facilitate rest and sleep prior to military missions (such as the raid on Entebbe).

Caffeine and other methylxanthines block adenosine receptors and enhance wakefulness (Mendelson 2001). Caffeine leads to marked sleep disturbances, increases wakefulness and drowsy sleep and reduces slow wave sleep (SWS) and total sleep time (Nicholson & Pascoe 1988). Caffeine attenuates the decrease in overnight performance and improves performance and vigilance during the day. (Nicholson & Pascoe 1988). Weiss and Laties (1962) however, make the point that performance is not normally improved unless previously suppressed by fatigue and boredom.

The effects of alcohol on performance are well documented in the transport, aviation and shipping industry and there are frequently legislative and company restrictions that apply to blood alcohol concentration or periods of abstinence prior to work. The extensive body of road safety research indicates that alcohol exerts a marked influence on tracking tasks, causes a deficit in information processing rate with a marked shift towards fast, inaccurate performance. (Hockey 1986). In addition, alcohol effects include problems with the acquisition of new material, with storage of order information more of a problem than that of item information (Hockey 1986).

The relationship between performance following sleep deprivation and performance following ingestion of alcohol (Lamond & Dawson 1999) facilitates comparison between these two variables (i.e. 20 hours of sustained wakefulness equates to a performance with a blood alcohol concentration of 0.10%)

The new 1995 amendments to the IMO International Convention on Standards of Training, Certification and Watchkeeping for Seafarers advises governments to prescribe a maximum of 0.08% blood alcohol level (BAC) for seafarers during watchkeeping and to prohibit alcohol consumption within 4 hours prior to serving as a member of the watch (The revised STCW convention 1995). It appears incongruous that though the new Convention is "... arguably the most important development concerning the improvement of maritime safety in over a decade" (The revised STCW convention 1995) it is still within the spirit of the standards that a watchkeeper may navigate a 100,000 tonne tanker with a blood alcohol concentration almost twice the legal limit of an automobile driver.

The physical environment

As distinct from continuous or sustained operations that have been discussed previously, the watchkeeping environment may also be contributory to fatigue. Human factors research involves the study of ergonomic design to adapt both work demands to human capabilities and human performance to work demands (Luczac 1991). The watchkeeping environment has changed dramatically in recent years, from the exposed ships wheel in traditional sailing ships, to the semi open wheelhouse in small coastal vessels (and as currently applies to most coastal fishing vessels) to the environmentally controlled bridge of a modern supertanker. Each watchkeeping situation presents its own environmental and ergonomic difficulties including heat and cold, noise, motion, visibility, exposure to climactic variation, illumination, and chemical and gaseous contamination.

The majority of performance studies have centred around heat and noise, however, aerospace medicine has also provided the impetus for work on the effects of gravity, acceleration and deceleration, and, along with diving and hyperbaric medicine, the effects of pressure. There is surprisingly little evidence of research on (sea) motion sickness in the medical literature.

Noise

The presence of unwanted sound on a ship bridge results from the constant sound and vibration of the ship's engines, the noise of wind and sea and to a lesser extent, the intermittent use of sound signalling devices.

Jones and Broadbent (1987) review the effects of noise on performance and describe deleterious as well as performance-enhancing effects. Performance will be temporarily disrupted by sudden bursts of noise, which may affect posture (due to the startle reflex) or intake of information (due to masking signals). Background speech will have damaging effects on remembering verbal material and continual unvarying noise will have damaging effects on performance at the end of a long period of work (Jones & Broadbent 1987). The effect of noise may, however, counteract the effect of sleep loss. Corcoran (1962) found that noise was arousing and reduced the decline in performance that is normally associated with loss of sleep. The author notes, however that separately, noise and sleep loss both serve to decrease performance. Noise usually accentuates strategies resulting in more extreme judgements and more confidence in the adequacy of a decision, even though this may be unwarranted (Jones & Broadbent 1987).

The effects of noise on watchkeeping and the interrelation of noise with other variables are not well documented. From the above studies, noise may contribute to erroneous and risky decision making and concentration on particular sources of information on the bridge, phenomena well documented in accident reports (Bryant 1991).

Finally, noise effects memory and cognition, however researchers have observed that continuous noise improves recall of the dominant aspects of a stimulus but impairs recall of contextual and spatial information surrounding the dominant stimulus (Hockey & Hamilton 1970). This tendency is described as the incidental-learning paradigm. Other researchers have found that increased alertness during learning facilitates recall after a delay but impairs immediate retrieval of the material (Kleinsmith & Kaplan 1963), though interpretation of this research is confounded by the often-different nature of tests of immediate recall and delayed recall (Hockey 1986).

The effect of noise on a ship bridge has the potential to affect watchkeepers decision making, tending towards more extreme decisions, based on the most dominant information with decreased accuracy with speed of cognitive activity. Though noise may enhance delayed recall, decision-making may be hampered by decreased immediate recall.

Heat and cold

A second significant environmental variable affecting performance is that of heat and cold. In the modern ship's bridge, the temperature is controlled by air conditioning and ventilation systems - a far cry from the open wheel on the deck, exposed to the ravages of wind and weather. Rarely would a watchkeeper suffer exposure to environmental temperatures so extreme, save for accidental immersion or tropical heat in brief periods on deck. The work in the engine department is quite a different matter with extremes of temperature and noise being experienced for virtually all of the time during the working period. Much of the research in the area of extremes of climate has centred on the determination of performance and length of continuous work in varying conditions of humidity and temperature under different types of work. The body has some capacity to adapt to changes in environmental temperature, however there is some cost both physiologically and in terms of performance.

Hockey (1986) describes the performance changes in cognitive reaction time associated with heat as including a clear trade off between time and temperature. Exposures to temperatures above 35°C should be limited to less than 2.5 hours, however continuous performance tasks are almost independent of exposure time, but sensitive to temperature increases above 30°C. Hockey (1986) notes that artificial increases in body temperature are not inductive to increases in performance unlike the increased temperature associated with circadian fluctuations in body temperature.

Extremes of temperature and humidity are unlikely to play a significant role in the performance of deck watchkeepers, except for brief periods of exposure to climatic factors in tropical or artic environments and during exposure to enclosed machinery spaces. This situation contrasts strongly to that of the engineer watchkeeper.

The job environment

Finkelman (1994) conducting a large database study (n=100 000) of factors associated with work-induced fatigue identified 3705 reports of fatigue. The study surveyed the employee database of a large regional employment agency in California and identified lack of job challenge as the major cause of fatigue (Finkelman 1994). Poor supervision ranked second with supervisor attributes being described as demanding, uncaring, unreasonable and unfair (Finkelman 1994). Less than 3% of temporary employees reported lack of sleep as a contributory factor, sleep deprivation being mainly due to travel between two assignments, work and financial anxiety and in some cases, the physical demands of the work (Finkelman 1994). From the database study, the author interprets five factors thought to be associated with either perceived or actual fatigue:

- Inadequate information processing demands; high information processing assignments being far less likely to be associated with reports of job fatigue than low information processing assignments,
- Lack of job control,
- Ineffective job performance
- Low pay rate,
- Low physical demands.

Finkelman (1994) concludes that the physical demands of a job assignment had the lowest correlation with reporting of fatigue whereas information processing demands of a job assignment had the highest correlation with reported job fatigue; assignments with an inadequate level of information processing were most likely to be associated with fatigue on the job.

2.8. Human error, watchkeeping and accidents

The concept of human factors and human error

The term human factors or human element has achieved popular usage in contemporary literature; the term human error indicating component failure where human intervention is involved as a component of a complex system. Bryant (1991) observes that separation of the human and technological elements of complex systems is difficult in practice and argues that "... seafaring is a way of life that cannot be separated from the physical environment and the technology that supports it." Similar views are expressed by Nitka and Dolmierski (1987), Nitka (1989 and 1990), and Dolmierski et al. (1990).

Human behaviour is far from totally predictable (Bryant 1991), however in most countries, attempts are made to analyse accidents with the view that human factors could be identified and behaviours studied and hopefully modified. Bryant (1991) proposes that marine casualty investigations are undertaken to explain and understand the event, to establish blame and liability and to comply with legal requirements. While some aspects of marine accidents may be able to be explained using the laws of physics, aspects involving human behaviour may not follow some scientifically reliable and valid pattern. However, from a cognitive control viewpoint, there is some predicability in error forms, as Reason (1990) states "far from being rooted in irrational and maladaptive tendencies, these recurrent error forms have their origins in fundamentally useful psychological processes." Reason (1990) claims that there are a limited number of ways in which errors may manifest themselves, depending on the " 'computational primitives' by which stored knowledge structures are selected and retrieved in response to current situational demands".

Error modelling systems

James Reason (1990) defines an error as a generic term to encompass those occasions in which a planned sequence of mental and physical activities fails to achieve its intended outcomes and when these failures cannot be attributed to some change agency. It is evident therefore that human errors are possibly contributory to incidents or accidents, however it is not sufficient or necessary that an error may cause an accident.

Reason (1990) explains this in terms of the failures in the elements of production in complex systems, namely corporate decision making, line management, preconditions (skilled workforce and reliable equipment), production activities (the interaction of human and mechanical elements) and defences against foreseeable hazards.

The model of accident causation due to human error proposed by Reason (1990) describes "windows" of weaknesses in "planes" of production, such that if all the "windows" line up, an accident results. This is the basis of contemporary "risk management" approaches to workplace safety.

Reason's (1990) planes of human contribution to breakdown of complex systems are:

1. **Fallible decisions by designers or managerial decision makers**. Fallible decisions are constrained by the conflicting goals of safety and production. In incidents at sea, a fallible decision might include

inappropriate or insufficient policy on manning levels, passage planning or operational instructions.

2. **Line Management Deficiencies.** Training and supervision act in concord to ensure that managerial decisions are carried out effectively and efficiently. A maritime example is the lack of proper monitoring by the watch officer or leaving navigation to unqualified hands.
3. **Psychological precursors of unsafe acts.** Each single precursor may contribute to many unsafe acts and such precursors may have no relation to the workplace (for example, home stress, illnesses and marriage breakdown). The maritime setting might include such psychological precursors as drinking during and before duty, intentional sleep restriction, attitudes of laxity and allowing personal problems to interfere with work demands.
4. **Unsafe acts.** Whereas preceding contributors are latent failures, unsafe acts are active failures – either by omission or commission, in the presence of a hazard. Unsafe acts involve the error types that will be discussed below – slips, lapses, mistakes and violations. In the maritime setting, such acts include overloading holds, ignoring signals, leaving the bridge, falling asleep and failing to alter course.
5. **Inadequate defences.** These are also active failures and present a limited window of opportunity to remedy the consequences of an unsafe act. Very few unsafe acts result in damage or injury and with "defences in depth" such as in nuclear power plants, unsafe acts are less likely to cause an incident. Maritime examples are failing to recognise that a vessel is aground, failing to ascertain injuries after an accident and failure to summon assistance.

Reason's (1990) classification of human contributions to breakdown of complex systems as described above is entirely appropriate to the maritime setting – one has only to reflect on the "Titanic" disaster to readily classify the human contributions of that incident according to the above categories.

Proctor and van Zandt (1994) review the acquisition of cognitive skill in expert systems and describes the levels of behavioural controls that interact in determining performance in specific situations proposed by Jens

Rasmussen (1986). Reason's Generic Error Modelling System (GEMS) is based on Rasmussen's three performance levels, namely:

1. **The skill-based level**; stored patterns of pre-programmed and largely automated instructions used as routine actions in familiar environments,
2. **The Rule-based level**; stored rules or procedures derived through instruction or experience and operating at a conscious level,
3. **The Knowledge-based level** occurs in situations for which no rules are applicable. Performance at this level involves problem solving, reasoning and decision-making.

Reason's (1990) Generic Error Modelling System uses Rasmussen's levels of behavioural controls to further subdivide slips and lapses, and mistakes. Reason defines slips and lapses as failures in execution and/or storage of an action sequence regardless of whether the plan which guided them was adequate to achieve its objective, and mistakes as deficiencies or failures in the judgement and/or inferential process involved in the selection of an objective or in the specification of the means of achieving it irrespective of whether or not the actions directed by this decision scheme run according to plan.

The three error types described by Reason (1990) are therefore:

1. **Skill-based slips and lapses** such as inattention, omissions, confusion and interference errors. Much of an experienced navigator's performance is skill-based.
2. **Rule-based mistakes** such as misapplying good rules or applying bad rules. Factors such as information overload, encoding deficiencies and existence of inelegant or inadvisable rules. Numerous formal navigational rules exist as well as less formal custom and practice.
3. **Knowledge-based mistakes** result from failure in the powerful, yet slow serial and effortful "on-line" reasoning. Problem configurations may be static (such as in many psychometric tests of performance) or dynamic (such as in real world situations). Navigation involves multiple dynamic configurations where strategies are developed to

manoeuvre large vessels, through a dynamic medium (the sea) in context with other dynamic structures (other vessels, tugs and sometimes aircraft).

Human error, watchkeeping and the task of navigation

Navigation of a ship is a slow system feedback model, whereby the actions of the navigator do not immediately result in any meaningful feedback (Bryant 1988). In addition to this lead time, navigation is also affected by tide, weather, water density and depth as well the complex mechanical systems as involved in propulsion and steerage of the vessel. The navigator must also be able to accommodate an increasing sophistication of instruments such as electronic charts, radar, satellite and other electronic navigation systems and incorporate this additional information, along with environmental and mechanical factors in a complex decision making process to ensure the safe command of the ship. Such decision-making behaviour could be described as predictive rather than reactive.

The implications of failure in the slow system feedback notion of ship handling coupled to a complex man-machine interface could be illustrated in the Chernobyl nuclear power plant disaster where management failure in a complex, dynamic environment led to a nuclear explosion (Luczac 1991). The disaster resulted from deficits in knowledge-based and social-interactive behaviour where 'intelligent idiots', intelligent enough to act as reactor operatives, but not intelligent enough to be aware of the consequences of their actions, brought the reactor to an unstable condition, with all automatic safety devices switched off, by following imperative orders with respect to an intended, but unauthorised test (Luczac 1991). Rasmussen (1986) describes similar deficiencies in the Three Mile Island disaster.

From the above analyses, neither overload, nor fatigue of the operators were major contributory causes, nor was automation alone a factor in these disasters, but a combination of management and system design interfacing with willing but uncritical human operators.

CHAPTER 3 - THE RESEARCH DESIGN

3.1. Methodological approach

The central research question and three related questions are best addressed from a qualitative stance. The basis for this approach is that:

1. Incidents at Sea reports are individual textual documents containing a rich body of description, analysis, interpretation and conclusion (for an example of an Incident at Sea Report, see Appendix 1). Each report can stand alone, is unique and needs no reference to other reports. Incidents At Sea reports are not presented as statistical (or numerical) data,
2. The conclusions of Incidents at Sea reports are informed opinions of skilled and experienced investigators, and are therefore already the result of some interpretation. They do not necessarily have the raw data that might be necessary for a statistical analysis,
3. Not all incidents at sea are investigated. Though there is a requirement for investigators to investigate incidents according to certain statutory criteria, for various reasons (such as simply failing to report an incident) not all incidents are investigated.

There is, however, some argument for utilising a quantitative, though not statistical, component to this study on the following basis:

1. Incidents at Sea reports in Australia are structured (i.e. have an introduction, summary, incident description, analysis and conclusions) and include all incidents required by statute to be investigated (though noting point 3 above),
2. The collective body of Incidents at Sea reports (almost 2000 paragraphs in summaries and conclusions alone) comprises data that can be used to establish themes, trends and patterns,
3. Conclusions of Incidents at Sea reports are comprehensive (i.e. contain latent and active errors, human and mechanical and environmental contributors), are mutually exclusive and are expressed in

behavioural, non-judgemental terms. A collection of 1224 mutually exclusive, behaviourally described conclusions forms a quantitatively valid (though not necessarily statistically valid) data set from which subsets of data can be extracted.

4. Software (such as NUDUST) currently exists that readily allows quantification of textual data in an investigative manner that was not possible with previous manual methods.

The methodological approach therefore used has been largely qualitative, looking at patterns, themes and ultimately coding and categorising text from Incidents at Sea reports. In addition some quantification of categories, particularly in respect of the "time of day" component where the incidence of particular behaviours during specific watch-keeping periods, were analysed.

3.2. Textual analysis

In this study, fatigue is considered from the viewpoint of the marine incident investigator and fatigue is primarily examined in the context of marine incident reports. Thus, the research objective is to show the way in which marine incident investigators identify fatigue as a possible cause of incidents and what possible fatigue-induced behaviours are implicit in marine incident reports.

There are two perceptions of fatigue that may be expressed in marine incident reports - firstly the individual subjective experiences of fatigue experienced by personnel on board ships (including watchkeepers) and secondly, the interpretation given to these experiences by accident investigators. In examining these perceptions, textual analysis approaches such as content analysis, analytical semantics and hermeneutics could be applied to Incidents at Sea reports.

In analytical semantics, text, particularly sentences, is interpreted against certain linguistic, logical, semantic or empirical claims (Lindkvist 1981). Sentences could be described in terms of their functions: analytical, synthetic, expressive, prescriptive and performative (Lindkvist 1981). The aim of analytical semantics is thus to eliminate ambiguity by showing the internal connection of the meaning of text (Lindkvist 1981). Semantic analysis of Incidents at Sea reports would identify meaning within strategically selected sentences that may determine whether the function of the text unit was, for example, to ask about the effects of fatigue, to interpret some information that had been provided, to express an opinion of the investigator or to prescribe some course of action as a result of some finding. Such an approach may be of use in determining the purpose of component parts of an investigation report, however the component sections of Incidents at Sea reports are invariably well contextualised. For example the text section of a report includes a summary, sources of information, sequence of events, comment, conclusions and subsequent action, which pre-empt the functions of component sentences. Unfortunately, transcripts of investigator's interviews are not readily available, but such documentary material could be analysed semantically in order to decrease uncertainty and better establish the reality of the event. An appropriate incident would be the grounding of the vessel *TNT Alltrans* on Lady Musgrove Island, which was a Court of Marine Enquiry (rather than an Incident Report), where evidence was circumstantial, conflicting, ambiguous and subject to expert professional testimony.

Hermeneutics considers the hidden meaning of text, emphasising the basic questions of thought (Lindkvist 1981). Lindkvist (1981) notes that text says nothing beyond what we knew before, and the text itself points to the method to which it is to be interpreted. As a phenomenological approach, hermeneutics is subjective, allowing the analyst to " 'enter the language', engage oneself as a subject, be influenced by the text" in order to understand the textual meaning (Lindkvist 1981). Hermeneutics is not a suitable methodology for relatively well-structured archival text, and it is unlikely that Incidents at Sea reports exhibit any "hidden meaning".

Finally, content analysis, as defined by Krippendorff (1980) is a "...research technique for making replicable and valid inferences from data to their context." Content analysis formed a suitable methodological basis for this study and arguments for its application are proposed.

3.3. Content analysis

Following Krippendorff's (1980) definition of content analysis, it is a "research technique" in that specialised procedures are used for processing scientific data and it is "replicable" in that, as an instrument of science, other researchers using the same data must be able to obtain the same results. These aspects of content analysis are reiterated by Lindkvist (1981) who discusses content analysis as a method for objective, systematic, and quantitative description of the manifest content of a text.

The place of procedures and impartiality of the researcher (objective) and the use of rules to ensure validity (systematic) are supported by Lindkvist (1981), however the issue of quantification versus generality is enigmatic. In most cases, the results obtained depend on the questions asked and content analysis (particularly using the speed and flexibility of a computer) allows the posing of theoretical questions and establishing meaning from the text based on those questions. This is supported by Lindkvist (1981) who states "...only by linking data together with theoretical questions is analysis meaningful."

In this study, examples of theoretical questions posed during analysis of Incident Reports included:

- What is the incidence of fatigue being determined as contributory to an incident?
- What is the nature and incidence of human error in conclusions of Incidents at Sea reports?
- What behaviours, consistent with being in a fatigued state, are evident in Incidents at Sea reports, and what is the distribution of those behaviours through the six watchkeeping periods?
- What part does sleep deprivation play in accident causation?
- How does the need for sleep, being asleep and the watchkeeping routine affect fatigue behaviours and possibly contribute to marine accidents? How do watchkeepers balance the need for sleep with operational demands?
- Who are the major contributors to marine incidents (i.e. master, mate, pilot etc)?

- What are the differences in behaviours, time of day and incident type for each of the major contributors?

Krippendorff (1980) claims that the requirement to be quantitative is restrictive and qualitative methods in content analysis have had many successful outcomes. Content analysis could quantify meaning through sampling, coding, recording and finally interpretation of textual information. Applications include the analysis of newspaper editorials, advertising, mass media, political speeches and propaganda, both from a quantitative (for example, the number of references to women in a political speech) and a qualitative viewpoint (for example, an anthropological analysis of the meaning of linguistic symbols). In this study, content analysis was used both in a qualitative (e.g. the development of the concept of fatigue behaviours) and quantitative (e.g. the differing distribution of these fatigue behaviours across the six watchkeeping periods) manner. In each case, text units (i.e. paragraphs) were isolated from the text, coded, contextualised (both again with the original text and with similarly coded paragraphs), interpreted and discussed. The software readily allowed both an objective and systematic coding of text units as well as contextualising the text unit within its origins and the wider data set of incident reports.

In defining content analysis, Krippendorff (1980) stresses two misleading connotations. First, "...messages do not have a single meaning that needs to be unwrapped" which signifies that text may contain many simultaneous messages. Secondly, "meanings need not be shared" (Krippendorff 1980). These two issues are central to the research questions stated in the previous section. What is perceived as a fatigue inducing factor by a seafarer may be considered a reasonable requirement of employment by a shipping company and similarly, fatigue induced behaviour as described by a watchkeeper may be interpreted as lack of attention by an accident investigator. Krippendorff (1980) notes that messages and communication generally are about phenomena other than those directly observed and that the receiver must make inferences according to his empirical environment - the context of the data.

In comparison with other research techniques, Krippendorff (1980) claims that content analysis has the following distinctions:

1. **Content analysis is an unobtrusive technique.** Any act of measurement will interfere with the behaviour of the phenomena being assessed - creating increasingly contaminated observations the deeper the observer probes (Krippendorff 1980). Laboratory investigations of fatigue, particularly those involving behavioural or subjective dependent variables, by their contrived nature frequently lack ecological validity. Incidents at Sea reports, being retrospective analyses of actual events have high ecological validity and contain data about the possible presence of fatigue as a contributing cause of accident as well as interpretation on the part of accident investigators - all occurring in the natural environment of the sea or during an actual accident investigation respectively.

2. **Content analysis accepts unstructured material.** The data language used in content analysis is that of the message sender rather than the engineered language of the receiver/analyst. One difficulty facing historians and of retrospective study in general is that the text exists in a form that may have never been designed for interpretation and even prospective studies may fail to generate the questions that may support or refute a hypothesis. Weber (1985) notes that such material may exist over long periods of time - even centuries, thereby providing a source for generation of cultural indicators from such historical unstructured data.

   Incidents at Sea reports however, could hardly be termed unstructured - on the contrary, they are the result of a methodical investigation as specified in the Regulations of the Navigation Act. The regulations apply to investigation for the purposes of identifying the circumstances in which an incident occurred and to determine its cause rather than for the purposes of research, though the Marine Incident Investigation Unit does maintain a database holding the essential details of each incident reported for use in research and for the publication of statistics. Incidents at Sea reports are structured for the purpose of meeting statutory requirements, determining cause and for statistical purposes. The use of these reports for determining a relationship between fatigue behaviours, sleep and accident may render them "unstructured" for this purpose.

3. **Content analysis is context sensitive and thereby able to process symbolic forms.** Krippendorff (1980) cites two reasons why a researcher

may wish to interpret data in context. Firstly, verbal data is symbolic phenomena, and exists in reference to its contextual surroundings. Secondly, data may exist in a context "...that is neither shared nor conceptualised in a manner similar to that of the individual communicators or subjects involved." Content analysis allows the researcher to establish not only the meaning of the data but to analyse data in its original context and in other contexts developed by the researcher. In Incidents at Sea reports, the data exists in the context of the statutory requirement to determine the cause of incidents, however a researcher may wish to view the data in the context of the human element as a contributing cause of accidents, fatigue behaviours or perhaps the perception of fatigue by incident investigators.

4. **Content analysis can cope with large volumes of data.** Though small and unique bodies of text could be subject to content analysis, the data generated could quickly exceed the capacity of a single researcher (Krippendorff 1980). This dilemma has historically been addressed by instituting a collaborative team of researchers and assistants that code and analyse considerable quantities of textual information. More recently, computer analysis of unstructured data has been readily achievable using personal computers and the Internet has not only assisted in the exchange of textual material, analytical software and methodological discussion but has been subject of considerable content analysis as a contemporary mass media.

Weber (1985) cites two additional advantages of content analysis over other data generating and analysis techniques:

5. **Content analysis operates directly on text or transcript of human communication, which is itself a central aspect of social interaction.** This differs from approaches whereby meaning, interpretation and linguistic aspects of communication are analysed. Though content analysis operates directly on text, Incidents at Sea reports are the result of an interpretive process. It could be argued that interview transcripts, communication records and original reports from those under investigation should form the text that is directly analysed.

6. **Both qualitative and quantitative operations on text can be utilised.** This thereby combines the complimentary strengths of what are sometimes thought to be antithetical modes of analysis.

Krippendorff (1980) describes three systems used in content analysis. Firstly, he describes the extrapolation of trends; an early form of content analysis (for example Speeds 1893 analysis of New York dailies). More recently, John Naisbitt (1982) has used content analysis in a futures study to project trends in the coming decade in his popular books Megatrends. In this analysis of Incidents at Sea reports, the determination of trends (across watchkeeping periods, with major human contributors and with incident type) formed a major component of the analysis. These trends are expounded in the discussion. The frequency and quality of reference to fatigue as a contributing cause of incidents at sea (or increasing awareness by incident investigators of fatigue) was not analysed due to the small sample size (being only seven reports where fatigue was contributory).

The predictive use of patterns is a second content analysis system whereby patterns in text have predicability regardless of particular contents (Krippendorff 1980). In this study, watchkeeper's behaviour was isolated from the context of the incident, and patterns across watchkeeping periods were established. The patterns of behaviour resulting from fatigue found in these real life incidents appeared to be consistent with those found under experimental conditions and described in the scientific literature.

Finally, content analysis may assess "... the differences in messages generated by two communicators, by one source in two different situations, differences in audiences addressed and differences between input and output" (Krippendorff 1980). This system was used in this study in order to determine the different manifestations of fatigue (termed fatigue behaviours) described by investigators in Incidents at Sea reports.

The research questions would be best answered by identification of both patterns of fatigue descriptors within Incidents at Sea reports and differences between these descriptions, and their interpretation and the subsequent conclusions made by the investigators. Patterns in the description of fatigue would best be extracted from the language used by seafarers - by actual transcripts of verbal information presented at investigations and during

Marine Courts of Inquiry. Differences could be obtained from comparison of the previous data and the language used in Incidents at Sea reports - the language of investigators. Limitations and assumptions using this approach are discussed below.

3.4. Sampling strategies

A comprehensive study of maritime incidents as a possible consequence of fatigue should consider two populations:

- The population of seafarers,
- The population of incidents at sea.

In consideration of the former, the following subpopulations exist:

The subpopulation of seafarers who may experience fatigue

Analysis of this subpopulation (which may be the same as the total population of seafarers) could provide data on the incidence and subjective experience of fatigue. Such data could be used to study the descriptors used to define fatigue in a maritime setting. In addition, performance decrement due to fatigue may result in "near misses" rather than catastrophes; in most instances fatigue does not result in an incident. This may be due to the human ability to adapt to physical and technical environments, to system automation and redundancy, and to the fact that not all human errors are critical. In the latter sense, fatigue may result in an error by an operator, however only a small proportion of such errors result in a catastrophic incident such as a collision, grounding or fire. Comprehensive records of such near misses are unlikely to be found in incident reports.

The subpopulation of seafarers whose competent behaviour is critical to the safe (i.e. incident free) operation of the ship

Without attempting to marginalise various aspects of maritime competence, some elements of competence, such as preparing a passage plan or fixing the ship's position, play a critical part in ensuring the safe operation of the ship whereas other elements of competence such as preparation of menu items and performing a stock take do not have an immediate impact on safety. It is arguable that inadequate or inappropriate diet or unavailability of critical parts may constitute a medium to long-term safety issue, however there is a less distinct causal relationship with such competencies. Within the population of seafarers one role, that of deck watchkeeper, embraces many critical competencies. The author proposes that the tasks performed in the deck watchkeeping role as performed by Deck Watchkeepers and supervised by the Chief Mate and Master were the most critical to the incident free operation of the ship and possibly the most sensitive to the effects of fatigue. This is supported by The United Kingdom Mutual Steamship Assurance Association [Bermuda] Limited (1993) assertion that the major cause of insurance claims is deck officer error (27% of all claims from 1987 to 1992). Analysis of elements of competency within the Maritime Competency Standards (ANTA 2001) and the (International) Seafarers Training, Certification and Watchkeeping Code revealed elements of competence that could be described as critical to the safe and incident free operation of a merchant ship. It was these critical competencies that were related to fatigue behaviours and error types in analysis of Incidents at Sea reports.

Though not central to this study, it was necessary from time to time to refer to the competence of personnel in other roles, such as integrated ratings, who may perform tasks in close association with watchkeeping tasks, or, in smaller vessels, where composite duties are undertaken.

In considering the populations of incidents at sea, not all incidents are reported, and of those reported, the statutory authorities only investigate a small proportion. In considering the populations of incidents at "sea", many incidents involve pleasure boats and occur in inshore waters. The issues of competence, and of training and experience in such cases are extraneous variables and adversely affect the validity of considering fatigue as a contributing factor to maritime incidents. It is preferable therefore to exclude such incidents from analysis. Subsequently, this study considered only the sample of incidents that have been investigated by statutory authority.

Incidents at sea investigated by statutory authority

In Australia, the Marine Incident Investigation Unit of the Department of Transport have statutory responsibility to investigate incidents at sea as defined in the Navigation (Marine Casualty) Regulations as specified in the Navigation Act of 1912.

Within the Regulations, an incident is defined as:-

"...an event:

(a) that has resulted in:

(i) the loss, presumed loss or abandonment of a ship; or

(ii) material damage to a ship; or

(iii) the death of, or major injury to a person, that is reasonably suspected of being caused by, or in connection with, the operation of a ship; or

(iv) the loss of a person from a ship; or

(v) the stranding or disabling of a ship or the involvement of a ship in a collision; or

(vi) material damage being caused or reasonably suspected of having been caused by, or in connection with, the operation of a ship; or

(vii) serious damage to the environment being caused or reasonably expected of having been caused by, or in connection with, the operation of a ship; or

(b) as a result of which:

(i) serious damage to a ship or structure might reasonably have occurred; or

(ii) serious damage to the environment might reasonably have occurred; or

(iii) it is reasonably suspected that the safety of a person was imperilled by, or in connection with, the operations of a ship" (Navigation Regulations 1990).

Further, the Regulations interpret reference to an incident as "...reference to an incident that involves, or involves the operations of, a ship:

(a) in the territorial sea of Australia or in waters on the landward side of the territorial sea; or

(b) if evidence relating to the incident is found in Australia; or

(c) to which part II of the Act applies (Navigation Regulations 1990).

There are four advantages of using the Incidents as reported under Statute:

- The Navigation Act of 1912 applies only to commercial vessels which infers a standard of training and competence of personnel,
- There are criteria for inclusion of incidents, in that an incident is defined,
- There is a statutory requirement to conduct investigations, maintain records and publish reports which provides a plethora of potential data,
- Data from incident reports (which are defined under Statute) may better integrate with other data prescribed by Statute including specifications of competence and technical standards.

Under the current Act, 105 incidents at sea had been investigated at the time of this study, resulting in publication of 91 Incidents at Sea reports by the Marine Incident Investigation Unit. It would be both impractical and inappropriate to analyse all 105 reports, hence a sampling strategy was considered.

There are both quantitative and qualitative rationale for sampling in content analysis. Krippendorff (1980), in his introduction to content analysis methodology has considered random sampling, systematic sampling, stratified sampling, cluster sampling and varying probability sampling. Given that this is a qualitative study, there is no statistical basis for using random sampling or systematic sampling (whereby every n^{th} unit of a list is selected), also a statistical sampling method.

Stratified sampling recognises subpopulations within a population, called strata. As a modification of random sampling, stratified random sampling offers greater matching of the subpopulation with the population on certain key variables (Mitchell & Jolley 1988). Again, stratified sampling offers representativeness and this method was not considered in this study.

Cluster sampling uses groups of elements as sampling units. The Incidents at Sea reports exist as clusters classified by type (i.e. fire, collision, grounding, foundering, injury and fatality), by location (either State / Territory or maritime area, e.g. Great Barrier Reef, Torres Strait) by time of day or by flag (i.e. country of registration). Analysis of certain clusters (e.g. collisions and groundings) yielded fatigue and performance-sensitive data.

Varying probability sampling assigns probabilities according to some *a priori* criterion in order that a representative sample could be obtained. Again, this option is based on the statistical requirements of quantitative methodologies.

Sampling for qualitative analysis

Mitchell and Jolley (1988) offer the option of convenience sampling, whereby subjects are sampled that are easy to survey. Analysis of the Incidents at Sea reports is aimed, in part, at identifying fatigue-sensitive behaviours. The use of computer-assisted analysis allowed some quantification of these behaviours. The aim of sampling is therefore aimed at achieving a workable sample based on the availability of data, on maximising the identification of fatigue-sensitive behaviours and descriptors of fatigue, and identification of elements of competence that are both sensitive to fatigue and critical to the safe operation of the ship.

Miles and Huberman (1994) suggest sampling options ranging from a single case study to more complex methods, however they expound the characteristics of qualitative samples as being small rather than large, purposive rather than random, evolving rather than pre-specified and theory-driven rather than context-free. Such characteristics allow analytic generalisations rather than the sample-to population generalisations found in quantitative work (Miles & Huberman 1994).

In this study, a generic, funnelling sampling sequence, as described by Miles and Huberman (1994) was used, allowing for a progressively deeper understanding of fatigue. First, the summaries and conclusions of 100 consecutive reports (comprising some 1966 paragraphs or text units) were analysed quantitatively and qualitatively in order to establish the incidence and nature of the incident type, human contributor, human contribution (i.e. fatigue behaviour) and error types and forms. As profile of human contribution became clearer and understanding deepened, the sample size decreased in order to study the phenomenon of fatigue (particularly sleep) in some depth. The latter part of the study considered the entire content of some 44 reports where there was evidence of considerable human contribution to the accident. In order to facilitate analysis, only reports available electronically were considered and in addition criteria for inclusion were:

- Fatigue was determined as contributory by accident investigators
- Fatigue behaviours were evident (usually three or more)
- Human factors were primarily contributory to the accident

The incident was excluded if the primary contributory factor was adverse weather or sea conditions, structural failure or fire in the absence of any initial human contribution.

The sample comprised all collisions and groundings, plus two other incidents where there was considerable human contribution.

Sources of data and analysis software

Of the 105 Incidents at Sea investigated by the Marine Incident Investigation Unit available at the time of analysis, 14 were under investigation and full reports were not available. Of the remaining 91 reports, numbers one to 26 were available in hard copy from libraries, numbers 27 to 91 were available in summary form (but including an unabridged list of conclusions) on the Marine Incident Investigation Unit's World Wide Web site on the Internet, while the most recent reports (87 to 91) were also downloadable via FTP from the MIIU homepage. Summaries and conclusions of the Incidents at Sea reports were scanned using optical character recognition software where the report was unavailable electronically, or downloaded from the Marine Incident Investigation Unit Web site (<http://www.miiu.gov.au> to June 1999) and imported into NUDIST®. In the second study, complete reports were imported into NUDIST®, again using the paragraph as the "text unit" for analysis.

The summaries of the Incidents at Sea reports comprise a brief outline of the incident and the context of the investigation, while the conclusions identify the different factors contributing to the incident. Conclusions are a mutually exclusive list of contributory factors as determined by the investigation process, each Report averaging 14 text units.

The availability or not of more detailed information is problematic as the publication of reports is not obligatory under the Regulations and "much of the investigation information is gathered under conditions of confidentiality and much of the detail...may be on file rather than in the report" (Filor, K., Marine Incident Investigation Unit, 1996, pers. comm.). There is, however, a rich source of data in the Incidents at Sea reports available electronically, and given that a small sample, in context and studied in depth, is both practical and desirable (Miles & Huberman 1994) in a largely qualitative study, transcripts and more detailed information on individual cases were not sought in this study.

Version 4.0 of the qualitative data analysis software NUDIST® (Qualitative Solutions and Research Pty Ltd) was utilised for storage of data, coding, analysis and reporting. NUDIST® (an acronym for non-numerical unstructured data indexing, searching and theorising) is a program designed for the storage, coding, analysis and retrieval of text and is regarded by Weitzman and Miles (1995) as "one of the best thought out qualitative analysis programs around". (For a discussion on the use of computers in qualitative analysis see Richards and Richards 1994). NUDIST® accommodates an indexing system of nodes (categories of related text units) and documents can be displayed, browsed and searched using Boolean, set logic, and sophisticated matrix and vector operators.

Once the Incidents at Sea reports were formatted according to NUDIST® requirements (text-only flies, without formatting) they were imported into the program, given unique identifiers and formed the "document system." The NUDIST® "index system" allowed "text units", complete reports, or sections of complete reports to be categorised ("indexed" as it is known in NUDIST®) and attributed a hierarchical indexing code. Incidents were indexed according to time of day (by watchkeeping period), incident type (collision, grounding etc), major contributor (master, pilot etc) and whether the investigator determined fatigue was a contributory factor.

Individual text units (conclusions in particular) were indexed according to fatigue behaviour, error type and human contribution. In many instances, NUDIST's powerful search capabilities were used to locate specific text items (e.g. the word "Radar") or to generate a list of paragraphs with common themes (e.g. reference to sleep, sleeping, being asleep, falling asleep, being drowsy, tired or run down). NUDIST® allowed the use of wild card commands (e.g. sleep* for any reference to any text containing the word sleep) and Boolean operators facilitated the narrowing of text for analysis.

Collections of coded text were exported as reports that were easily assimilated into word-processing packages. The examples of behaviours in tables 2, 3 and 4 in the results chapter were taken from NUDIST® reports. Appendix 2 illustrates the nature of a NUDIST® report, in this instance the 47 text units coded against the node pertaining to the fatigue behaviours presenting as information-processing deficiencies. It is of note to refer to the summary information provided at the end of a NUDIST® report, which assisted checking data for omissions or duplication.

3.5. Data analysis

Data analysis, as described by Miles and Huberman (1994) consists of three concurrent flows of activity: data reduction, data display and conclusion drawing/verification.

"Data reduction refers to the process of selecting, focussing, simplifying, abstracting, and transforming the data that appears in written-up field notes or transcriptions" (Miles & Huberman 1994). Such condensation allows for chunking of data that facilitates the drawing of final conclusions and verification (Miles & Huberman 1994).

There were two components to the data analysis, the first being the qualitative and quantitative analysis of the conclusions of 100 consecutive reports, primarily identifying the time of day contribution to fatigue and accidents. The second aspect involved a qualitative analysis of the full text of 44 selected reports looking at aspects of sleep and sleep deprivation. Specific coding, analysis and analysis details for each component are outlined below.

Time of day component

The paragraph was chosen as the unit of analysis and is termed a "text unit" by NUDIST®. The 1224 text units (comprising all conclusions of 100 reports) were categorised as follows:

1. Incidents type (collision, grounding, fire, foundering, fatality/injury and other)
2. Human contribution to the breakdown of complex systems (after Reason 1990)
3. Error type (skill-based slips and lapses, rule-based mistakes and knowledge-based mistakes (after Reason 1990)
4. Investigator's determination that fatigue was a contributory factor
5. Reference to time of day by watch period (based on the six watch system)
6. Reference to fatigue behaviour (obtained from the literature review).

Incidents at Sea reports make reference to the behaviours of the various actors in the scenario. For example, in Incidents at Sea report 52 (the grounding of the *Malinska*), reference is made to the Master who, in taking evasive action, considered mistaken information and "failed to verify the validity of the information before acting upon it". There were many instances of behavioural information and description in Incidents at Sea reports that were coded and later compared with fatigue behaviours, subjective experiences and physiological states that had been described in the scientific literature.

Sleep factors component

The sleep factors component involved a content analysis of a sample of 44 Incidents at Sea reports. The sampling criteria included reports where human factors contributed to the incident (i.e. excluding fires, foundering and injuries to crew and collisions and groundings where the main contributing factors were weather and equipment failure). In the main, this comprised collisions and groundings; however one report of injury and one of overpressurisation were included due to the involvement of substantial human error. Reports prior to 1991 were excluded due to the heterogeneous nature of these earlier reports, the newly formed MIIU adopting a pro forma for incident reporting from this date.

Again, the paragraph was chosen as the unit of analysis (text unit). The 44 reports comprised some 6,208 total paragraphs (an average of 141 paragraphs per report). References to sleep made by accident investigators was determined by conducting a text search for sleep and related words (such as sleep, slept, asleep, rest, wake, awake, alert, bed etc.).

Reference to sleep was coded into three levels of possible association[4] with accident (high, medium and low) and five descriptive categories (see Table 5). Three of the five categories were subsequently subdivided into specific, described behaviours or factors.

3.6. Trustworthiness of the study - limitations of the data source

Differing views are held on the relevance of marine incident reports as a source of data for analysis of fatigue. The pilot study focussing on the quantitative aspects of marine casualties conducted by the Tavistock Institute of Human Relations (reported in 1982) showed that "valuable information on the human factor could be extracted from the Department's casualty records (Bryant 1991). Similarly, Remi Joly of Transport Canada (1996, pers. comm.) states that "accident reports...have relevant data...to draw on" for the purposes of researching the effects of fatigue on the performance of ship watchkeepers. However these views conflict with that of Brown (1989) who states that "...the marine Surveyor's files are not a reliable source of evidence in the contribution of fatigue to shipping accidents, because those files provide inadequate information on accident-involved individuals' prior

[4] The term <u>associate</u> was used by the author to infer some possible degree of involvement of one factor with another. The term <u>contribute</u> is the term used by accident investigators to infer a causal relationship between one factor and a consequence.

working arrangements and this information usually provides the only clue to their possible fatigued state." In addition, Brown (1989) notes the concern expressed in the Tavistock Report, which expresses difficulty in investigating the effects of fatigue given the strong commercial pressures to sail and the unlikelihood that fatigue would be proffered as a possible cause of accident in this environment. As stated in the Tavistock Report, "information derived from any reporting scheme is likely to be systematically biased by the very process of data collection itself" (Bryant 1991). Bryant (1991) notes that lack of supporting documentary evidence on the work patterns and watchkeeping system on board hampers the investigator's ability to determine the extent to which fatigue may have been a factor. In addition, Finkelman (1994) claims that the measurement of fatigue in the real world is difficult, due to the great variety of moderating variables.

Since 1991, marine incidents in Australia have been investigated by a Marine Incident Investigation Unit operating under statute. Investigators determine the circumstances of an incident and publish a report (Marine Incident Investigation Unit 1996). It is not the role of the Unit to assign fault or determine liability (Marine Incident Investigation Unit 1996).

Although the Australian Navigation Regulations provide criteria for inclusion of incidents in the Marine Incident Investigation Unit database, the possibility of excluding some incidents (through non-reporting) does exist. Such exclusions should be minimal where other statutory (e.g. coronial, environmental and Port Authority By-Laws) and insurance reporting mechanisms exist. In addition, the identification of a second party in most collisions and the highly conspicuous nature of groundings renders non-reporting less likely.

This study, however, concentrates on fatigue behaviours present in Incidents at Sea reports, the reporting of being asleep and being sleep deprived, rather than identification of fatigue as a contributing factor. The concerns expressed by Bryant (1991) relate to Type 2 errors (overlooking fatigue as contributory to an incident); such errors are less likely to apply to a broad list of behaviours determined by an objective investigation than the more specific determination that fatigue was a factor.

CHAPTER 4 - RESULTS

4.1. Time-of-day factors

Incident type and distribution

Of the 100 Incidents at Sea reports analysed, there were 38 groundings and 24 collisions. The remainder comprised foundering, fires, injuries/fatalities and a small number of other incidents such as structural failures and incidents alongside wharves (Figure 2).

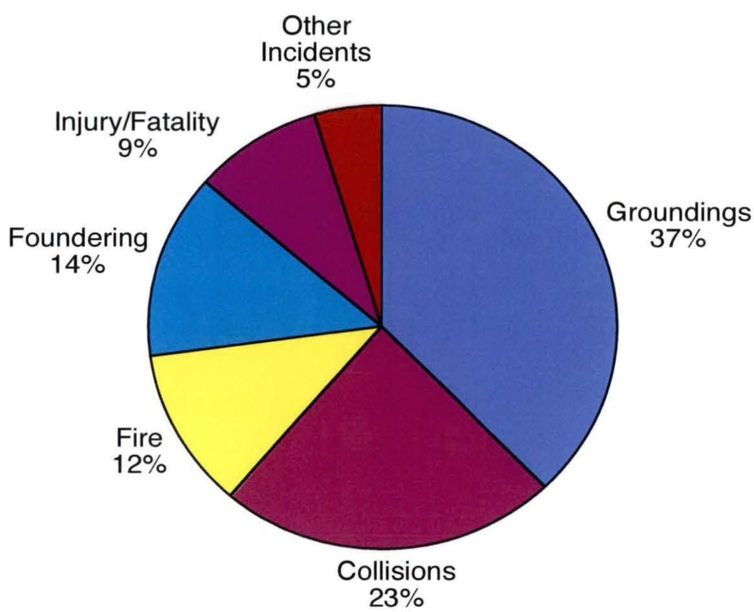

Figure 2: Distribution of Incidents at Sea (from 100 consecutive reports)

Founderings (13) involved vessels lost at sea (some with all hands); however, incident time and contributing details were often undetermined. Fires (11) usually involved latent failures such as design and maintenance deficiencies, and usually involved machinery spaces. Human factors were difficult to determine in both of these categories.

The distribution of incident type by watch period varied; collisions and groundings exhibited a peak during the early morning, then decreased during the day and increased again during the afternoon. The frequency of other incident types remained reasonably static throughout the 24 hour period (Figure 3).

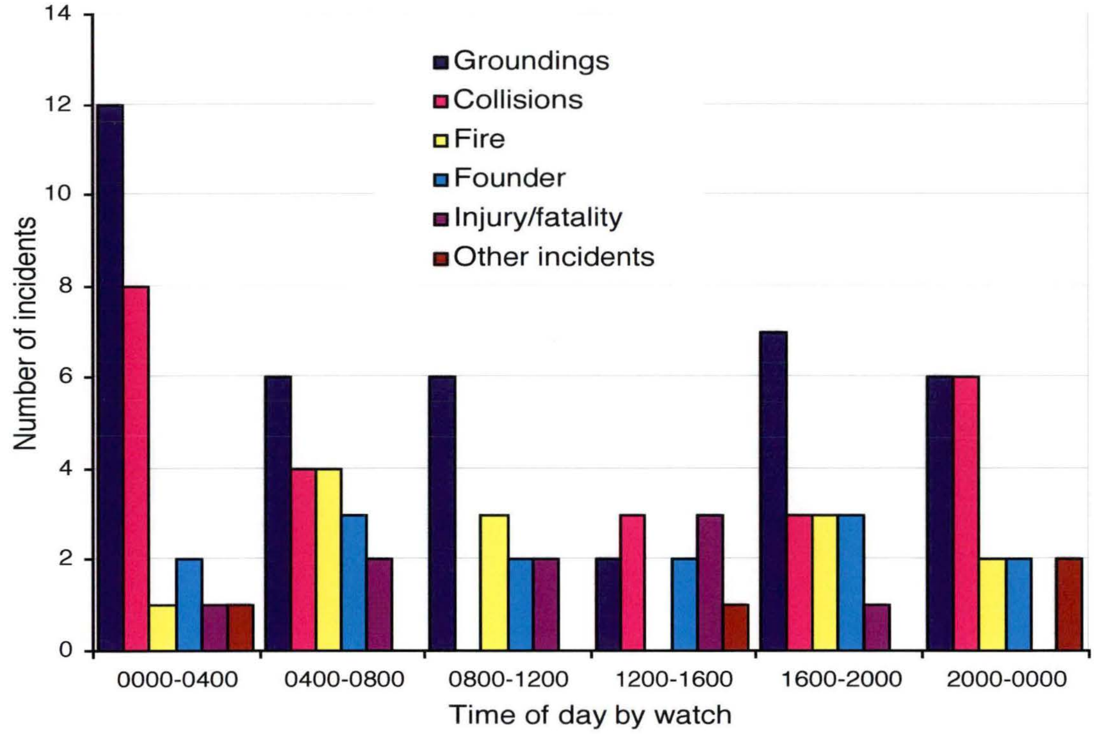

Figure 3: Time of day and incident type

Given the greater proportion of latent errors in fires, and meteorological and structural factors in foundering, these categories were excluded from further time of day analyses. Similarly, the disparate nature of the incidents in the injury/fatality and "other" categories, in addition to their relatively small number, also justified their exclusion. The distribution of these incidents according to watch is given in Figure 4.

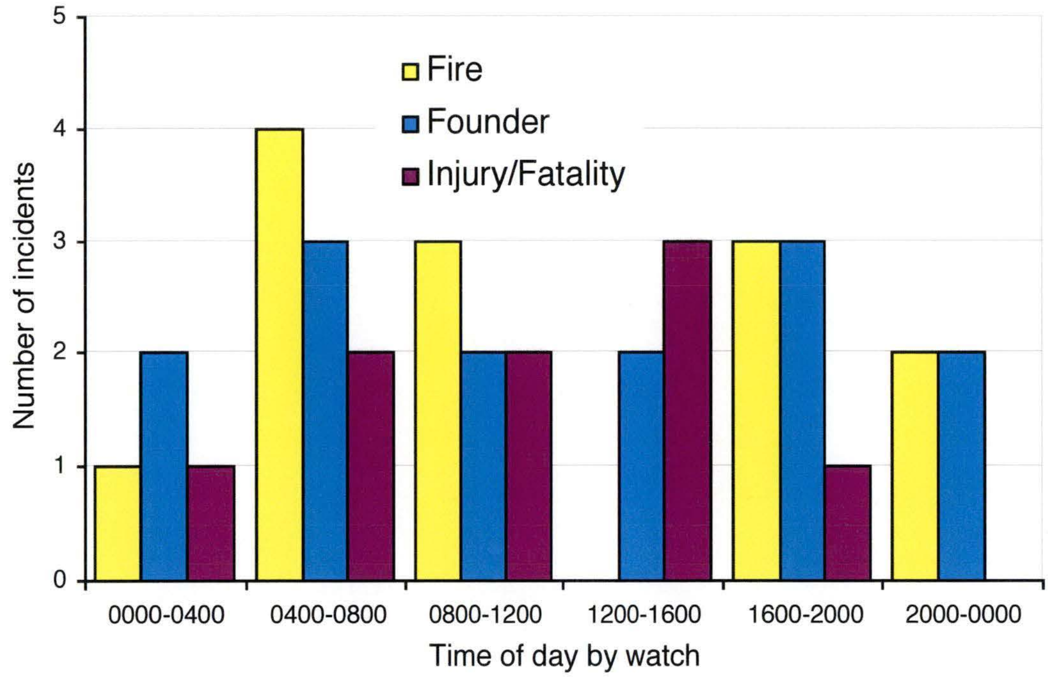

Figure 4: Time of day and fire, foundering and injuries

There appeared to be a diurnal distribution of the 62 collisions and groundings, peaking during the 0000 to 0400 watch, with a trough during the day (0800 to 1200 for collisions, 1200 to 1600 for groundings) (Figure 5).

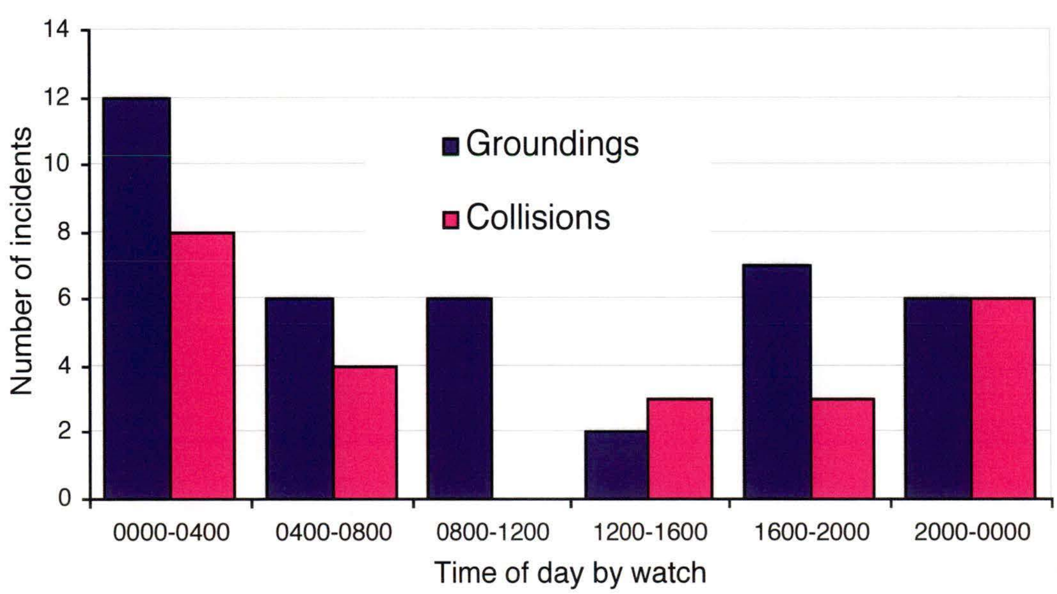

Figure 5: Time of day and collisions and groundings

Human factors in Incidents at Sea: error type and human contribution to the breakdown of complex systems

All conclusions were coded according to Reason's (1990) Generic Error-Modelling System in an attempt to locate the origins of human error types within incidents (Figure 6). Examples of error types are shown in Table 2.

Table 2: Examples of conclusions coded by error type (after Reason 1990)

Skill-based slips and lapses
1. Maersk Tapah's Pilot accepted an unnecessarily close quarter situation in the overtaking manoeuvre, resulting in contact between the two vessels.
2. When Searoad Mersey made contact with No.15 beacon, the Master lost his orientation, over reacted and applied excessive helm.
3. The Pilot and Master did not jointly consider any sailing plan for Conus, taking into account the prevailing conditions, rather they relied on a 'standard' departure which did not take into account the possible effect of the wind or tide.
4. New Noble's Master was preoccupied with the recovery of the anchor and did not drive the ship ahead, either dragging the anchor or releasing the bitter end and allowing it to pay out, while the opportunity existed.
Cont'd

Rule-based slips and lapses

1. With Maersk Tapah's automatic radar plotting aid giving inconsistent data for the vessels being overtaken, the Second Mate did not use compass bearings to establish whether the bearings of the vessels being overtaken were altering appreciably.
2. The Khudozhnik Ioganson was an overtaking vessel within the meaning of the International Regulations for the Prevention of Collisions at Sea (Colregs) and had a duty to keep clear of the Zodiac, irrespective of whether or not the Zodiac was engaged in fishing, until finally passed and clear.
3. Given the situation on the day, there was no compelling reason for ships to overtake in such close proximity.
4. Having observed a structure and a number of fishing craft in proximity to it, the Master did not maintain a sufficiently safe passing distance.
5. The Third Mate absenting himself from the bridge before the Second Mate arrived to take up his watch.

Knowledge-based mistakes

1. Inadequate strategic and operational planning, in particular in the consideration, by all parties involved, of the safety case and the determination of safety parameters and precautions to be taken for the berthing operations.
2. The grounding was caused by an error of judgment by the Pilot turning the ship to port rather than to starboard.
3. The Second Mate failed to advise the Master of his concern with regard to the passage plan, and also failed to properly monitor the tidal heights and advise the Master of their significance.
4. The Master failed to fully assess the situation before altering course to starboard, placing undue reliance on the ARPA, misreading or misinterpreting the distance to the collision point, and failing to check the ship's position.
5. The absence of any contingency planning for the passing of machinery control from the bridge to the engine room under emergency conditions or plans to utilise the backup pitch control and the emergency steering in the steering flat.
6. The Pilot did not plan the undocking and take full account of the wind strength and direction.

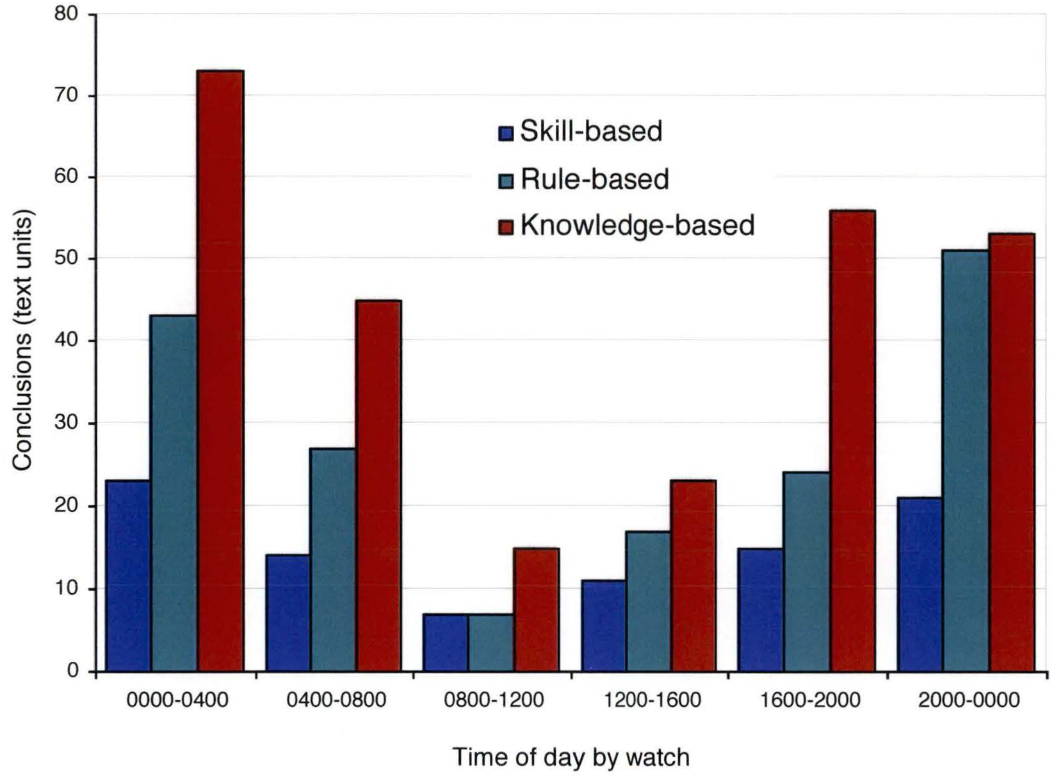

Figure 6: Time of day (by watch) and error type based on the Generic Error Modelling System of Reason (1990)

All conclusions were also coded according to Reason's (1990) human contribution to the breakdown of complex systems in order to exclude latent failures from further analysis. Examples of human contributions are shown in Table 3.

Table 3: Examples of conclusions coded by human contribution to the breakdown of complex systems (after Reason)

Fallible decisions

1. The anchors on Sampet Hope are apparently not arranged so that they can be slipped in an emergency.
2. The audible alarms on the gantry cranes are not sufficiently loud or 'startling' as to hold a person's attention while the cranes are moving along the deck, particularly in a strong wind and against the background noise of the hydraulic machinery.
3. The regulatory minimum manning requirements for a vessel the size of Teresa, engaged in the fishing industry, virtually preclude the keeping of a look-out while the vessel is anchored for the night.
4. The labelling and instructions for the lifeboat release gear, although clear, were not in the language of the crew.
5. Had a safety net been rigged underneath the gangway (as required by the Port of Townsville By-laws) during the weeks immediately preceding the incident, it may have prevented the Master from falling into the water.

Line management deficiencies

1. A lack of communication and co-ordination between the two principal companies, which resulted in the vessel being misinformed.
2. The lack of Bridge Resource Management procedures on board, which resulted in the wheelhouse being unattended, the vessel's progress not being monitored and the order to go hard to port not being challenged by the Officer of the Watch.
3. The Master's decision to release the seamen from lookout duties, in order to maximise their time on maintenance work.
4. The Pilot did not fully brief the Master and Third Mate on the manoeuvre, to enable them to operate as a fully integrated, supportive team. The Skipper of the Zodiac failed in his responsibilities by leaving the navigation of the vessel in the charge of an unqualified deckhand.
5. The Master in command on 24 June had ordered that a seaman should act as look-out during the hours of darkness. This instruction was not complied with possibly due to a misunderstanding and a lack of effective communications in the form of written notification, and because of the entrenched practice for the officers to keep a watch alone during the night.

Cont'd

Psychological precursors of unsafe acts

1. A perceived need, on the part of the Adviser, to get the job done, which would have affected the level of caution adopted.
2. Maersk Tapah's Second Mate, having voiced a concern about the overtaking situation, did not inform the Master of his concern.
3. The progress of Gumbet was not properly monitored, the risk of collision was not assessed and the developing situation was not appreciated.
4. There is a possibility that the cadet, mistakenly thinking he had time to cross in front of the moving crane, attempted to cross the crane track to get to the space between the after end of No.2 hold and the deckhouse.
5. Reduced alertness on the part of the Watch Officer, brought about by a sleep debt and "jet lag".

Unsafe Acts

1. A spark from the grinder being used by the student ignited the hydrogen air mixture causing an explosion within the battery locker.
2. An inappropriate course alteration was made, which nullified action taken by the other vessel.
3. The spontaneous and simultaneous reactions of the Master and the Pilot to go hard to port, towards the intended track, before a full appraisal of the situation was carried out.
4. The boat was released by the operation of the releasing handle by one of three people actually in the boat.
5. The bridge was unmanned because the Second Mate left the bridge at shortly after 0105 and failed to return because he fell asleep.

Inadequate Defences

1. After the incident with Moonshot, he did not make contact with the fishing vessel to ascertain whether the crew were injured and whether they needed assistance.
2. The Master of the Jin Shan Hai was not informed of the developing situation and only became aware of the incident after the collision.
3. When Searoad Mersey made contact with No.15 beacon, the Master lost his orientation, over reacted and applied excessive helm.

This categorisation allowed the author to differentiate between latent errors (which were excluded from subsequent analysis) and watchkeeping errors. In each incident, a number of human contributions types coexisted; both latent and active errors. The distribution of the human contribution is given in Figure 7.

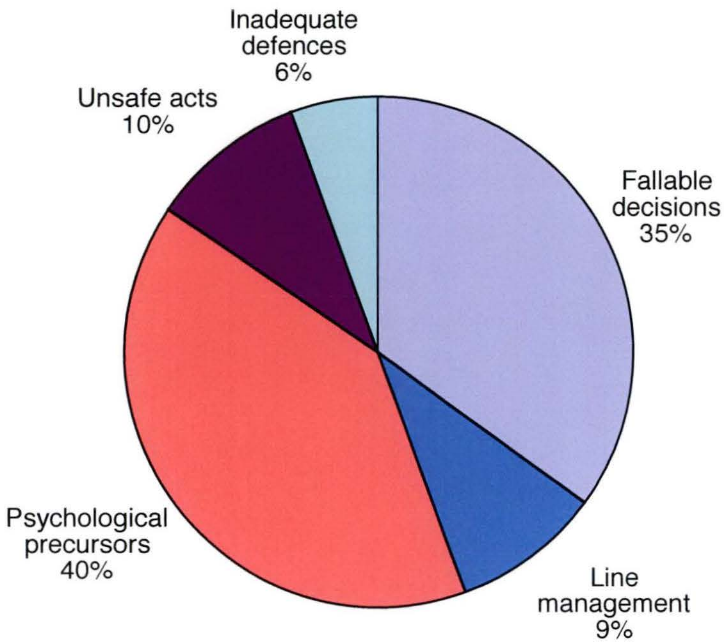

Figure 7: Human contributions to the breakdown of complex systems (expressed as a percentage of total text units)

The distribution of error type (skill-based, rule-based, knowledge-based) for all conclusions appeared to follow the diurnal variation of collisions and groundings; knowledge-based errors having the highest incidence, skill-based errors the least.

Incidents where investigators determined that fatigue was a contributing factor

Investigators determined that fatigue was a factor in seven of the 100 incidents in the study. Five of the seven incidents were groundings, one a collision and one an over pressurisation. Four of the seven incidents occurred between 0000 and 0400, with two more occurring between 0400 and 0800. Only the over pressurisation incident occurred on day watches.

Factors contributing to these incidents included prior use of alcohol, sleep deprivation, failure to use all available information in navigation, failure to keep a proper lookout and failure to monitor progress. The most common unsafe act in groundings was a failure to alter course; in the collision, failure to keep clear.

Fatigue behaviours and time of day

In order to constrain behaviours to watchkeeper error, the analysis of fatigue behaviours was limited to collisions and groundings, which were coded according to fatigue behaviours obtained from the literature review. Examples of conclusions coded according to fatigue behaviour are given in Table 4.

Table 4: Examples of conclusions coded by fatigue behaviour.

Activation problems.
1. A reduced alertness on the part of the Harbour Master, due to the combined effects of his work regime and a slight sleep dept.
2. Low level of alertness and possible acute fatigue of the Tugmaster, caused by the recent shift change.
3. Reduced alertness on the part of the Watch Officer, brought about by a sleep debt and "jet lag".
4. The deck hand aboard Ronda Lene failed to keep a proper lookout and was unaware of the presence of Fareast until just before the collision.
5. The Mate was overcome by drowsiness, which caused him to loose track of time and space.
Cont'd

Input Limitations.

1. Readily available, up to date information on the approaching front was not obtained from the Bureau of Meteorology.
2. He did not use visual bearings or the radar to full effect to correctly ascertain the courses of the fishing vessels and to determine whether or not the risk of collision existed.
3. There was no full exchange of views, in line with Bridge Resource Management procedures, on the developing situation and the appropriate action to be taken.
4. The Second Mate on River Embley made assumptions regarding the nature of Bronze Wing's operation based on scanty information and an inaccurate perception of the situation, during a time when other duties may have led to a degree of distraction.

Information-processing problems.

1. With Maersk Tapah's automatic radar plotting aid giving inconsistent data for the vessels being overtaken, the Second Mate did not use compass bearings to establish whether the bearings of the vessels being overtaken were altering appreciably.
2. A proper appraisal of the possible movement of the cyclone was not made, and no account taken of the steady fall in barometric pressure and lack of wind directional shift, which resulted in Osco Star passing close to the centre of the cyclone.
3. The lack of any planning of the approach, with no delineation of danger areas or safety limits on the chart, or consideration of possible contingencies.
4. The Master failed to fully assess the situation before altering course to starboard, placing undue reliance on the ARPA, misreading or misinterpreting the distance to the collision point, and failing to check the ship's position.
5. Faced with a deviation from the usual operational procedures, the Harbour Master did not fully evaluate the changed circumstances and assess what appropriate action was required.

Cont'd

Aversion to Effort.

1. The lack of decision to move the vessel at 2000 when the Master of Columbus Victoria voiced his annoyance at Sampet Hope's position, when the distance between the two ships had apparently reduced from 0.5 miles to 0.3 miles.
2. Maersk Tapah's Pilot accepted an unnecessarily close quarter situation in the overtaking manoeuvre, resulting in contact between the two vessels.
3. The collision between the Jin Shan Hai and the Kekenni was caused by the failure of the of officer of the watch, the Second Mate, of the Jin Shan Hai to take early and substantial action to avoid a close quarter situation.
4. The movement of the rudder to starboard 20 [degrees], the resultant sheer, and hence the grounding, would most probably not have occurred had the steering been conducted manually.

Differing nature of effort.

1. Inappropriate action to provide the necessary lee to enable the Pilots to board.
2. The spontaneous and simultaneous reactions of the Master and the Pilot to go hard to port, towards the intended track, before a full appraisal of the situation was carried out.
3. The grounding was caused by an error of judgment by the Pilot turning the ship to port rather than to starboard.

The literature revealed a variety of behaviours associated with fatigue and its independent variables such as time-on-task, sleep loss and time of day. These are summarised in Table 1 (page 36). These behavioural manifestations were obtained from laboratory experiments (including perceptual, motor and cognitive tests, sleep propensity, reaction time and simulations) as well as field experiments including shipboard, aviation and road transport studies.

Behaviours were sorted into the following categories using an information-processing model similar to that described by Wickens (1997):

1. Activation problems - attention failures, slips and lapses
2. Perception limitations - limiting visual and auditory sensation
3. Information processing problems - interpretation, encoding and correlation deficits

4. Aversion to effort - failure to act
5. Differing effort - failure to act appropriately.

The literature review, however, also referred to non-behavioural measures of fatigue such as subjective assessments of fatigue (rating scales, sleep quality, records and logs) and physiological tests (body temperature rhythm, EEG, heart rate and clinical chemistry assessments). As Incidents at Sea reports rarely report such potential data, subjective assessment and physiological tests, although potentially sensitive indicators of fatigue, were not included in this study.

The initial analysis identified the frequency of particular fatigue behaviours in each watchkeeping period (Figure 8).

The frequency of all fatigue behaviours was higher during the night watches and lower during the morning and afternoon watches. This distribution was most noticeable in the activation behaviours, with a ten-fold increase in the 0000 to 0400 watch compared to the 1200 to 1600 watch.

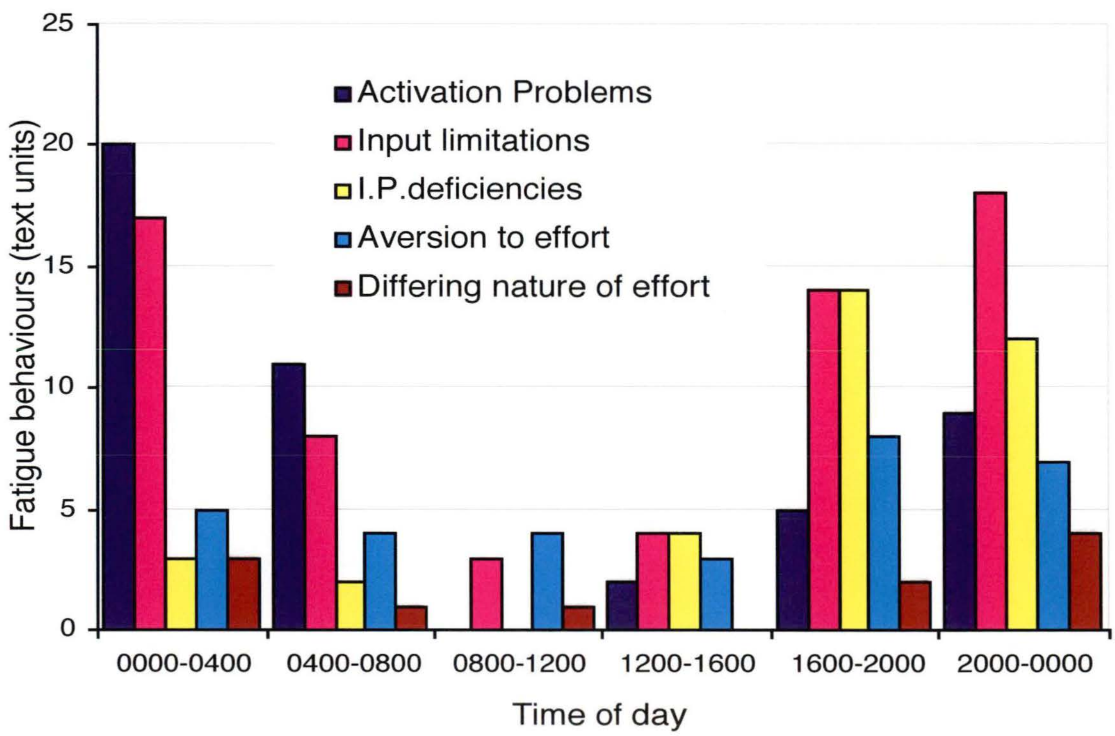

Figure 8: Time of day and fatigue behaviour

As the distribution of collisions and groundings exhibited a strong diurnal variation, fatigue behaviours were expressed as relative frequencies - the number of text units corresponding to a particular fatigue behaviour relative to the total number of conclusions in that watchkeeping period. Figure 9 shows the relative frequencies of all fatigue behaviours, which highlights watchkeeping periods where particular fatigue behaviours predominate. The 0000 to 0400 watchkeeping period was also corrected to accommodate one report comprising a disproportionately large number of text units (the *TNT Alltrans* Report being a Marine Court of Inquiry rather than a standard incident report) by attributing the average number of text units for the watchkeeping period to that report.

When the relative frequency of each category of fatigue behaviour was analysed within each watchkeeping period, the distribution revealed that activation problems and information processing deficiencies exhibit a strong diurnal variation, with the activation problems peaking during the 0000 to 0400 and 0400 to 0800 periods and the information-processing problems peaking during 1600 to 2000 watch. Both activation problems and information processing fatigue behaviours were absent during the 0800 to 1200 watch; however, this was the peak of the aversion to effort and differing nature of effort fatigue behaviour.

Input limitations remained fairly evenly distributed throughout most of the day but were slightly higher in the 1600 to 2000 and 2000 to 0000 watchkeeping periods.

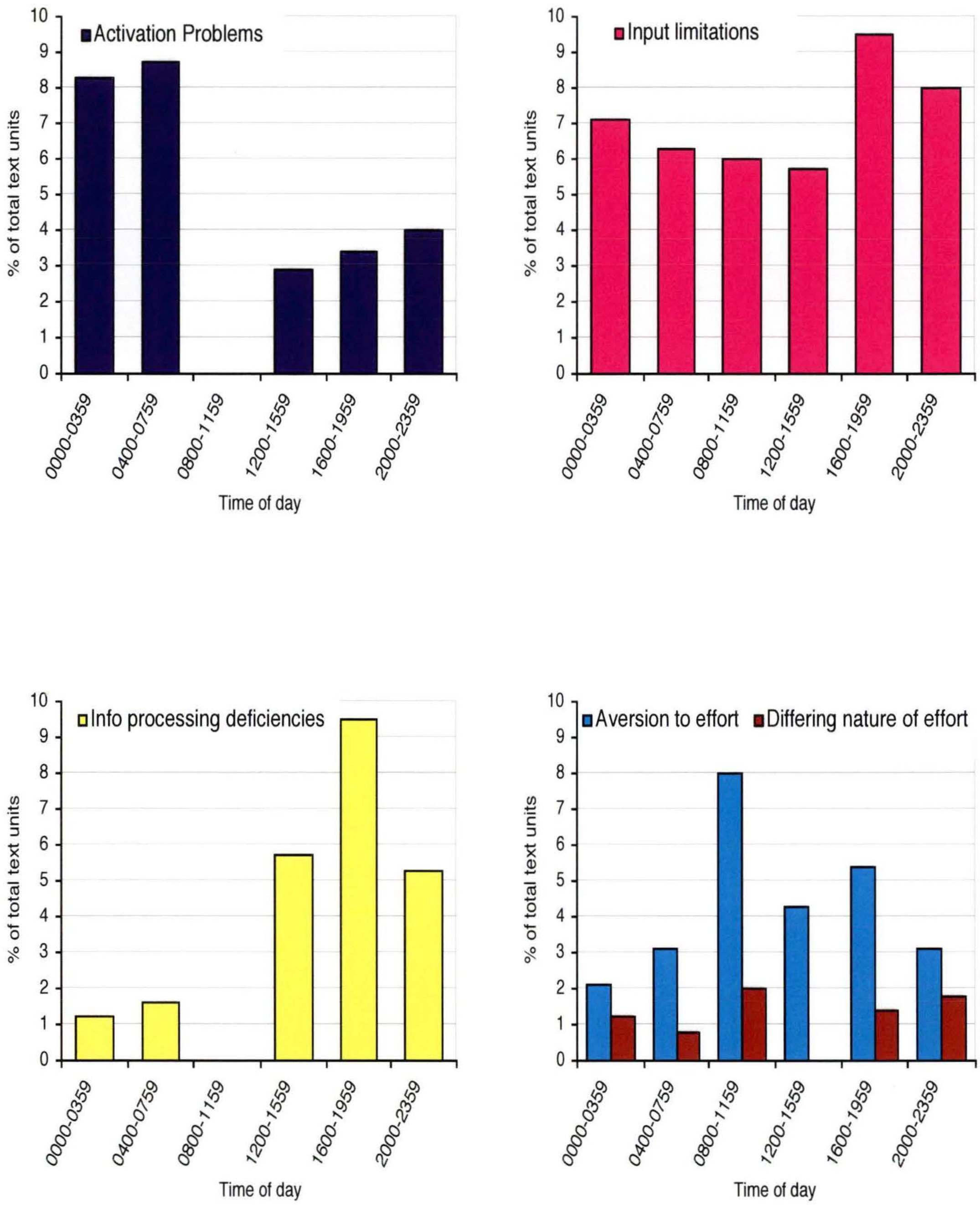

Figure 9: Fatigue behaviours as a percentage of text units (ie. all behaviours) and time of day. Each graph expresses the relative incidence of a particular fatigue behaviour as a percentage of all behaviours for that watchkeeping period.

4.2. Sleep factors

Quantitative analysis

Accident investigators made reference to sleep in 38 of the 44 (86%) reports analysed. Of the 44 incidents analysed, 21 were groundings and 21 were collisions, the remaining two comprising an injury and a tank over-pressurisation.

Reference to sleep was made predominantly in the Analysis (122 references) and Narrative (103 references) sections of the report. Only 15 references to sleep were made in Conclusions and 8 in Summaries. Only 2.9% of all Conclusions contained reference to sleep, compared to 5.6% of Narrative and 5.1% of Analysis text units (paragraphs).

Most references (34%) were made to sleep loss as a way of life (waking at odd hours, daytime sleep, working instead of sleeping and sleep hygiene factors) followed by sleep as routine (28%). Only 23% of sleep references described sleep as having high levels of association with accidents (sleeping as contributory, 12% and sleep loss as contributory, 11%). These results are summarised in table 1.

In the study sample, there were 11 collisions and 8 groundings on day watches (0800 to 0000) compared to 10 collisions and 13 groundings on night watches (0000 to 0800). More sleep references were made in reports of incidents occurring during the 0000 to 0400 watch than any other watchkeeping period. Most references were to sleep loss as a way of life (42 references) and sleep as routine (31 references). Seventy-seven percent of all sleep references corresponded to incidents that occurred during the first two watchkeeping periods (i.e. 0000 to 0800). There were only 6 sleep references inferring a high level of contribution to accidents that corresponded to the four daytime watchkeeping periods (i.e. 0800 to 0000).

Accident investigators' reference to sleep was evenly distributed between collisions and groundings (125 references in groundings, 119 references in collisions and 9 references in other incidents). Groundings contained more references to sleep loss and sleep deprivation (29) than collisions (22 references). Groundings also contained more references to sleep loss as a way of life than collisions (52, compared to 45 references). The sleep routine was referred to in more collisions than groundings (45 compared to 27 references). Reference to being asleep was associated with twice as many collisions (8) as groundings (4), whereas being sleep deprived corresponded to twice as many groundings (4) as collisions (2).

Table 5: Accident investigators' reference to sleep

Descriptive Category and Level of Contribution	Behaviour/factor	Number of References
Sleeping as contributory (high level of contribution)	Watchkeeper asleep on watch	13
	Crew asleep at anchor	6
	Master or pilot asleep	12
Sleep loss as contributory (high level of contribution)		27
Sleep loss as a way of life (medium level of contribution)	Waking at odd hours	28
	Daytime sleep	13
	Working, not sleeping	5
	Sleep hygiene	16
Rest rather than sleep (medium level of contribution)		37
Sleep as routine (low level of contribution)	Sleeping accommodation	7
	Sleep routine	60

The master was the major human contributor in 12 of the 44 incidents, the second mate in 9, and the pilot in 8 incidents. Association of the master with accidents occurred across all watches, but predominantly on both 4 to 8 watches (with 3 incidents occurring during each watch). The second mate was predominantly associated with accidents during the 0000 to 0400 watch (in 6 incidents), whereas the pilot's association followed a similar distribution to the master (three incidents on the 0400 to 0800 and two on the 1600 to 2000 watches). It is noteworthy that the second mate was associated with twice as many incidents in the 0000 to 0400 watch-keeping period than any other officer in any other watchkeeping period.

Behaviours of the pilot were associated with 7 groundings, but only 1 collision, whereas behaviours of the second mate were associated with 6 collisions and only two groundings. Ship's masters were associated with 6 groundings and 5 collisions. The distribution of incidents according to major contributor is given in Figure 10.

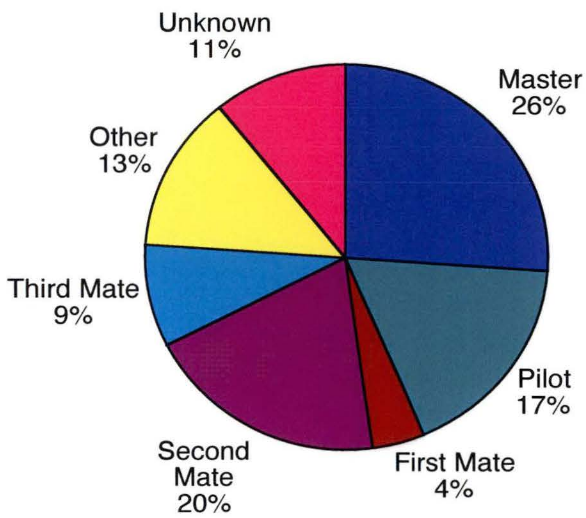

Figure 10: Major contributor to collisions and groundings (from 44 incidents)

Accident investigators' reference to sleep in Incidents at Sea reports

Accident investigators report sleep at three levels of association with accidents. Being asleep on watch or being sleep deprived are conditions classed at the highest level of association with accidents - the condition was contributory to the accident. Reference to seafarers being woken at odd hours, sleeping during the day or working instead of sleeping describes a moderate level of association with accidents. Accident investigators also frequently refer to environmental aspects of sleep and sleep hygiene, sleeping and watchkeeping and resting rather than sleeping which have the lowest level of association with accidents.

Reference to sleep by accident investigators does not always correspond with fatigue being determined a contributing factor to an incident at sea. For example, the investigator determined in three out of four incidents where the watchkeeper was asleep on watch that fatigue was a factor. However, the investigator determined that fatigue was not a contributing factor in the three incidents where all the crew were asleep on board vessels at anchor or lying ahull (not under command), even though it is a requirement to maintain a watch at sea. Though being asleep was a contributing factor to the accident, fatigue was not. In each of the latter incidents, the two crew members of fishing boats were asleep following a period of fishing activity, the 24-hour work schedule making it extremely difficult to maintain the lookout required by regulations.

Similarly, accident investigators have identified seven incidents where the master or pilot was asleep when the incident occurred. In five instances, in order to get some sleep, skippers of fishing vessels had handed over command of the vessel to an unqualified crewmember. Once again, though fatigue was not determined as a contributing factor by accident investigators, sleeping of critical crewmembers certainly was. In two instances on commercial ships, the master, or the pilot and the master were asleep when the watchkeeper became incapacitated through fatigue. In these two incidents, the sleep condition of the critical crewmembers was associated with the accident and the fatigue state of the watchkeeper was contributory.

There are 22 references to waking at odd hours (16 reports), 15 of which correspond to reports where accident investigators determined that fatigue was a contributing factor. Seven references to waking at odd hours refer to waking to take over the watch. Other references include pilots being called to the bridge for pilotage duties, the master being called to the bridge due to fog, or to wait for a pilotage transfer, fishing boat crew waking to attend to nets, and in three instances, waking following a grounding or collision.

Daytime sleeping was referred to 13 times in 9 reports. Most references to this are to crewmembers of fishing boats engaged in night-time fishing (such as prawn trawling). Remaining references to daytime sleep were to sleeping following or preceding a night watch or pilotage. Daytime sleeping in fishing boats at anchor or not-under-command is associated with the risk of collision with commercial vessels that fail to maintain a proper lookout. In some instances, fishing vessels may not be exhibiting the correct lights and, in the early morning hours, risk being run down by commercial vessels.

Accident investigators make five references to watchkeepers working instead of sleeping while off watch. In addition to watchkeeping, officers also supervise loading and unloading operations in port, write reports, conduct exercises and drills, supervise staff and manage aspects of ship operations. Reference to these additional duties competing with sleep time is made in five instances. In one instance, the master was on the bridge for 16 out of 28.5 hours but didn't consider himself tired (investigators subsequently finding the master partially contributory to a collision). Another report describes a master writing a report to the shipping company at 0100 following his watch (during which the sleep-deprived pilot lost situational awareness and the vessel run aground). Fishing boat skippers are often described working alone, steaming to and from the fishing grounds, fishing and selling the catch and fishing during the day.

Sixteen references (in six reports) to environmental and sleep hygiene factors illustrate some of the difficulties associated with sleeping aboard ships and fishing boats. One fishing boat skipper bunked in the wheelhouse so as to be instantly available, and reference is made to deckhands on prawn trawlers sleeping between winching prawn nets, cleaning and packing prawns, the intermittent nature of the job hardly being conducive to sleeping.

Investigators raise three critical sleep hygiene issues in two reports. Firstly is the need for socialisation and activity outside the operational routine on board. In the case of the *Svenborg Guardian* (report 82), the already fatigued ship's crew watched a Rugby Union match on television, an action that contributed to the second mate falling asleep in his cabin during the 0000 to 0400 watch. Watching late night sport on television is hardly an issue in many land-based jobs; however, the failure of the second mate to remain vigilant during his watch due to watching evening television was described by the investigator as " ... displaying inexperience and irresponsibility".

The second sleep hygiene factor relates to the influence of occupational stress on sleep. One incident (*Peacock*, report 95) refers to changed conditions of service of pilots resulting in anxiety and stress, and affecting an individual's sleep and concentration.

Thirdly, in the same report, investigators make reference to the possibility of sleep disorders such as sleep apnoea and snoring affecting the quality of sleep. Though it may be difficult for accident investigators to retrospectively evaluate the effect of sleep disorders, they are valid in identifying body weight, diet, domestic and occupational concerns, snoring and daytime sleepiness as factors possibly contributing to fatigue, and hence to accidents.

Accident investigators occasionally refer to sleeping accommodation. Each of the seven references is to the general layout of sleeping accommodation in fishing boats. No reference is made to the sleeping arrangement on commercial vessels. Fishing vessel sleeping berths are commonly described as being below deck, usually accessed from the forecastle, the wheelhouse or a separate companionway from the deck. Because of the integrated nature of work on fishing boats, coupled with the small crews, accommodation is usually combined with the working areas of a fishing vessel. For example, the galley and sometimes a skipper's berth share space in the wheelhouse, and sleeping accommodation for the deckhands is usually under the working deck adjacent to the fish hold.

Seafarers on commercial vessels enjoy a separate accommodation block that is remote from the operational areas of the deck, holds and bridge. Masters and pilot's cabins are usually close to the bridge.

CHAPTER 5 - DISCUSSION

5.1. Coding, categorisation and analysis of Incidents at Sea reports

The two analyses of Incidents at Sea reports attempted to present a profile of the human contribution to marine accidents (specifically time of day and sleep factors) from the perspective of marine investigation. Prior to discussion of these two analyses, it is appropriate to discuss the issue of coding and categorisation of data.

In the first analysis, coding according to Reason's (1990) "human contribution to the breakdown of complex systems" was relatively straightforward and allowed the exclusion of latent errors (specifically fallible decisions and many line-management decisions) from subsequent fatigue analysis. Though fatigue may have contributed to a design error or inappropriate policy prior to an accident, it is not appropriate to be included as a watchkeeping error. It is unlikely that fatigue as a contributing factor to latent errors would ever be determined in maritime investigation. Fatigue behaviours therefore included psychological precursors (such as self-induced sleep deprivation, poor monitoring of vessel progress and inadequate crew communication), unsafe acts (such as accepting a close quarters situation or leaving the bridge unattended) and inadequate defences (such as failing to alert the master, communicate with the other vessel or overreacting to an unsafe act).

In contrast, coding according to the predetermined categories of error type (skill-based, rule-based or knowledge-based) proved difficult due to the limitations of the data. Skill-based errors are automated and unconscious, whereas rule-based errors are consciously executed. Differentiation between these categories, in the absence of the appropriate context, made coding difficult. For example, an inappropriate course alteration as described by an accident investigator may have been a skill-based error if it was failure to execute a pre-programmed manoeuvre, or a rule-based error if there was a conscious misinterpretation of the rules. The conclusion of the Incidents at Sea report often does not provide enough contextual data to allow differentiation between these two error types. Conversely, knowledge-based mistakes are usually information-processing deficiencies (i.e. conscious, judgement or problem solving errors) and were much easier to distinguish and code.

The difficulty distinguishing between skill-based and rule-based errors led to the evolution of a fatigue behaviours categorisation based on an information-processing model. This model is easily applied to the tasks of watchkeeping and has its origins in basic communications theory. It also forms a basic level of description of human neurological function. In summary, the watchkeeper receives sensory (afferent or input) information, that is then processed (interpreted, coded and analysed) and an appropriate motor program is executed. The model assumes that the subject is conscious and alert, however this is not always the case in watchkeeping situations. The state of alertness (depending on time of day, prior sleep, the environment etc) and information processing as outlined above exhibit a complex interplay resulting in explainable changes in performance.

Unfortunately, fatigue is frequently described only in terms of decreased alertness rather than combinations of decreased alertness and compromised information processing. Indeed, in the seven Incidents at Sea reports where fatigue was determined a contributing factor, investigators were able to identify only the decreased alertness component. If the conclusions of Incidents at Sea reports are categorised according to the information-processing model as well as decreased alertness (comprising fatigue behaviours as described earlier) a more complete picture of the contribution of fatigue to accidents emerges.

The fatigue behaviours model was developed both through a review of the literature (identifying behaviours consistent with being fatigued) and through coding and categorisation of conclusions of Incidents at Sea reports. This discussion will initially address the two contributing factors investigated in this study (time of day and sleep) and conclude with discussion on the possible relationship between fatigue, watchkeeping and accidents.

Figure 11 illustrates the relationships between sleep deprivation, time of day, watchkeeper fatigue and accidents. This concept will be built on further in this discussion.

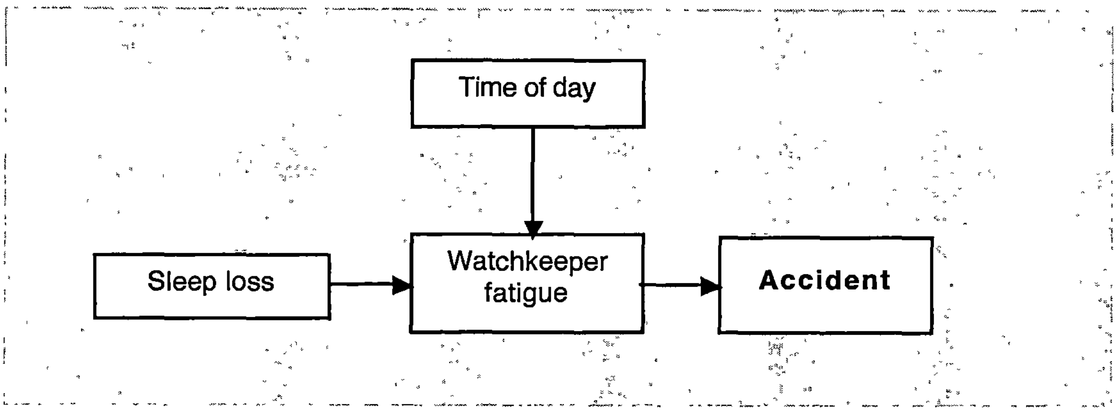

Figure 11: Sleep loss, time of day and accidents: the basic model

5.2. Time-of-day factors

Incidents where fatigue was determined to be a contributing factor

Of the 62 collisions and groundings, fatigue was found to be a factor in only five (8%). Activation problems (or decreased alertness) and input limitations were the only fatigue behaviours identified in these incidents; no other fatigue behaviours were evident. Activation problems were manifest in the case of the *Carola* (report 79) where investigators found that the mate was overcome by drowsiness, and in the case of the *Peacock* (report 95 – see appendix 1) the pilot lost situational awareness and fell asleep. The second mate of the *Svenborg Guardian* (report 82) left the bridge and failed to return because he fell asleep, resulting in the ship being effectively out of control for almost five hours. In the case of the *TNT Alltrans* (report 8), the watchkeeper, due to alcohol and excessive tiredness, failed to alter course, resulting in the 35,000 tonne vessel, steaming onto Lady Musgrove Island at over 13 knots with those in charge of the vessel being unaware of the predicament for over 20 minutes. Input limitations commonly included lack of proper monitoring and lack of effective communication on the bridge (between master and watchkeeper and between pilot and watchkeeper).

The theme in five of the seven fatigue incidents was a decrease in watchkeeper alertness and either failing to initiate a course change or take action to keep clear of another vessel or obstruction. Due to a combination of fatigue and personal problems, the deck officer of the *Osco Star* (report 63) miscalculated the time to fill a tank, loaded the tank at an excessive rate and failed to act on an alarm, resulting in overpressurisation and structural failure of that tank. In the case of *Boa Force* (report 66), fatigue resulting from the operational program, although not explicitly stated as a contributing factor, was not ruled out.

In reports where investigators determined that fatigue was a contributing factor, contributory behaviours were expressed as deficiencies in alertness - investigators did not identify fatigue behaviours in the form of deficiencies in information processing or problems with execution. It appears that fatigue was determined to be a factor only where the investigation process was able to demonstrate lack of activation (by decrease in vigilance or alertness) by the watchkeeper. As activation problems were generally most prevalent during the 0000 to 0800 watchkeeping periods, most incidents where fatigue has been determined to be a factor occured during these watches. This issue is pursued by Brown (1989) who questions the Tavistock team's finding of "'no direct evidence of the presence of fatigue in the Marine Surveyors' files' in the light of findings of carelessness, over-confidence and other risky behaviour, with errors of judgement and excessive speed in poor visibility being plausibly associated with the mental exhaustion associated with fatigue". It may appear that unless fatigue is explicitly presented as evidence in an inquiry (as evidenced by lack of alertness), other behaviours resultant from fatigue may be overlooked or attributed to some other cause.

Fatigue behaviours in collisions and groundings

The distribution of these incidents is diurnal - most occurring during the period 1600 to 0800, least during 0800 to 1600. Human factors weigh heavily in collisions and groundings, with most errors being errors of navigation. Activation problems and input limitations are the modal fatigue behaviours, which follow the circadian performance rhythm described by Folkard (1996).

Activation problems

The predominant unsafe act during the night watches was failing to keep a proper lookout, as with the watchkeepers on board the *Metal Trader* (report 25), *Jin Shan Hai* (report 31), *Khudozhnik Iaganson* (report 35), *Far East* (report 49), *Libra* (report 54), *Iron Prince* (report 81) and *Midas* (report 91). Although the possibility of fatigue existed in these incidents, there were also other explanations for such errors, such as low personal standards of performance, an on-board culture of poor watchkeeping practices or the watchkeeper being distracted with another task. For example, the Second Mate of the *Jovian Loop* (report 36) busied himself with writing up the log book and failed to notice an incorrect course setting on the autopilot. Other specific behaviours during the night included failing to alter course and to monitor progress - behaviours also prevalent in incidents where fatigue was determined a contributing factor. Activation problems during the day watches were less frequent, with the predominant behaviour being failure to keep a proper lookout.

Though activation problems can be explained in terms other than fatigue, there was a ten-fold increase in problems with activation and three times the proportion of activation behaviours per report during the midnight watch compared to the midday watch. Broughton (1988) notes that a major peak of alertness usually exists in the early evening and proposes that the peak of evening alertness is due to "...synchrony of minimum pressures for both SWS and REM sleep associated with maximum body core temperature (all optimising vigilance functions), whereas the a.m. memory peak may be due to facilitation of REM sleep mechanisms which in extended sleep persists well across the morning."

It is problematic whether errors resulting from decreases in activation at certain times of the day can be attributed to fatigue. Just because an error occurs at one o'clock in the morning and a decrease in human performance occurs at that time does not necessarily mean that the operator was fatigued.

A review of the behaviours for the period 0000 to 0800 identifies the following possible alternative explanations for the increased incidence of activation errors during this period:

- There is a lack of supernumery personnel during the night watches on large commercial vessels – this is a period where the pilot, the seaman watchkeeper or the master are more likely to be sleeping or absent from the bridge.

- Likewise on fishing vessels, there is greater likelihood of an untrained watchkeeper, or perhaps no watchkeeper at all during night watches.
- The glare of working lights on fishing boats has been noted in report conclusions, both from the perspective of inducing loss of night vision as well as from obscuring navigation lights.
- Where alcohol is be a contributing factor, the effect is more likely to be noticed following the evening meal and during the night watches, rather than the early morning and daytime.
- Finally – the traditional need for evening socialising is more likely to affect performance during the evening and early morning watches rather than following during day. This was evident in the case of the Svenborg Guardian (report number 82) where the crew were tired as a result of watching a rugby match.

Fatigue behaviours result from many other contributing factors, including time on task and the period of prior wakefulness. The United States Coast Guard (McCallum et al. 1996) have developed a fatigue index score as a potential indicator of the fatigue contribution to an incident, which incorporates fatigue symptoms, hours worked and hours slept. It is noteworthy that time of day is not considered a parameter in this study despite the unequivocal evidence linking time of day with human performance; for example, Åkerstadt and Folkard's (1995) interactive computer program linking time of day and hours of prior waking with alertness.

Limitations to perception

Limitations to perception were characterised by failure to utilise all available information (particularly navigational information) and failure to ensure effective communication (verbal, radio and signals). Such behaviours were fairly evenly distributed over both day and night watches as a proportion of text units. The most common input-limiting behaviour during both day and night watches was failure of the watchkeeper to make use of all available navigational equipment. Such behaviours included failure to take visual bearings but, more commonly, failure to fully utilise the radar and Automatic Radar Plotting Aids (ARPA). As supporting evidence, Bryant

(1991) also notes misinterpretation of radar (despite improvements in training and equipment) and reliance on visual cues (where navigational aids are available) in an analysis of findings on collisions and groundings.

As with incidents where fatigue was determined a contributing factor, misunderstandings and failing to advise others of intentions were frequent input-limiting behaviours, such as the master of the *Jovian Loop* (report 36) failing to advise the pilot that he was leaving the bridge. In several incidents, such as the *Jhanski Ki Rani* (report 13), the *Mobil Endeavour* (report 16), the *TNT Carpentaria* (report 37), the *Kapitan Serykh* (report 72), the *River Torrens* (report 80) and the *Maresk Tapah* (report 103), those on the bridge failed to effectively exchange information, thereby limiting the decision-making process of the watchkeeper. Ohashi and Morikiyo (1974) note that the uncertainty and extensiveness of information sources increased at nighttime, largely due to the uncertainty of information in the dark environment. The authors note that the human difficulty in processing information from different sources (such as visual and radar) is more evident at night, with intership communication requiring more questions, confirmations and inferences concerning the situation.

The issue of ship-to-shore communication problems was noted in the Tavistock Report where Vessel Traffic Services (VTS) fail to communicate the very information that would have prevented a collision (Bryant 1991). Analysis of accidents has previously shown that factors such as anxiety, boredom and fatigue influence the navigator's ability to perceive and process information and there is a reliance on sight or radar as the primary navigational equipment, discounting much of the information that is available to prevent the incident (Bryant 1991).

Information-processing deficiencies

The distribution of information processing deficiencies differed from the previous two fatigue behaviours in that the peak occurred in the late afternoon and evening - the incidence of information processing deficiencies during the 0000 to 1200 watches was quite low. Common specific behaviours during the day watches included planning deficiencies, making assumptions and making incorrect assessments. Information processing deficiencies in association with a concomitant performance of a secondary task was also evident in many incidents. For example, the captain of the *Charles H McKay* (report 7) and the skipper of the *Saltiford* (report 10) both failed to make an appraisal of a developing collision due to preoccupation with the radios. The master of the *New Noble* (report 86) was preoccupied with recovering an anchor and the third officer of the *Iron Cumberland* (report 10) was assigned to a phone call which reduced his ability to act as a lookout and contributed to the collision with the *Saltiford* (whose skipper was preoccupied with the radios). This phenomenon is reflected in the results of a maritime simulation study by Sablowski (1989), where assessment of workload revealed a decrease in performance in a secondary task (mental arithmetic) during the execution of a simulated navigational task. Performance in the primary task was unchanged. Though this may be more an issue of methodology, one implication is that information processing deficiencies may not be evident in the task of navigation but may present in other, more subtle ways; unless such deficiencies are actively sought, they may remain undetected.

Whereas activation problems predominated during the early morning, information processing problems occur mainly during the evening watchkeeping periods. While the distribution of activation problems is consistent with the circadian rhythm of subjective alertness (for example, as described by Folkard 1983) the distribution of information processing deficiencies is more consistent with the decrease in accuracy over the working day (as described by Monk & Leng 1982). This phenomenon may well be related to time on task effects in addition to circadian influences, due to the difficulty in separating on-duty time from off-duty time on a ship.

Buxton (2003) reviews the effect of cognitive load on performance and notes that tasks with a high cognitive load may be performed satisfactorily in the early morning hours, usually the worst time for tasks involving low cognitive load (simple repetitive tasks). It appears from analysis of activation and information-processing behaviours that performance is about 180 degrees out of phase. This is consistent with the interpretation of the literature by Buxton (2003). It appears that though complex tasks may be sensitive to the effects of sleep deprivation (Wallace 2002) they are performed better at night than routine or monotonous tasks.

Scott (1994) also reviews the effect of varying task complexity and notes that for simple tasks, the performance rhythm is in phase with the temperature rhythm, however as complexity increases, performance peaks earlier in the day.

The information processing fatigue behaviours that occurred late in the day included making assumptions, incorrect assessments and inadequate planning (although aspects of the latter may be latent). Behaviours under contrived experimental conditions may not be easily transferable to analysis of real world situations. Indeed, one researcher claims that speed accuracy trade-off only occurs under strict laboratory conditions where subjects are asked to make a speeded response (Williams, D. 1996, pers. comm.).

The greater frequency of information processing errors during the late afternoon may be attributed to factors other than a decrease in human performance during the working day. Alternative explanations for this increase include:

- The greater likelihood of the presence of others during daytime operations, which may lead to confusion and distraction during information-processing tasks.
- The possibility of complacency that is less likely at night, due to the presence of more evident visual cues during daytime navigation. This could be compounded by greater reliance on direct visual cues and less reliance on radar and automated radar plotting aids (ARPA) during daytime watches.
- The possibility that port arrival and departure times may also play a part in the increased incidence of information processing errors during the late afternoon. An analysis of shipping arrival and departure times for the Port of Hobart for the financial year ending 2003 (n=350) showed that arrival and departure times were not evenly distributed throughout the day. Arrivals tended to predominate on the 0400 to 1600 watchkeeping periods, whereas departures predominated during the 1200 to 2000 watchkeeping periods, probably as a result of the timing of loading and unloading operations in this port. The arrival and departure from port requires significant judgement on the part of

> the watchkeeper, with the need for coastal pilotage, avoidance of other shipping and interpretation of navigational information. It is relevant to note, however, that the greatest number of accidents occur during the watchkeeping period (0000-0400) associated with the lowest number of port shipping movements (based on the Port of Hobart data).

Information processing is also coupled to the issues of automation and crew size. As automation and advanced technology increase to accommodate a decrease in crew size, the need for higher levels of information processing, particularly during peak information load such as aircraft take off and landings and piloting a ship up a narrow channel, increase. Brown and Groeger (1990) suggest that "... the human ability to correlate dynamic processes is rather low, especially if the variables in these processes change their states rapidly, and if the anticipation of change is impossible because of the stochastic signal characteristics of unforseen action to reaction cycles."

There has been considerable work on the effects of information processing demands on ship handlers, air traffic controllers and in aviation. Ohashi and Hirota (1969) noted the heart rate increase of a master manoeuvring a ship, rising to 120 beats per minute during turning and 140 during docking. The authors noted that significant changes in the manoeuvrer's heart rate showed when:

- there was a need for more information to manoeuvre the ship,
- the needed information to manoeuvre the ship was not easily obtained,
- important decisions were made by the manoeuvrer (Ohashi & Hirota 1969).

Ohashi and Hirota (1969) attributed the mental strain to poor manoeuvrability and size of the ship, the increase in local shipping, poor navigation instruments and lack of information from land. In a later study of shiphandling in narrow channels, Luczac (1991) refers to a relationship between different information processing independent variables and the physiological dependent variables, finding that different navigational situations produce different influences on the stress-strain relationship. For example, in an oncoming traffic situation, radar and map information predominated resulting in an increase in attention whereas an introduced radar defect situation resulted in increased emotional strain as measured by increased heart rate.

In summary, the variables of crew size, automation and information processing are interrelated and complex man-machine systems such as those that existed at Three Mile Island and Chernobyl both generate fatigue and are vulnerable to human error caused by fatigue (Luczac 1991). In instances of maritime incident, investigators have found that operators have failed to consider all the information available to them. Information overload, however, presents a challenge for better data display.

Aversion to effort

Aversion to effort includes such behaviours as failing to reduce speed, failing to avoid a close quarters situation and failure to take avoiding action (in the absence of deficiencies in alertness). This behaviour excluded instances where the action could be categorised as being caused by a loss of alertness, limitation to perception of information-processing deficiency. The incidence of aversion to effort was relatively small.

This behaviour predominates during the day (late in the day in absolute frequency, but earlier in the day as a relative frequency). Examples include failure of the chief mate of the *Ruca Challenge* (report 18) to continue to plot the vessel's position, failure of the second officer of the *Han Gil* (report 4) to take avoiding action and failure of the watchkeeper of the *Gumbet* (report 106) to take a sufficiently wide berth when passing fishing vessels. In a number of incidents such as the *Jhanski Ki Rane* (report 13), *Yue Man* (report 7), *Great Brisbane* (report 17), *River Embly* (report 19), and *Berlin Express* (report 53), appropriate action in reducing speed was not taken.

As with the previous behaviour, problems with execution follow the reported phenomenon of a decrease in accurate performance during the day (Monk 1989a). Other authors have described forms of aversion to effort as a consequence of time on task (Hockey 1986) but inevitably, in real world situations, a combination of partial sleep loss, time on task and circadian performance rhythm will all interplay in producing this pattern of behaviour.

Differing nature of effort

Differing nature of effort was categorised on the basis of an inappropriate action being undertaken by the watchkeeper. As with the previous behaviour, this behaviour excluded instances where the action could be categorised as being caused by a loss of alertness, limitation to perception of information-processing deficiency. As the frequency of differing nature of effort fatigue behaviours was typically less than 2% (corresponding to only 11 text units), no analysis of temporal distribution was made.

One unsafe act, however, predominated in this category. In eight separate instances, port instead of starboard helm was inappropriately applied, resulting in the grounding of the *River Boyne* (report 9), the *Alam Indah* (report 14), the *Berlin Express* (report 53), the *TNT Carpentaria* (report 37), and collisions involving the *Iron Cumberland* (report 10), *Yue Man* (report 7), *Longevity* (report 41) and the *Searoad Mersey* (report 64). In most instances a course alteration to starboard is the correct action to avert a collision.

Summary

Accidents resulting from human error are caused by latent errors or active errors in the form of inappropriate line-management decisions, psychological precursors of unsafe acts, unsafe acts, or inadequate defences following unsafe acts. Such human contributions are evident in Incidents at Sea reports as behaviours of the various contributors.

These behaviours were categorised using an information-processing model and their relationship with time of day is summarised in figure 12.

Time of day affected the type and degree of behaviours; several behaviours exhibiting a diurnal variation. It is possible that time of day exerts a modulating influence on a fatigued watchkeeper – behaviours that may be suppressed or overcome by effort of will, motivation or circumstance at one time of the day, may become overt at another. Decreased alertness and information-processing behaviours are significant human error behaviours, both in terms of absolute frequency and diurnal variation and are perhaps the two manifestations of fatigue that are most likely modulated by time of day.

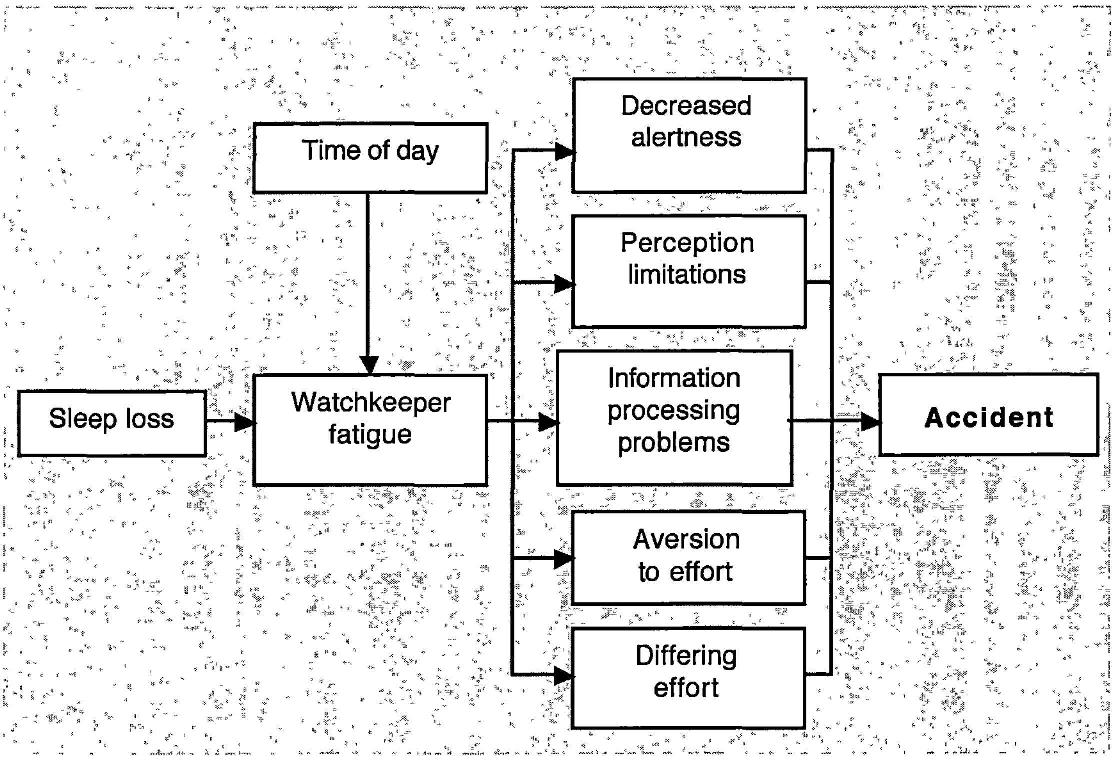

Figure 12: Sleep loss, time of day and accidents: the modulating influence of time of day on fatigue behaviours

5.3. Sleep factors

Sleep and sleep deprivation

Accident reports describe a complex interrelationship between sleep, work and leisure existing among those involved in watchkeeping activities. Falconer's Marine Dictionary of 1780 describes the adverse consequences of watchkeeping: "Those whose rest is regularly broken by watch-duty, generally put on an appearance of premature old age, that a person unacquainted with them would be liable to err several years in forming a calculation of their ages from their exterior physiogomy, owing principally to their abridged and broken sleep at night" (Parkin 1997). At the time of Cook's voyage to Australia, regulations for watchkeeping were brief, article XXVII of the Kings Regulations and Admiralty Instructions stating that "No person in or belonging to the fleet shall sleep upon his watch, or negligently perform the duty imposed on him, or forsake his station on pain of death..." (Parkin 1997). While incidents at sea had life or death consequences for those 18th century seafarers, the contemporary situation is arguably more threatening, as described by Dinges (1995): " ... it is now possible for a fatigue-related vigilance error of a single person working on the night shift and/or without adequate sleep to trigger an industrial accident that can kill thousands of people, damage major proportions of the environment and/or cost billions of dollars".

Unfortunately, accident investigators are more able to assign watchkeepers frank-sleep episodes as contributory to an accident than the more subtle deficiencies in cognition and judgement resulting from fragmented and deficient sleep.

Not all sleep is associated with the fatigue state. As will be detailed below, the routine on board coupled with the biological need for sleep infers that all crewmembers will sleep from time to time during the day, hopefully, but not always while off watch. At times, all crewmembers of fishing vessels with small crew number may be asleep without posting a watchkeeper. At other times, significant crewmembers, such as the master, the pilot or the skipper of a fishing vessel may be asleep, when ideally their presence on watch may avert some incident.

Accident reports describe contributory factors such as long work periods, poor quality sleep, "jet lag", broken sleep, self-inflicted sleep deprivation, disrupted sleep patterns and a poor sleeping environment. As the master, second mate and pilot were the primary contributors in two-thirds of all incidents, the routine and contribution of these particular watchkeepers could be considered in comparison to each other and to other watchkeepers.

The Master

The master's involvement is reported across all watches and evenly distributed between collisions and groundings. Only in one incident however is the master's contribution associated with being sleep deprived (the tugmaster of the *Wambiri* suffering slight sleep debt) and in no instance is the master reported as being asleep while on watch. The relative lack of association of sleeping and sleepiness with accidents involving masters is remarkable given the master's overall responsibility for the safe operation of the vessel and the requirement to take command during critical manoeuvres. Webb and Levy (1982) and Carskadon and Dement (1981) comment that neither prior experience with sleep loss nor perceived adaptation result in adjustment to sleep loss. It is unlikely therefore, that the master has adjusted to working in a sleep deprived state, but rather is in an advantageous position to adapt his sleeping habits around the work routine. For example, the master of the *Karin B* (report 100) arranged a pilot boarding time to "allow him to get some sleep", and the master of the *Columbus Victoria* (report 102), "went to bed some time before 2200 … anticipating an early call to weigh anchor". There are numerous references to masters getting some rest prior to berthing, anchoring or some demanding manoeuvre. Sanquist et al. (1997) report command personnel having the highest average sleep duration of all personnel in a field study of 141 marine personnel. They also report lower levels of subjective decreased alertness among command personnel than other watchkeepers (Sanquist et al. 1997).

The master's responsibility for overall command as well as his ability to exert some control over his sleeping pattern may also lessen the impact of disrupted and deficient sleep. Haslam (1982) and Krueger (1989) report a greater deterioration in event-paced tasks than self-paced tasks. In addition, Krueger (1989) notes that following sleep deprivation, vigilance and detailed cognitive tasks deteriorate more rapidly than simple and well-learned tasks. The master's experience as well as a greater capacity to self-pace tasks may help mitigate against the effects of sleep deprivation.

The Second Mate

The second mate's contribution is mainly to collisions (6 collisions compared to 2 groundings and one other incident) and incidents occurring during the second mate's watch (6 incidents on the 0000 to 0400 watch, 2 on the 1200 to 1600 watch). Reference to the second mate either being asleep or sleep deprived is made in three incidents, the highest frequency of any individual contributor. The second mate being contributory is associated with the highest number of sleep references (44% of all sleep references) and the second highest number of incidents, yet the literature suggests that the second officer's watch allows longer sleep time than the average for watchkeepers (Ruterfranz et al. 1988; Sanquist et al. 1997). In contrast, however, Sanquist et al. (1997) report the second officer's watch as having significantly more work periods with critically low alertness levels than that of personnel on other watches.

Rutenfranz et al. (1988) note that the second officer typically has two equal sleep periods commencing about 0500 and 1900. Sanquist et al. (1997) reports a similar pattern. Though the second mate's average sleep duration is reported to be longer, sleep commencing in the morning is shown to be less beneficial than sleep commencing in the afternoon (Naitoh 1981, in Haslam 1982). Åkerstedt (1995b) also reports a circadian influence resulting in short morning sleeps. In addition, the early evening time of sleep resistance reported by Lavie (1986) as the "forbidden zone" for sleep corresponds to the approximate starting time for the second mate's evening sleep. Finally, Carskadon et al. (1982, in Roth et al. 1989) note the relationship between sleep fragmentation and daytime sleepiness, a similar finding to Stepanski et al. (1984). It appears that though the second mate enjoys greater than average sleep duration, the split sleep periods occur at the least efficient times of the day for sufficient restorative value.

The majority of behaviours associated with incidents occurring on the second mate's 0000 to 0400 watch are associated with decreased alertness (Phillips 1998). This is consistent with Monk and Embury's findings (1981, in De Vries-Griever & Meijman 1987) that perceptual and sensorimotor errors predominate following sleep deprivation, but less errors are found at night in complex monitoring and control tasks. The sleep-deprived and fatigued second mate simply loses alertness and his vessel runs aground, or more likely collides with another vessel.

Most collisions reported in this study involve commercial vessels and fishing boats. Fishing boat manning levels frequently lead to unsafe practices such as not posting an anchor watch or posting an unqualified watchkeeper (such as the cook). Five of the eight collisions where either the fishing boat skipper and/or crew were asleep occurred on the second mate's 0000 to 0400 watch. Accident investigators usually find that a combination of the second mates decreased vigilance (possibly from sleep deprivation) and inappropriate or absent watchkeeping (possibly due to being asleep) on board fishing vessels is a common cause of collisions.

The Pilot

The pilot was associated with seven groundings and one collision, predominantly on the 0400 to 0800 watch. This distribution is not surprising, given the coastal nature of pilotage. In seven of the eight incidents, accident investigators describe various errors of judgement, disorientation or failure to appraise a situation. In only one incident was sleep a contributory factor, the pilot of the *Peacock* (report 95) losing situational awareness, in all probability by falling asleep. This incident occurred on the 0000 to 0400 watch, consistent with most other instances of watchkeepers falling asleep on watch.

The role of the marine pilot is substantially different from that of others involved in watchkeeping. Pilotage involves complex issue of port-state sovereignty, and the use of local knowledge and judgement by the pilot in navigating coastal waters. Carpenter and Huffner (1977) describe the retrieval of information stored in the pilot's long-term memory as he scans information sources in the environment in a repetitive manner, with experienced pilots being able to anticipate situations well in advance before they become critical. It is therefore not surprising that incidents involving pilots are associated with failure of higher-level cognitive processes, rather than a decrease in alertness.

There is considerable literature linking sleep deprivation with decreased vigilance and alertness (e.g. Åkerstedt 1995b; Bonnet & Arand 1995, Wilkinson & Haines 1966); however, the pilot's role is more complex than just maintaining alertness. De Vries-Griever and Meijman (1987) note that performance in complex tasks that utilise high memory load (such as that of pilots) gets worse in the course of the day, whereas performance on tasks utilising low memory load seem to improve in the course of the day. Krueger (1989) notes that both vigilance and more detailed cognitive tasks deteriorated most in 90 hours of sleep deprivation and 4 hours sleep per day for 6 days (the latter resembling marine pilots average sleep), simple and well-learned tasks deteriorating little. Similarly, Haslam (1982) reports a deterioration of cognitive function and logical reasoning following one night without sleep. Parker and Hubinger (1998) describe decreased sleep time (an average of 0.59 hours per 24 hours in the Great North East Channel pilots) and fragmented sleep (an average over three sleep periods per 24 hour period on the Great Barrier Reef Inner Route), with pilots accumulating a daily sleep debt of 5.6 to 6 hours. Sleep latency and sleep efficiency data in Parker and Hubinger's study (1998) was consistent with pilots being in a fatigued state.

Other Watchkeepers

The first and third mate are only associated with six incidents, with only one incident each associated with sleeping. The first mate of the *Carola* (report 79) fell asleep due to fatigue during his 0400 to 0800 watch, while the master and the pilot were asleep off-watch. The first mate was described as a conscientious and keen officer, but following an intake of alcohol and a shorter than normal prior sleep, he probably fell asleep a little after 0430 during the circadian low. This incident illustrates the extreme sleepiness as described by Åkerstedt (1995a) due to the interrelationship between working during the circadian low, extended work hours and reduced sleep length.

The compounding effect of alcohol would have also exacerbated the first mate's sleepiness.

The third mate of the *Eternal Wind* (report 131) failed to maintain an effective lookout (he was working out compass error while the seaman-lookout was working on deck). At 0815 the *Eternal Wind* collided with the fishing boat *Melinda T*. The watchkeeping deckhand noticed the *Eternal Wind* only seconds before the collision. The skipper of the *Melinda T* routinely slept in the wheelhouse in order to be immediately available, three-hour watches being maintained by the deckhands. During the voyage, the vessel experienced 20-25 knot winds and 2-2.5 metre seas, with the vessel yawing through 20 degrees. Though sleep deprivation was not identified by accident investigators, the need for daytime sleep by *Melinda T*'s off-watch and the disagreeable sleeping environment for the skipper illustrates a number of sleep hygiene factors associated with fishing vessels. Torsvall and Åkerstedt (1988) note that on-call conditions shorten sleep duration and sleep quality, with an increased sleepiness on the following day. The need to be readily available, in conjunction with the compounding effects of noise and motion on board a fishing vessel at sea may have adversely affected the skipper's sleep. There has been little sustained research on the effects of the physical environment other than noise and heat (Hockey 1986). Parker and Hubinger's 1998 study of the work and rest patterns of Great Barrier Reef Pilots found that it was unlikely that sleep at sea was affected to any degree by sea conditions, noting that such waters are generally protected from extreme weather found on the open sea.

Intrinsic physiological and psychological differences

The previous section of this thesis considered the individual watchkeeping periods and the corresponding watchkeeper role, their opportunities for sleep and the possibility of sleep deprivation. It is also appropriate to consider the possibility of individual differences in tolerance to sleep deprivation among those keeping watch.

Horne and Ostberg (1977) reviewed individual differences in circadian rhythm and note that individuals may be classified as either morning types or evening types according to the phase of their body temperature rhythm.

These "types" have also been related to personality theories. Colquhoun (1960), in a study of personality and performance involving 102 adult males, noted that at 10.00 a.m. introvert subjects tended to be more efficient at an inspection task, whereas at 3.00 p.m. extraverts were more efficient. In a study comparing morning-eveningness in 48 subjects, Horne and Ostberg (1977) supported the notion that extraverts tend to be evening types and introverts tend to be morning types. They noted studies that find this correlation becomes stronger after 40 years of age, with marked differences in sleep habits, with extraverts sleeping progressively longer and waking later and introverts shorter (Horne & Ostberg 1977).

Given the years of experience required by Pilots or Masters, it is more likely that these officers are also older than Mates and possibly exhibit the morning-type chronotype with a corresponding difference in performance profile and coping strategies. Harma (1993) notes numerous studies relating morningness to decreased tolerance to shiftwork.

In a recent survey of 2007 subjects by Taillard and Bioulac (1999), evening types were found to react differently to sleep deprivation than other chronotypes. The authors found that although evening types went to bed later and woke up earlier than morning types, they presented a daily sleep debt of 9-90 minutes, but slept more on weekend, thereby repaying their sleep debt. Evening types varied their bedtime more often than other chronotypes as well as consuming more coffee. It appears that evening types demonstrate more flexibility in sleep patterns and strategic measures, a characteristic identified by Costa et al. (1989) as associated with better tolerance and adjustment to shiftwork. It is possible that the sleep deprived, and possibly younger second mate (and therefore more likely to exhibit evening type characteristics) is being taxed in flexibility of sleeping habits and the second mate's less-than-average total sleep time exacerbates shift-induced sleep deprivation (especially where that officer is unable to achieve recuperative off duty sleep).

Åkerstedt and Torsvall (1981) surveyed 390 workers on various shift systems and found that with increasing age and experience of shiftwork, sleep quality and sleep length were reduced. The authors note that in light of morningness increasing with age, the morning peak in alertness may inhibit the morning sleep necessary for recuperation following night work. Harma (1993) notes that elderly people have a two hour earlier peak of activity than younger people, which coupled with an increase in sleep disturbances and lower quality sleep (i.e. a greater proportion of stage one sleep) may result in poorer adjustment to shift work with advancing age. Harma (1993) noted that studies comparing male and female workers have not found differences between the genders in shiftwork tolerance.

The quantity and quality of sleep of seafarers

Åkerstedt et al. (1997), from a study involving eight subjects undertaking short sleep episodes, describe the factors that contribute to a good night's sleep:

> A good night's sleep, then, seems to involve a long prior wake span, a location close to the circadian nadir, a long and continuous sleep sequence, and considerable amounts of SWS. For an easy awakening and a feeling of being refreshed from sleep some disturbance towards the end of sleep would be required, perhaps via a slightly delayed bedtime in order to terminate sleep higher up on the circadian upswing.

These factors are frequently diminished or absent in the on board environment and conditions are less than ideal for Åkerstedt's "good nights sleep". Sleep, sleeping and sleep deprivation are central issues in the life on board commercial ships and fishing boats. A number of studies have been undertaken to quantify the amount of sleep taken at sea. Rutenfranz et al. (1988) refer to a study of the sleep habits of submariners undertaken by Kleitman in 1949 where 75% of respondents described sleep quality as poorer at sea than ashore, though sleep time was 8.6 to 9.6 hours per 24 hours. Rutenfranz et al. (1988) found average sleep duration of 7.55 hours per 24 on watchkeeping duties compared with 11.02 on days off in a diary study of 68 subjects over 540 days. Sanquist et al. (1997), in a study of 144 mariners on tankers and freighters on US west coast runs, found average sleep duration of watchkeepers of 6.6 hours (5.2 hours for the 0400 to 0800 watch on freighters.) This compares with home sleep of 7.98 hours, inferring a daily sleep debt of some 1.3 hours aboard ship. Thirty-eight percent of respondents indicated that they experienced fatigue or decreased alertness while watchkeeping and 11% of work periods were associated with low levels of alertness (Sanquist et al. 1997).

Marine pilots appear to suffer even greater sleep restriction. Parker and Hubinger's (1998) logbook study of 23 Queensland pilots based on 146 assignments found that sleep time per 24 hours varied between 0.59 hours and 5.25 hours depending on the pilotage route. In this study, sleep latency varied from 4 to 7 minutes, consistent with the fatigued state. Sleep debt per 24 hours was about 6 hours (compared with sleep ashore between assignments). In earlier studies of pilots, Cook and Shipley (1980) found that " ... pilots are extremely tired after a 'long-haul' pilotage, particularly at night ... and frequently need an 'effort of will' to maintain vigilance when on watch during uneventful passages". In a study of Port Phillip Sea Pilots, Berger (1984) suggests that a pilot might get 3 hours poor quality sleep in 27 to 30 hours.

Sleep loss and performance

While ships officers clearly suffer considerable risk of sleep deprivation, what are the likely consequences of this in performance terms.

Hockey (1986) states that "...the general finding from studies that have used tasks involving the use of working memory is that sleep loss impairs performance." Hockey's (1986) assessment of the effect of sleep loss on memory is that "...the sleeplessness state is quite suitable for maintaining the accessibility of recently acquired information, although less suitable for encoding or registering it." This may serve to explain the late afternoon increase in information processing problems described in the previous section.

In a study utilising both a tracking task (keeping a cursor in the centre of a moving target on a computer screen) and time estimation (estimating time intervals), Bohnen and Gaillard (1994) found that following one night of sleep deprivation, "...performance in the tracking task gradually degraded during the half hour working session... but performance in the time estimation task was not impaired". Experimental design (allowing the subjects undertaking the time estimation task to make observation responses of status) allowed the researchers some measure of subject confidence and noted in this study "...the tendency to make more observations indicates that sleep deprivation may lead to a higher uncertainty" (Bohnen & Gaillard 1994). The authors propose that their subjects' observation responses required less cognitive resources than the continuous monitoring of an internal clock; it was easier to make more frequent checks than rely on internal resources.

Performance deficit due to total sleep loss may be mitigated by modifying either the task or the environment. Gaillard and Steyvers (1988) found that the performance deficit effects of total sleep loss were greater with degraded stimuli than with intact stimuli which "...suggests that the perceptual encoding process is affected by sleep loss." In addition, Gaillard and Steyvers (1988) claim that the effects of sleep loss are greater in the afternoon than in the morning and that the effects increase towards the end of a task.

Angus and Heselgrave (1985), in a total sleep deprivation study involving 12 female students, considered that previous studies had underestimated the effects of sleep deprivation, their subjects experiencing a decreased reaction time performance of 76% of baseline after one night of sleep deprivation and only 43% of baseline following the second night. Angus and Heselgrave's study did, however, involve substantial cognitive activity (simulating a military setting), and this demanding workload could have depleted the reserve capacity normally available to subjects during daytime periods. In this study, the authors propose no sound rationale for selecting female subjects to participate in a study and extrapolating results to a particularly male domain (i.e. the military in the mid 1980's). In addition, the authors note that though the results of their studies are "... directed towards a military command and control environment", their results are also applicable to "... a variety of crisis situations... as well as to non crisis situations involving alternative work cycles." Given the small sample in the study, the narrow age bracket (19 to 24 years) and the gender homogeneity, this is an ambitious claim.

A more recent study of total sleep deprivation (up to 102 hours) in a group of 20 naval gunners showed a deterioration in performance in a battery of neurobehavioural tests with increased hours of sleep loss with troughs at between 36 and 42 hours and between 66 to 78 hours (How et al. 1994). There was a similar pattern with short-term memory and muscle fatigue tests Subjective sleepiness assessment and mood scale showed an upward trend with peaks at 36 to 42 hours and again at 80 hours. This two-stage deterioration with total sleep deprivation may indicate some adaptation occurring during the intervening plateau, however the exact nature of such adaptation remained undefined in this study (How et al. 1994).

Consistent with the findings of Haslam (1982), How et al. (1994) found that performance in "...routine military tests which involved well-learned mechanistic manoeuvres were not affected". This observation is consistent with the suggestion that "...lower and more peripheral processes are more sensitive to sleep loss than central, cognitive or memory processes" (Gaillard & Steyvers 1988). Wilkinson (1962) claims that the latter tasks are more intrinsically motivating to the subject and therefore better performed.

Horne (1988) studied creative thinking in 24 subjects who went 32 hours without sleep, finding that sleep loss impaired performance on all creative thinking test scales. In a later study, Harrison and Horne (1999) utilised a marketing decision-making game to evaluate flexible thinking and cognitive responsiveness. The authors found that though critical reasoning (approximating information acquisition) was unaffected by sleep loss, 32-36 hours of sleep deprivation led to more rigid thinking, increased perseverative errors and difficulty in appreciating an updated situation. The authors comment that well-rehearsed or familiar tasks are largely unaffected by one night of sleep deprivation, consistent with the observation by How et al. (1994) on the performance on routine military tests described above.

Harrison and Horne (2000) reviewed the impact of sleep deprivation on decision making and surmised that though rule-based convergent and logical tasks are unaffected by short term sleep deprivation due to compensatory effort and heightened participant interest, divergent, unexpected and innovative skills are affected. The authors also confirm that monotonous and dull tasks are vulnerable to sleep loss.

Partial sleep loss

Though there have been many studies (e.g. Freidmann et al. 1977; Webb & Agnew 1974; Horne & Wilkinson 1985) in which reduced sleep resulted in minimal performance disruption, partial sleep loss has been shown to contribute to a progressive impairment of vigilance. Webb and Agnew (1974) studied 15 male subjects on a sleep regime of 5.5 hours a night for 60 days and determined that only vigilance performance declined with restricted sleep (a 28% decline in correct responses), behavioural consequences being minimal. Friedmann et al. (1977) concluded that 6-8 months of gradual sleep reduction, down to 4.5 - 5.5 hours per night did not result in behavioural effects, subjective fatigue being the limiting factor determining tolerability. The authors did find however that 4.5 hours sleep per night was a possible genetic limit beyond which sleep cannot be reduced in most people. Horne and Wilkinson (1985) paired twelve subjects comparing performance of 6–hour sleepers with 8-hour sleepers. The authors found no significant differences in daytime sleepiness measures (subjective sleepiness and vigilance), concluding that two hours sleep reduction can be achieved relatively easily in young adults.

In contrast to the above studies, Wilkinson and Haines (1966) reported on vigilance and calculation tests in their study involving groups of 6 enlisted men on a regime of sleeping with either 0, 1, 2, 3, 5 or 7.5 hours sleep on the preceding night, the authors concluding that a reduction in sleep by about half on a single night can produce a significant fall in working efficiency. In addition, the authors noted that performance decrement is unlikely to show up on short duration tests (i.e. about 5 minutes), but is clearly evident on prolonged tests (i.e. 15-40 minutes).

Bonnet and Arand (1995) refer to studies measuring multiple sleep latency (MSLT) and sleep propensity, noting that modest sleep reduction (1-2 hours per night) is associated with decreased sleep latency and increased sleep propensity. The authors review several studies where a reduction in sleep times in normal young adults is associated with a decrease in alertness by up to one third.

In a field study of partial sleep deprivation over nine successive days, Haslam (1982) showed that sleep deprived subjects demonstrated a deterioration in a range of cognitive and motor skills over the nine day period and that even small amounts of sleep may be beneficial, compared with no sleep at all.

Rutenfranz et al. (1988) in a study of watchkeepers sleep patterns while on active duty using both traditional watchkeeping systems (two four hour watches per day) and on daywork found that among watchkeepers using the traditional system, sleep was broken and that there were indications of a lack of adaptation of the sleep-wakefulness cycle. Mean sleep duration for watchkeepers was 7.55, for daywork was 7.51 and for days off was 11.02 (Rutenfranz et al. 1988). The authors claim that as sleep duration is dependent on the time of sleep onset; "...sleep which begins in the daytime is in general shorter than sleep which begins in the evening", this fact in association with non watchkeeping duties and social activities contributes to fragmented sleep (Rutenfranz et al. 1988). This study also revealed that the shortest sleep duration of all (6.93 hours) was shared by the subjects on "stand by" duties (Rutenfranz et al. 1988).

Selective sleep loss

Very few performance studies have been carried out on the selective reduction in REM sleep (with a consequent reduction in total sleep time), however other studies have confirmed the view that REM sleep is important for the consolidation or elaboration of learned material (Hockey 1986).

Fragmented sleep, as a result of noise, interruption or sleep disorders such as obstructive sleep apnoea may lead to selective sleep loss. Stepanski et al. (1984) studied the effect of arousals on daytime sleepiness on 45 subjects including those affected by sleep apnoea, myoclonus, insomnia as well as normal controls. The authors found that though arousal during sleep failed to significantly alter total sleep time, the proportion of various stages of sleep varied significantly. The percentage REM sleep in sleep apnoea subjects was 10.3% compared to 17.4% with normal subjects, though the apnoea group enjoyed a greater total sleep time (7.3 hours compared to 7.0 hours). In addition, the authors found a positive correlation between nocturnal arousal (and hence fragmented sleep) and excessive daytime sleepiness as measured by the multiple sleep latency test. The authors conclude that consolidation of sleep is crucial and that arousals during sleep directly produce daytime sleepiness.

In the study of on-call ship's engineers, Torsvall and Åkerstedt (1988) found that being on call reduced REM and slow wave sleep and the first sleep cycle contained less stage four sleep and more stage two sleep. Given the predominance of slow wave sleep in the early part of the night and the relative increase in the incidence of REM sleep as the night progresses, any delay in the onset of sleep time will subsequently reduce the proportion of slow wave sleep (Hockey 1986). Torsvall and Åkerstedt (1988) identified in their study that "...sleeping while on-call shortens sleep duration and reduces the amount of REM and slow wave sleep as well as the spectral power density...these negative effects on sleep are followed by an increased sleepiness during the subsequent day". The duration of sleep, independent of actual waking to attend to alarms, was approximately 1.5 hours shorter during on-call nights.

Factors mitigating sleep deprivation

While nothing appears to be as effective as a good nights sleep in mitigating the effects of sleep loss, there are a number of strategies that have been studied that may reduce the consequences of sleep loss.

Carskadon and Dement (1981) found that daytime sleepiness returned to basal levels following one full night of sleep in a study involving sleep restriction to 5 hours in 10 young adult subjects. Foo et al. (1994) in a study on total sleep deprivation (42-104 hours) of 20 male naval volunteers found that performance in routine tasks, mood and sleepiness improved following a sleep period of 4 hours (following 42 hours of sleep deprivation), however cognitive and perceptive skills did not. A similar finding was made by Haslam (1982) who noted that daytime recovery-sleep is less beneficial on performance than early morning recovery-sleep.

Numerous authors have referred to the restitutive effects of naps, Graeber et al. (1990) evaluating the benefits of pre-planned naps by pilots in Boeing 747 cockpits. Napping and pre-planned rest periods are now common practice as fatigue countermeasures in many long-haul commercial flights.

Buxton (2003) reviews the nature of naps and classifies naps as either maintenance (usually short duration, to supplement main sleep in advance of an extended work period) or recovery (longer duration, to help make up for lost sleep during a work period). The author notes that naps need to be more than ten minutes in duration in order to be effective, but that naps of 120 minutes do not produce any better performance than naps of 60 minutes. Buxton (2003) also notes the danger of waking from slow-wave sleep with subsequent sleep inertia and initial performance difficulties. She cites research by Ferrara and De Gennaro (2000) recommending a nap length of about 20 minutes or else about 80 to 100 minutes in order to minimise the chance of waking from slow-wave sleep.

Reyner and Horne (1997) compared a <15 minute nap and caffeine (150 mg) with a placebo, finding a substantial reduction in the number of incidents (drifting from the lane) in a driving simulation study in an experimental group of 12 graduate students. The effect was evident for about one hour and a benefit was also evident for a higher dose of caffeine (200 mg) for a second hour. In a later study, Reyner and Horne (2002) found that 200 mg caffeine reduced early morning driver fatigue for about 30 minutes following a night without sleep, and for about 2 hours following a night with only 5 hours sleep. (The authors note the relatively short duration of the caffeine effect in the light of its plasma elimination half-life of 5 - 7 hours.) Reyner and Horne (2002) considered the effect of a "functional energy drink" (Red Bull®) containing 80 mg caffeine in a similar driving simulation study and found reduced subjective sleepiness, decreased driving incidents, particularly during the first 90 minutes of the drive. The authors noted that the magnitude of reduction in incidents with the energy drink is similar to the reductions following consumption of coffee containing 200 mg caffeine, the authors concluding that the energy drink is more effective than coffee with the same amount of caffeine.

Stampi, (1988) in addressing sleep strategies for those engaged in continuous work (emergency services, health providers, astronauts etc) proposes that adopting polyphasic sleep and ultrashort sleep-wake patterns could mitigate against the effects of sleep deprivation. Stampi (1988) states that adult humans are the exception in the animal kingdom in adopting a monophasic sleep-wake pattern given the polyphasic nature of other animals' and human neonatal and early childhood sleep patterns.

Linear regression analysis of mean sleep episode duration of single-handed sailors in three international competitions showed that "...the shorter the sleep episode duration, the better his race standing" (Stampi 1985). Similarly, Bennet (1973) noted that "...certain highly motivated people can wake themselves up at hourly intervals for 4 of 5 weeks on end and still apparently be functioning at a high level of efficiency." Bennet's (1973) study of the medical and psychological effects of the 1972 singlehanded transatlantic race did document errors of navigation, probably due to fatigue, however it is remarkable that no evidence of fatigue was documented as a contributing factor in the several major mishaps that occurred during the race. It is noteworthy that in this environment, there is an absence of social, cultural and occupational cues, which may have a significant impact on regulating the nature of conventional monophasic sleep.

Hartley (1974) has shown that "...a polyphasic schedule of three 80-minute naps lead to a significantly higher performance level compared to a monophasic pattern of the same amount of sleep per day."

Summary

The literature strongly suggests that seafarers, like contemporaries in other professions, are obtaining less sleep than desirable, or in fact essential for efficient functioning. Ship's watchkeepers enjoy less total sleep time and suffer partial sleep deprivation by virtue of life on board and the essential requirement to be part of watch. Watchkeepers are shift workers, but with the added burden that they are unable to go home or return to a stable day/night pattern of activity and rest – their work is their home for weeks at a time. This is particularly true of those engaged in the fishing industry. The integral nature of work and sleep on board, in addition to the sleep loss suffered by watchkeepers is summarised in figure 13.

It is evident from the figure that the data supports two patterns where sleep factors may contribute to accidents. First, the nature of seafaring is not particularly conducive to sleep in sufficient quality or quantity, such environmental factors contributing to sleep loss, which, at certain times of the day may manifest as a fatigue behaviour, which, in turn, may contribute to an accident. The second pattern results from a routine on board where the work environment necessitates daytime sleep which may result in critical crewmembers being asleep or a vessel being "not under command." These circumstances usually result in a watch not being kept or inappropriate responses from untrained crewmembers in critical situations (such as close quarters requiring navigational decision making).

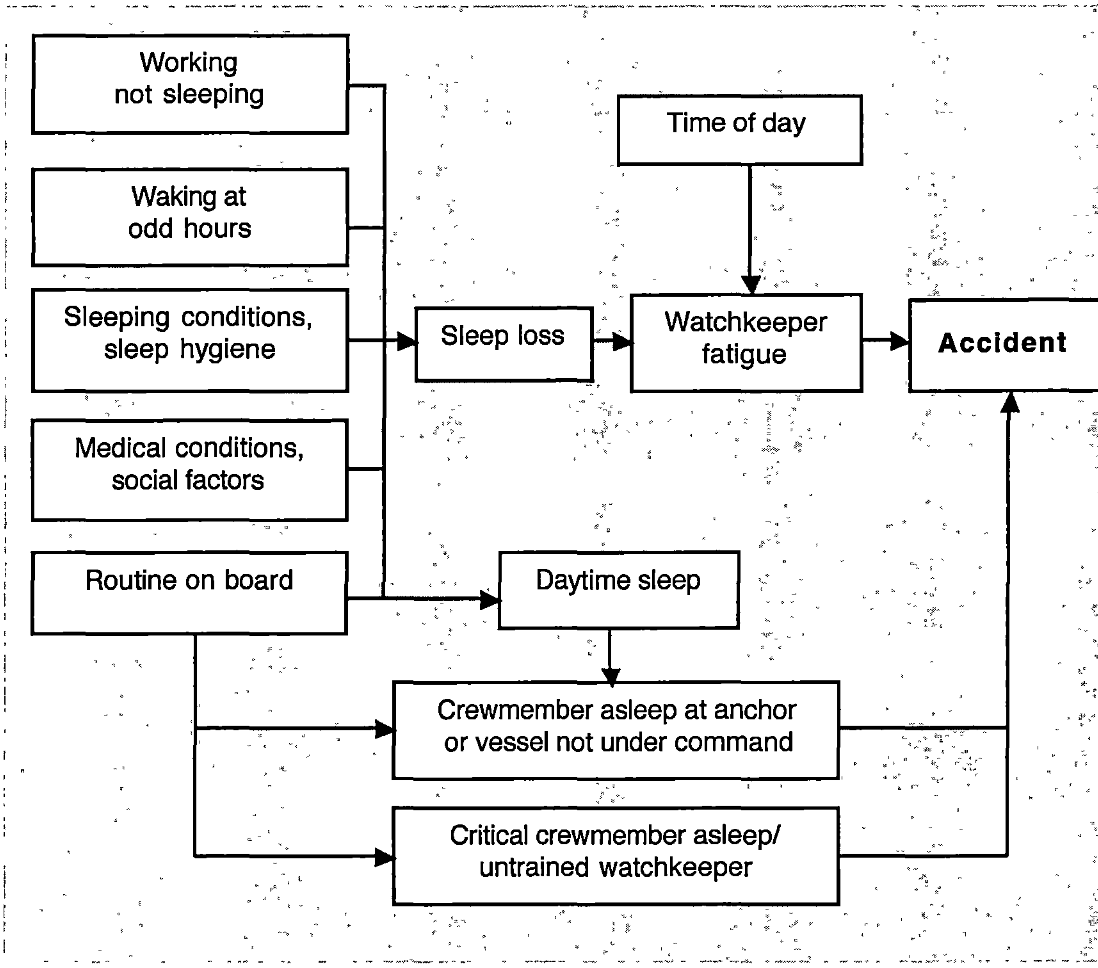

Figure 13: Sleep loss, time of day and accidents: the effect of the integrated nature of work and sleep and factors contributory to sleep loss

5.4. The task of navigation

In an analysis of findings on collisions and groundings, Bryant (1991) and the Tavistock team noted that collisions often occur where a vessel traffic service (VTS) is set up to convey information about traffic in the vicinity. In addition, the team noted misinterpretation of radar (despite improvements in training and equipment), reliance on visual cues (where navigational aids are available) and invoking close encounters with other vessels, possibly as a means of reducing uncertainty (Bryant 1991). It appears that the behaviour adopted in shipping collisions and groundings is compounded by factors other than the simple logic of decision-making. In the luxury of hindsight, there appears, in many cases at least, a number of simple explanations to account for such incidents, for example, failure to consider all available information in decision making, insufficient utilisation of electronic aids and failure to maintain a safe distance off. Unlike the hard digital logic of electronic information and the predicability of mechanical automation, the involvement of the human element in the control loop adds another complex dimension.

In comparison to the observations of poor navigation instruments and lack of information, by Ohashi and Hirota (1969), Bryant (1991) in the later Tavistock Institute Report observes that in over half the cases of collisions studied in depth, all the information to prevent the collision was on hand. Bryant (1991) notes that "it is doubtful whether additional technical aids and data sources would be used any more than the information currently available to the navigator and, rather than providing him with more information, greater benefits are more likely to be obtained from better data display." Johansson (1975) notes that there are "... more things out there in the environment than are worth paying attention to" and "much of everyday perception is overdetermined." Bryant (1988) notes that ship navigators are aware of much more information than they ever use. Factors such as anxiety, motivation, fatigue and boredom could influence their ability both to perceive and to process information, and hence to use it effectively.

Brown (1989) quotes Merchant Shipping Regulations, which require that "The watchkeeping system shall be such that the efficiency of watchkeeping officers and watchkeeping ratings is not impaired by fatigue. Duties shall be so organised that the first watch at the commencement of a voyage and the subsequent relieving watches are sufficiently rested and otherwise fit for duty." (This requirement, which forms part of the 1978 Standards for the Certification and Training of Watchkeepers was replaced in 1996 by more specific amendments which have become the international standard.) This objective should be read in conjunction with the United Kingdom Merchant Shipping Notice No.M1178 which places the onus on any person sending a ship to sea to ensure that it is seaworthy in respect of manning, having regard to the nature of the service for which the ship is intended. Brown (1989) notes the approach of ensuring fitness for duty by requiring that vessels be adequately manned. In the days of sail and later steam, where voyages took many months and most maintenance was carried out while underway, considerable manpower was required for sail handling, maintenance, attending boilers, greasing and oiling and preparation of meals. The scene has changed considerably and in the modern complex sociotechnical ship consisting of technologies, people, organisational structures and the external environment (Committee on the Effects of Smaller Crew Size on Maritime Safety 1990) a vessel that carried a crew of 40 a few years ago now carries a crew of less than 20.

In summary, navigation involves a complex interface of the ship and its environment, technology and systems, and the human element. In the context of increasing automation and decreasing crew size the changing nature of these factors may contribute not only to a change in the work of seafarers but also to a change in the nature of accidents, specifically less frequent but more catastrophic.

5.5. Watchkeeping and shiftwork

Adaptation to shift work

In a temporally ideal world, the nocturnal decrease in performance, alertness and mood would coincide with sleeping. Indeed this was the case until Thomas Edison invented the light bulb with the possible exceptions of traditional night-shift workers in the medical and seafaring professions. With the industrialisation of society during the 20th century, and the modern world of "24/7", services are provided around the clock, necessitating an increasing number of workers involved in shift work with performance demands occurring at biologically inappropriate times.

A number of studies have demonstrated that the human circadian rhythm does not adjust well to shiftwork. Åkerstedt (1995b) in his review of work hours and sleepiness noted that adjustment to a new circadian phase position occurs at a speed of about one hour per day. Monk (1989b) states "... the prime impact of the circadian system stems from its inability to adjust instantaneously to the changes in routine that shiftwork requires."

Nicholson and Spencer (1988) in a study of the effects of irregularity of work and rest claim that desynchronisation of temperature and sleep wake rhythms occur during a schedule which involves irregularity of periods of work and rest and that the phase change suggests that the sleep wake cycle is acting as a zeitgeber for the temperature rhythm. Nicholson and Spencer (1988), using a mathematical model, have been able to predict the effects that both time since sleep and time of day have on a performance test (digit symbol substitution test). The authors describe a low but constant performance with work that starts in the early hours of the morning (opposing effects of time on task and time of day) and an ever-decreasing performance for work commenced in the evening due to the combined effects of time on task and time of day (Nicholson & Spencer 1988). Nicholson and Spencer (1988) therefore warn of the risks of a shift schedule where a long period of duty terminates near the low point of the circadian rhythm of body temperature.

The ability of the body to successfully be entrained into a pattern of different schedules and the effect that this has on performance has significance for those designing shift schedules. Studies reviewed by Hockey (1986) reveal that adjustment to a new shift schedule takes between 7 and 14 days and is rarely, if ever complete. Folkard et al. (1976) has demonstrated however, that this slow adaptation of performance is in jobs that are low in cognitive complexity; cognitive tasks with a high requirement for internal processing that use the working memory system have been shown to adapt more quickly to phase shifts that are produced by alterations of the work rest schedule. Folkard and Monk (1979) suggest that performance efficiency exhibits a circadian rhythm and is at low ebb at night, and that this rhythm adjusts fairly slowly to night-work. Knauth et al. (1978) found in both experimental and field studies that re-entrainment of the body temperature rhythm took two or more days after two or more successive nightshifts, but only one day after a single nightshift.

Early shift starts are associated with sleep loss as found by Folkard and Barton (1993). In their study involving 297 shift workers, the authors found that (in comparison to a nominal starting time) for each hour earlier that shift workers needed to leave home before morning shift, they went to sleep only 5.3 minutes earlier, slept for 46 minutes less and were awake for 8.7 minutes less before leaving home. This study appears to illustrate that workers on early shifts are largely unable to compensate for their early start by going to bed earlier. The authors propose that the individually stable "forbidden zone" for sleep propensity proposed by Lavie, may discourage individuals from going to bed earlier than normal.

In a study of 23 female SAS cabin crew by Kecklund et al. (1994) early morning work was associated with more difficulties waking up, more discomfort due to insufficient sleep and more afternoon sleepiness. Waking at 0416, compared with the control group at 0733 was associated with over two hours less sleep. The authors also noted that participants undertaking early morning shifts went to bed approximately one hour earlier, though their wake up time was approximately three hours earlier than the control group. In addition to the deficiencies in performance associated with shift work in this study, recovery was also associated with adverse after effects.

Meijman et al. (1993) studied the effects of physical exercise (a momentary state change to tax participants of their available resources) on memory, in participants 32 hours after night, day and afternoon shifts. The authors found that while no differences in a memory search task were found between day shift and night shift groups on baseline days, physical exercise adversely affected performance in the night recovery group significantly more than the day recovery group; the authors contributing this to the burden of night work.

Smith et al. (1994) found a 23% increased risk of sustaining an injury while on night shift compared to day shift in a review of 4350 accident records from a large engineering company. Moore-Ede and Richardson (1985), in a review of medical implications of shiftwork note an association with sleeping disorders, daytime sleepiness, falling asleep on the job, peptic ulcer disease, eating disorders, increased alcohol and tobacco consumption, and acute myocardial infarction. Moore-Ede and Richardson (1985) note the methodological difficulties associated with studies involving shiftworkers, specifically the phenomena that poorly adapted shiftworkers self-select to leave shift work, and older shiftworkers tend to be promoted to day work supervisory positions. Adaptability to shift work seems to be affected by personality, age and medical disorders such as sleep apnoea, which are known to affect sleep.

Knauth (1997) gives 20 ergonomic recommendations for shift systems that incorporate shift sequencing, duration and distribution of working time, position of the working time during the day and provision for short term deviations.

Sustained operations

In military operations and increasingly in civil applications the need for continuous (around-the-clock) and sustained operations (unusually long work stints) places specific additional demands on workers, either due to the nature of the operation, economic necessity or personal choice of the employees. Such tasks may be physically demanding, require prolonged attention or may require long periods of reduced activity, with well documented effects on performance over time (e.g. Mackworth 1950; Angus & Heselgrave 1985). Vigilance in a monitoring task deteriorates rapidly over time with substantial deterioration occurring within 20-35 minutes and monitoring stints less than 4 hours are recommended (Krueger 1989).

The distinction between worker-controlled tasks (such as making telephone calls or data entry) and machine or event-controlled tasks (such as assembly line work or navigating a ship in a confined waterway) is important in determining the effect of sustained and continuous operations on performance. Williams et al. (1959) notes that performance on machine-paced tasks is often affected by small amounts of sleep loss leading to errors of omission. Similarly, it has been claimed that task based (i.e. machine-paced) pacing is most influenced by fatigue (Joly, R. 1996, pers. comm.). Navigation of a ship may include aspects of worker-controlled tasks (for example underway while at sea in the absence of other shipping) and machine-controlled tasks (for example pilotage in a confined waterway in traffic, under the influence of tide and wind.

In military applications, sustained operations are often conducted without incident as evidenced by Operation Southern Watch in 1992, where the Navy Air Wing flew more hours than during an equivalent time during Desert Storm In this operation pilots flew approximately 100 sorties per day for the 18 days of the operation without mishap. A survey of 125 aircrew members (55% response) conducted by Belland and Bissell (1994) indicated that only

18% said fatigue was not a factor and sleep decreased by only 0.4 hours per night. Aircrew utilised caffeine and nicotine tablets to maintain performance levels and to decrease drowsiness. Survey respondents indicated that fatigue was most evident at times of decreased sensory inputs such as flying in marshal (waiting to be recovered on the deck of the carrier), long monotonous flights and flying during circadian troughs (Belland & Bissell 1994). One individual response is noteworthy - "continuous operations were not a problem as long as we could take naps".

The highly restitutive nature of naps in sustained and continuous operations is well established (e.g. Graeber et al. 1990, Reyner & Horne, 1997). Graeber (1989), aware of the soporific nature of the long-haul cockpit observed the napping propensity of international flight crews during the course of trip patterns lasting up to nine days finding that on one seven day eastward trip, unplanned naps of over 20 minutes duration occurred on 20% of opportunities. Generally these naps are not approved by management and given the presence of an observer, probably underestimated the extent of this practice. Graeber (1989b) again notes that napping may have an overall beneficial effect on the vigilance level of the crew.

The differences between flying medium duration military sorties (4 to 6 hours as described by Belland and Bissell, 1994) and the long-haul civil aviation operations of up to 16 hours may be explained in terms of motivation and exhorting subjects to perform. In addition, the highly specific selection process, training and technical and logistical support of naval aviators, coupled to the highly intense and infrequent nature of actual live missions may account for the difference in incident rate between military and civil sustained operations.

In summary, sustained operations have the potential to expose the consequences of vigilance decrement, however the human ability to adapt is evident in prolonged military operations. In comparison, long-haul aircraft operations have a higher rate of accident than short and medium haul operations, possibly due to flight duration and time zone changes. The combination of sustained operations, particularly machine-paced operations (such as a prolonged ship pilotage), has the potential to adversely affect performance and result in accidents.

5.6. Fatigue and Accidents

Sleep loss, fatigue and accidents

Åkerstedt (1995b) states that a series of reliable events occur when people attempt to remain awake and alert during times of endogenous pressure for sleep. These are reviewed by Dinges (1995) and include:

- an increase in sleep propensity
- an increase in the compensatory effort required to remain awake and perform effectively
- an increase in involuntary intrusions of drowsiness or EEG microsleeps despite compensatory effort
- an increase in periods of poor, inefficient and variable performance
- performance deficits in elementary cognitive processes (that form the building blocks for higher order functions)
- increased periods of non-responding or delayed responding (lapses) on attention-based tasks
- reduced accuracy of short-term memory
- accelerated decrements in performance with time on task.

The interaction between the drive for sleep and time of day are dynamically complex (Dinges 1995). Åkerstedt (1995a) notes that alertness impairment in night work results from working at the circadian low point, an extended time of prior wakefulness and poor prior daytime sleep. Though most errors occurring during night shifts involve errors of vigilance (Reason 1990), errors in cognitive processing probably contribute substantially to incidents at sea. Dinges (1995) notes that although frank sleep-onset episodes underlie the most serious performance failures, some of the performance effects resulting from sleepiness can occur without microsleeps. Folkard (1997) also notes that " ... any parallelism found between sleep propensity and accident risk need not imply that those involved fell asleep, but may simply reflect a reduced speed and an increased error rate in prolonged performance".

Reduction in sleep by as little as 1.3 to 1.5 hours per night has been shown to decrease daytime alertness by as much as 32% (Bonnet & Arand 1995). Carskadon and Dement (1981) state that modest sleep reduction of one hour per night will accumulate over time to progressively increase daytime sleepiness. Working during the night has well-documented consequences, partly due to difficulty in obtaining sufficient daytime sleep (Monk 1989b; Tepas & Monk 1987; Åkerstedt 1995b; Folkard 1996).

Compounding the effect of sleep reduction is the displacement of work to the circadian phase that is least conducive to alert behaviour (Åkerstedt 1995a). Early morning work (such as the first mate's 0400 to 0800 watch) is also fatigue inducing. Compounding the sleep-depriving effects of early morning watches is the fragmented nature of sleep brought about by two daily work periods. Higher rates of sleep fragmentation lower the recuperative value of sleep and minimise restorations in cognitive function (Krueger 1989).

Fatigue effects appear to be prolonged with ongoing sleep debt; however, it is unclear in the literature as to the extent. Meijman et al. (1993) note that shiftworkers are still in a sub-optimal state during the second day after a prolonged shift period; however, Carskadon and Dement (1981) note that a single full night of sleep can completely reverse daytime sleepiness.

A concise summary of the significance of sleep as contributory to accidents is the consensus of the international group of sleep scientists compiled by Torbjorn Åkerstedt and his colleagues and presented in the Journal of Sleep Research in 1994. These scientists make seven recommendations:

- "greater attention be paid to developing guidelines that regulate the hours of work and stipulate hours of rest;
- the responsibility for these guidelines be shared amongst government, industry, the work force, the public and the scientific community;
- regulations, practices and policies be based upon sound scientific research;
- there should be more systematic consideration on the role of sleepiness in accident investigation;

- a uniform set of standard reporting criteria be established to document accurately the occurrence of sleep-related accidents;
- public education campaigns be undertaken on the importance of sleep and circadian rhythms, the adverse effects of sleep loss, and the symptoms of sleep disorders;
- preventative countermeasures to sleep-related accidents receive increased attention." (Åkerstedt et al. 1994)

It is evident from this summary document that an evidence-based approach to regulation and public education is desirable – though beyond the scope of this thesis, an important subsequent outcome would be to make available to members of the maritime industry, including managers, shipowners and seagoing personnel, information on sleep, and circadian rhythms such as that referred to by Åkerstedt et al.

Accidents and time of day

Folkard (1997) notes that transportation accident risk peaks at particular times and analyses the possible causes. The author undertook a "macro-analysis" (an analysis based on a z-score transformation of the means obtained from the published studies, not taking into account the size of the data sets) of road transport accidents and found that accident risk was clearly highest in the early hours of the morning (about two standard deviations higher than the overall), with a secondary peak in the early afternoon, corresponding to the "post-lunch dip". Similarly, the author noted a time of day effect in maritime collisions taken from 123 collision claims (except for a slightly later peak, at around 0600-0700) and Filor (1996) reported a similar pattern from an analysis of Australian collisions and groundings. However Craig and Condon (1984) claim "...that in the absence of evidence on the actual diurnal distribution of critical...human errors at sea, conclusions on vulnerability at times when performance on the bridge of a ship is likely to be below the expected norm must remain tentative."

A consensus study by the Association of Professional Sleep Societies (Mitler et al. 1988) reported that in addition to a diurnal distribution of fatigue-related vehicle accidents, meter-reading errors and anecdotal evidence of circadian influences in industrial catastrophes, there existed a diurnal distribution in heart attacks and even human mortality! Folkard (1997) concurs with Mitler et al. (1988) that the human species habitually sleeps at night and is awake during daylight hours, and that the increased tendency to sleep during the early morning, and to a lesser extent in the early afternoon results in an increased risk of human error and accident.

Stokes and Kite (1994) cite a study within the Israeli Air Force which revealed that the daytime accident rate was highest during the first hour after awakening in the morning, decreased until late afternoon and rose again during the evening. A review of fatigue-related incidents across the 24 hours identified the largest number of fatigue-related errors occurred between midnight and 6.00 a.m. (Stokes & Kite 1994). The authors caution against the possible compounding of errors in such studies where the effects of visibility, air traffic density, sleep deprivation and accumulated fatigue may be more likely to occur at night. Simulation studies of pilot performance have revealed results consistent with less complex experimental studies (Stokes & Kite 1994). Pilots undergoing brief but demanding missions at three hour intervals during the day have demonstrated a relatively high error rate in the morning, which progressively decreased until about 3.00 p.m., with errors increasing again and reaching their highest frequency between 3.00 a.m. and 6.00 a.m. (Stokes & Kite 1994). The authors note that this pattern has been observed in studies where sleep was permitted apart from actual testing periods and that performance does not degrade in a linear fashion with sleep deprivation; thereby supporting the case for an independent daily rhythm in performance.

To associate accident risk with a loss of alertness is to oversimplify the complex interrelationship between circadian and sleep factors and their contribution to human error. Folkard (1997), in noting the parallelism between sleep propensity and road traffic accident risk, also notes the time on shift effect, whereby it appears that the safest duty duration might lie in the region of 8-10 hours, and that the four hour watch might be associated with a 20% increased accident risk relative to 8 hour duties. The author suggests that in land transport statistics at least, commencement of duty and circadian factors interact to provide a transient 2-4 hour peak in risk superimposed on the otherwise exponential increase in risk over time on task, with circadian factors exhibiting their characteristic bimodal distribution.

Summary

Based on the Incidents at Sea reports analysed it would be inappropriate to claim unequivocally that fatigue was causal to these incidents. In conjunction with the body of literature that establishes clear associations between sleep loss, time of day and fatigue, and the body of literature that establishes association between fatigue, human performance (human behaviour) and accidents, relationships can be established between the behaviours described in the Incidents at Sea reports. These behaviours (by virtue of being reported in this literature must constitute error behaviours) and the descriptions of life on board (particularly relating to conditions conducive to sleeping and sleep loss) present a characteristic distribution of behaviour over the working day.

Figure 14 provides a model outlining the relationships between sleep factors, time of day factors, fatigue and accidents obtained from analysis of the data in this study.

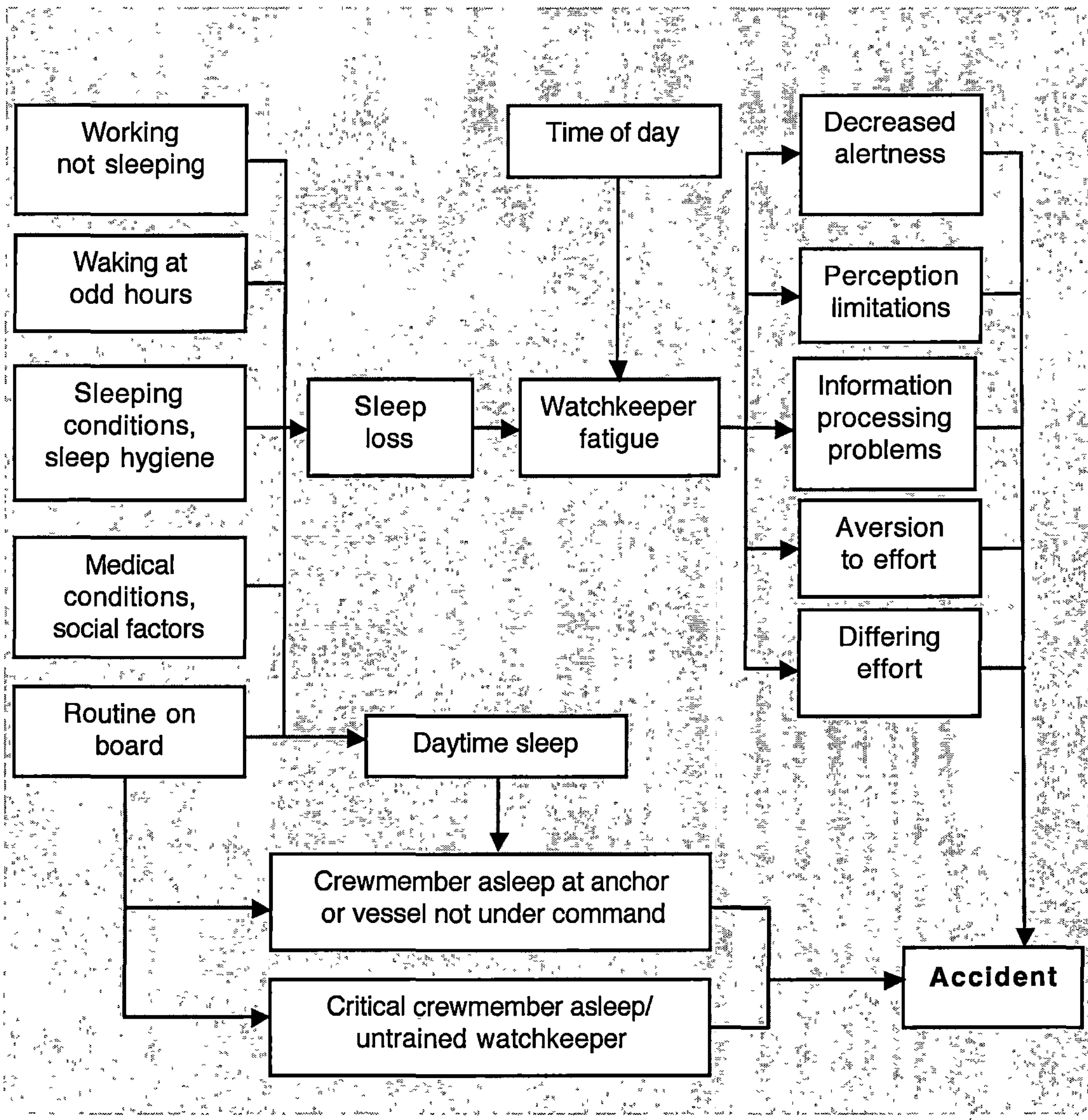

Figure 14: Sleep loss, time of day and accidents: the interaction of sleep loss and time of day and the contribution to fatigue and accidents

CHAPTER 6 – SUMMARY AND CONCLUSION

6.1. Summary

Maritime incident reports form a rich source of human performance data with high face validity. However, fatigue, as contributory to human error, is elusive and direct evidence of accident causation is difficult to come by. The present study aimed to determine the nature and distribution of behaviours associated with fatigue in Australian Incidents at Sea reports. Using a qualitative content analysis of reported behaviour patterns of ship's watchkeepers, 100 consecutive reports were analysed on the basis of incident type, error types, and factors contributing to fatigue, using non-numerical unstructured data indexing, searching and theorising software (NUDIST®). Although fires, foundering and injuries were evenly distributed throughout the day, collisions and groundings were more prevalent during the early morning watches. Investigators found fatigue was a contributing factor in only seven incidents, six of which occurred during the 0000 to 0800 watches.

Behaviours consistent with fatigue, identified from the scientific literature, were categorised and compared with investigators' descriptions of behaviours in incident reports. Such "fatigue behaviours" were richly distributed throughout the 62 collisions and groundings analysed, with alertness and information processing fatigue behaviours exhibiting different diurnal variations. Behaviour patterns, consistent with fatigue, are described for different times of the day.

The unique profession of seafaring involves rest and sleep in a 24-hour-a-day work environment that is usually mobile, with time-zone crossings, noise, heat, cold and motion. Sleep under such conditions is often difficult to obtain, and sleeping and sleep loss is often related to fatigue and contributory to accidents. This study aims to determine how accident investigators report sleep in Incidents at Sea reports and subsequently analyse the relationships between sleep, fatigue and accidents in these reports.

The full text of 44 Incidents at Sea reports was coded and analysed using NUDIST® software. This sample included collisions and groundings reported since 1991, where significant human factors contributed to the incident. The

Incidents at Sea reports were electronically searched for reference to sleep and content was indexed against parameters such as fatigue behaviours, time of day and contributing personnel.

Incidents at Sea reports incorporate three levels of reference to sleep, analysis of which may associate sleeping and sleepiness with accident causation. The highest level of reference unequivocally associates either being asleep, or being sleep deprived with accidents, but not always with fatigue. At an intermediate level, reference to the conflicting pressures of work and sleep on board fishing boats and ships suggests a work environment that is not conducive to obtaining sufficient sleep, and accident investigators are usually unable to link the watchkeeping environment with fatigue as a contributing factor. At the lowest level of association, reference is made to the integrated nature of sleeping and work on board.

6.2. Conclusions

The ship's watchkeeper is a fallible human operator in a complex technological system and unsafe acts by such operators may result in subsequent incidents being investigated. Collisions and groundings are two categories of incident where the fatigued watchkeeper may perform unsafe acts. Fatigue is one factor that contributes to such unsafe acts but many authors feel that its contribution is under-reported; indeed fatigue was identified as a contributing factor in only seven of 100 Incidents at Sea reports. In this study, a model of fatigue behaviours was developed from a review of the scientific literature and subsequently applied to a content analysis of Incidents at Sea reports of collisions and groundings.

The literature revealed fatigue presenting as activation problems, sensory limitations, information processing problems, aversion to effort and differing nature of effort, and that these behaviours had characteristic distribution throughout the working day. Activation problems were most evident during the early morning watches, whereas information-processing problems predominated during the afternoon and evening watches. Aversion to effort was behaviour most evident during the morning and afternoon watches. Specific unsafe acts were associated with each category of fatigue behaviour;

for example, activation problems commonly presented as failing to keep a proper lookout and monitor progress whereas information processing problems presented as planning and assessment deficiencies, frequently in association with secondary tasks.

Fatigue behaviours, as reported in the scientific literature, are evident in real world situations - in this study the fallible behaviours of ship's watchkeepers. Fatigue is an elusive variable; however, the increasingly automated and technological working environment of the ship's watchkeeper provides an ideal environment for further study.

While no rigorous causal link can be established between the watchkeeping environment, sleepiness and accidents, this analysis shows that Incidents at Sea reports are a rich source of descriptive data showing a high level of association of sleeping and sleepiness with accidents. Thirty nine percent of Incidents at Sea reports where human error was a contributing factor describe sleeping or sleepiness as contributory to an accident. The Incidents at Sea reports also paint a picture of the truncated and fragmented sleep of watchkeepers, critical fatigue behaviours, and occasionally the unfavourable sleeping environment found on board fishing vessels.

The nature and distribution of the accident investigator's references to sleep compared to the incident type and watchkeeping period allowed some analysis of the contributing factors of sleepiness between key crewmembers. Ship masters rarely exhibit sleepiness, but appear to have well-developed strategies for coping in a sleep-depriving environment. Second mates, however, suffer a greater frequency of decreased alertness than other officers, possibly due to their watch times and sleep times. Marine pilots may be the most sleep-deprived of all watchkeepers, but rarely suffer loss of alertness. The pilot's contribution to accidents is in the form of errors of judgement and disorientation. First and third mates are rarely associated with incidents at sea. There is considerable scope for further work to establish the relationship between the tasks, sleep opportunities and circadian factors affecting the performance of the various officers involved in watchkeeping.

Though accident investigators may experience difficulty retrospectively analysing the contribution of sleep loss to behavioural manifestations of fatigue other than decreased alertness, the investigation process should continue to consider the effect of sleep deprivation and time of day on errors involving judgement, reasoning and higher level cognitive functions.

Finally, the unique nature of watchkeeping and seafaring demands that further industry-specific research should be undertaken to identify and quantify the manifestations of fatigue other than that of decreased alertness.

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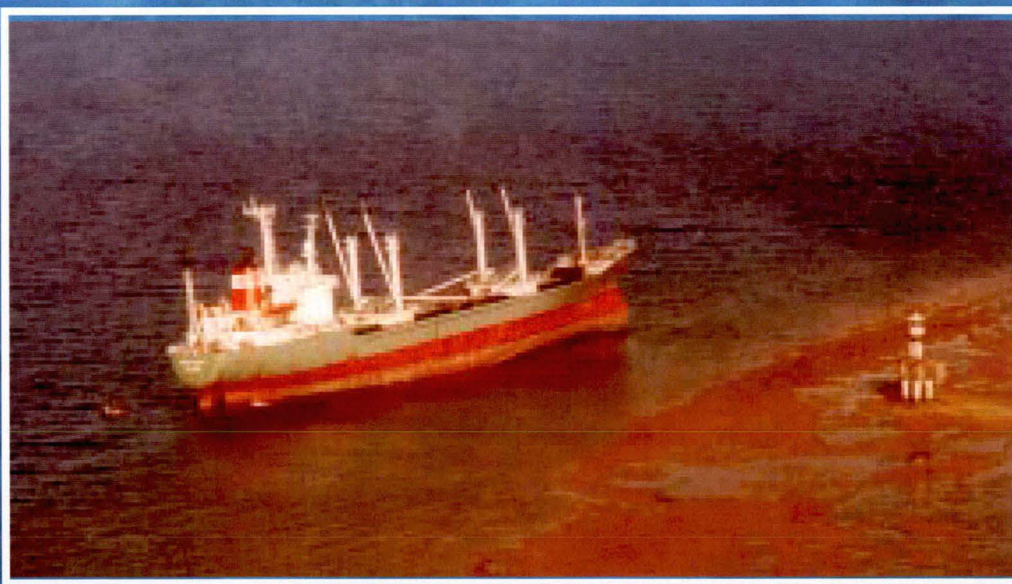
APPENDIX 1

INCIDENT AT SEA REPORT 95

Departmental investigation into the grounding of the Panamanian flag refrigerated cargo vessel PEACOCK on Piper Reef, in the Great Barrier Reef on 18th July 1996.

Departmental investigation into the grounding of the Panamanian flag refrigerated cargo vessel PEACOCK on Piper Reef, in the Great Barrier Reef, on 18 July 1996

MIIU



Report 95

Transport and Regional Development

Contents

Navigation Act 1912

Navigation (Marine Casualty) Regulations

into the grounding of the Panamanian flag

refrigerated cargo vessel

PEACOCK

on Piper Reef, in the Great Barrier Reef,

on 18 July 1996

No 95

Published: January 1997

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Investigation into marine casualties occuring within the Commonwealth's jurisdiction are conducted under the provisions of the Navigation (Marine Casualty) Regulations, made pursuant to sub section 425 (1) (ea) and 425 1 AAA of the Navigation Act 1912. The Regulations provide discretionary powers to the Inspector to investigate incidents as defined by the regulations. Where an investigation is undertaken the Inspector must submit a report to the Secretary of the Department. It is Departmental policy to publish such reports in full as an educational tool.

 Additional copies of the report can be obtained from:

Inspector of Marine Accidents
Marine Incident Investigation Unit
Department of Transport and Regional Development
G P O Box 594
CANBERRA ACT 2601

Phone: 06 274 7324
Fax: 06 274 6699
Email: MIIU@dot.gov.au

MIIU on the INTERNET
Information relating to this report and other marine investigation reports can be located from the Marine Incident Investigation Unit's Internet homepage at our URL:

http://www.dot.gov.au/programs/miiu/miiuhome.htm

Summary

The Panamanian flag refrigerated cargo vessel Peacock, on a ballast passage from Singapore to New Plymouth, New Zealand, embarked a licensed pilot off Goods Island at 1630 AEST on 17 July 1996 for the passage through the Torres Strait and the Inner Two Way Route of the Great Barrier Reef.

At about 0155 on 18 July 1996, the vessel grounded on Piper Reef at full speed, in a position 100 metres eastward of the light beacon. Initial attempts to refloat the vessel by going astern on the engine were unsuccessful.

Peacock remained stranded on Piper Reef until the late afternoon of 26 July 1996, when salvors successfully refloated the vessel after having transferred some of the fuel oil bunkers to a barge.

The vessel's hull was not breached and no pollution occurred. However, machinery tests showed that only one steering motor was fully functional, therefore Peacock was towed to Cairns for necessary repairs.

Sources of Information

Master, Second Mate and Helmsman

Pilot

Queensland Coastal Pilot Service Pty Ltd

Australian Reef Pilots Pty Ltd

Australian Maritime Safety Authority

Acknowledgement

Professional opinion on fatigue was provided by:

Director of Aviation Medicine, Civil Aviation Safety Authority

Circadian Technologies Inc

Portion of chart Aus 835 reproduced by permission of the Hydrographic Office, RAN.

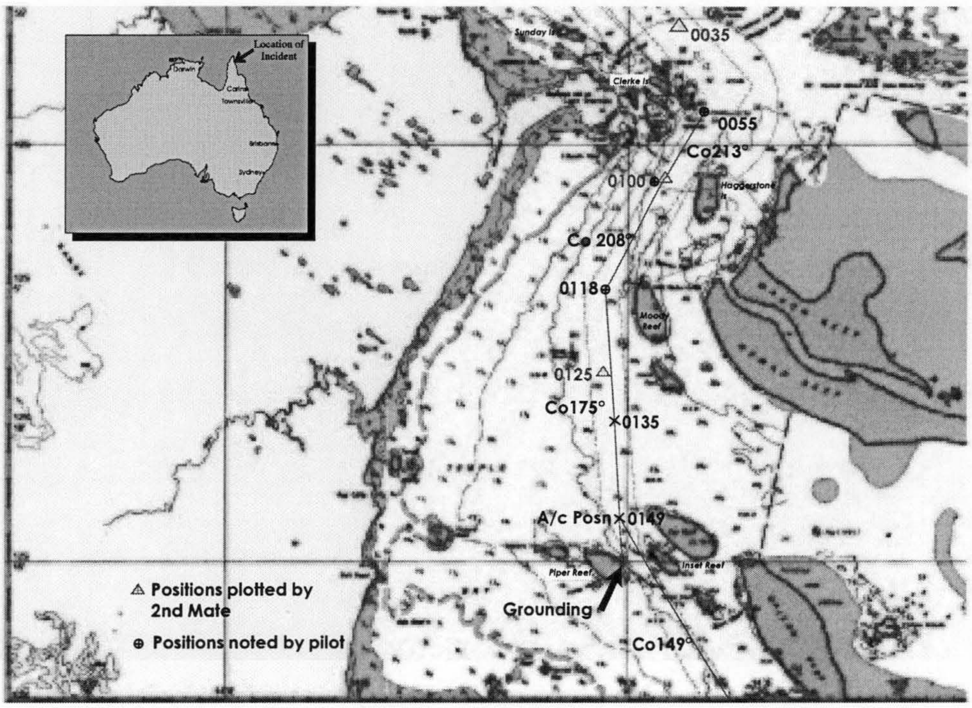
Narrative

The Panamanian registered, four hold, refrigerated cargo vessel Peacock has an overall length of 124.7 m, a beam of 17.8 m and a moulded depth of 9.85 m. The vessel has a gross tonnage of 4964 and a summer deadweight of 6541 tonnes at a mean draught of 7.317 m. Built in 1986 at the Kochi Jyuko K K shipyard in Japan, the vessel is powered by a six cylinder, 5149 kW Mitsubishi diesel engine, driving a single fixed propeller and providing a service speed of 16½ knots.

Owned by Libero Panama SA and operated by Shunko Shipping Corporation of Tokyo, Peacock is engaged in world-wide trading. The vessel has a Korean Master, a mixture of Korean and Indonesian officers, and Indonesian ratings. The three Deck Officers maintain the traditional "4 on, 8 off" bridge watchkeeping routine, each bridge watch being comprised of one deck officer and one helmsman/ lookout.

In common with a number of small Japanese owned/operated vessels engaged in world-wide trading, Peacock carries extra fuel oil and diesel oil bunkers. This additional fuel oil is carried in the double bottom tanks and the only ballast tanks in the vessel are the fore peak and aft peak tanks.

Peacock sailed from Singapore in a light condition, at 0220 local time (UTC + 8) on Wednesday 10 July 1996, having discharged the second consignment of a full cargo of apples loaded in Chile. The vessel was bound for New Plymouth, New Zealand, its route being via the southern China Sea, the Flores Sea and the Torres Strait and Inner Two Way Route of the Great Barrier Reef to the South Pacific Ocean. As part of the passage plan for the voyage, the Second Mate had laid



Portion of chart Aus835 showing course of Peacock

off the courses in the delineated two-way route of the Torres Strait and the inner route of the Great Barrier Reef.

A licensed pilot of the Queensland Coastal Pilot Service Pty Ltd boarded the vessel to the west of Goods Island, at the western end of the Prince of Wales Channel, Torres Strait, at 1630 AEST on Wednesday 17 July. Another eastbound vessel was approaching about three or four miles astern of Peacock, so the Pilot immediately called for full harbour speed. After being advised of the vessel's draught (3.3 m forward and 5.1 m aft) and full sea speed (16 knots) the Pilot ordered full sea speed.

Harrison Rock buoy was passed abeam to port at 1650 and the Pilot then concentrated on conning the vessel clear of Mecca Reef, Hammond Rock and Nardana Patches. Once Peacock was lined up on the East Strait leads, and before the vessel reached Ince Point, the Pilot laid off his intended courses on the chart to take the vessel clear of Alpha Rock. While on the East Strait leads, the Pilot ascertained that there was an error on the gyro compass of between ½° and 1° high.

After clearing the Alert Patches the Pilot, watched by the Master, laid off his courses down to Cairncross, rubbing off the Second Mate's courses as he did so. While engaged in this, he noticed that apart from a position off Hammond Rock, no positions had been marked on the chart by the Watch Officer. He brought this to the Master's attention and placed on the chart table a copy of his "Standing Procedures for Pilotage in the Reef", detailing position fixing requirements. These "Standing Procedures" stipulated that the vessel's position was to be plotted every 15 minutes when the Pilot was absent from the bridge. The Master discussed this with the Mate, the Watch Officer, and thereafter the vessel's position was plotted on the chart at regular intervals.

With just the one helmsman to the Watch, the practice was for the ship to proceed in automatic steering, with the helmsman taking the wheel for course alterations. Once the vessel was steadied on the next course, the steering would be changed back to automatic mode, the change-over being achieved by the helmsman using a single, positive, two-way switch located on the steering console.

Wyburn Reef was rounded at 1945 and, when the vessel was steadied on the new course of 167°, the Pilot, satisfied that it was safe for him to do so and with the Master's agreement, left the bridge to take a rest in the pilot's cabin, two decks below. Before leaving the bridge, he gave instructions that he should be called at any time considered necessary and when the vessel arrived at the position he had marked on the chart, just northward of Cairncross Islets, 25 miles to the south.

The Pilot was called at about 2110 and returned to the bridge, having spent the time in the cabin resting, mainly awake. On his return to the bridge, the Master was still there and the Third Mate had taken over from the Mate as Watch Officer. The Pilot checked the chart and noted that the vessel's position had been plotted on the chart at 15 minute intervals, as required by his "Standing Procedures".

After the vessel had altered course off Hannibal Island, at 2220, the Pilot left the bridge for another rest period, leaving instructions that he be called at a position off Sunday Island, about 23 miles distant, which he calculated would be at about 0020. On this occasion he slept, and was asleep when called at 0010. When he arrived on the bridge, he found that he had been called slightly early, with still seven miles to run to the course alteration point off Clerke Island (off Cape Grenville). The reason for his being called early was that the Master had had a plate of noodles prepared for him. He noted that the Third Mate had been relieved by the Second Mate as Watch Officer and that the steering was still in automatic.

Rounding Clerke Island, the Pilot followed his normal procedure, waiting until Moody Reef light was in transit with Clerke Island light and altering to 180°, bringing the eastern edge of Haggerstone Island right ahead. Just before Clerke Island light was abeam to starboard, course was altered to 212° (on this occasion 213°). The pilot noted the time of Clerke Island light being abeam as 0050. Once steadied on this new course, the Master, who had been on the bridge since before the Pilot had boarded off Goods Island, asked the Pilot if it would be all right if he went down to his cabin to get some sleep. The Pilot assured the Master that that would be all right and the Master left the bridge at about 0100, having first instructed the Second Mate to follow the Pilot's instructions and to ensure the safety of the navigation.

After rounding Clerke Island, the Pilot felt that the wheelhouse was becoming rather stuffy. He checked the air conditioning vents and, as the issuing air was warm, thought the air conditioning unit had either been turned down or off.

Haggerstone Island was passed at a distance (by radar) of two miles, about two cables greater than his normal passing distance, so the pilot adjusted the course to 208°, in order to pass between 1.2 and 1.3 miles off Moody Reef light when it was abeam to port. The radar distance off Moody Reef light, when abeam, was 1.3 miles, so the pilot let the vessel run on for about two cables before altering course to 175°. With Peacock steady on the 175°course and Moody Reef light abeam at 1.3 miles, Piper Island light lay between ½° and 1° on the starboard bow, rather than the normal right ahead, this to make allowance for any drift effect of the 15 to 20 knots south-easterly wind on the ship in light condition.

With a little over seven miles to run to the next alteration point, 1¾ miles north of Piper Reef light, the Pilot went to the chartroom and did some paperwork. After a few minutes, he went into the wheelhouse to check that all was well, then, returning to the chartroom, he saw that the Second Mate had plotted the vessel's position on the chart for 0125. Satisfied that the position was correct, the pilot returned to the wheelhouse, where he walked up and down for a while, watching Piper Reef light, very fine to starboard, and Inset Reef light, broader on the port bow.

After plotting the position on the chart at 0125, the Second Mate checked the radar and visually checked through the wheelhouse windows to see that everything was all right. He then returned to the chart table and got out the next chart to check the courses laid off by the Pilot.

At about 0135, the Pilot glanced at the radar and saw that there was about 3 to 3½ miles to run to the point where he normally starts to alter course off Piper Reef. He calculated that after another seven or eight minutes there would be ¾ mile or so to run to the position and therefore sat in the pilot chair, chin cupped in the palm of his left hand, to await that moment. He watched the lights, Piper Reef light still very fine to starboard and occasionally becoming concealed from his view by the forward starboard Samson post and Inset Reef light broadening out to port. He also kept an eye on the clock, located on the forward bulkhead, as the time moved towards 0140.

Suddenly, the ship vibrated, described by the Pilot as being similar to that caused by a ship moving from a calm to a choppy sea, or feeling a few waves. The Pilot moved out of the pilot chair, ordered "hard a port" and as the vibration increased, called "stop engines", realising the vessel had run aground. As he moved to the starboard wheelhouse door, which he had some difficulty in opening, he was aware of someone behind him moving to the engine telegraph and putting the telegraph to stop. The time of the grounding, although not recorded, was considered to have been about 0155. Peacock had come to rest on a heading of 166°.

After leaving the bridge at about 0100, the Master, instead of going to bed, had started to write a report to the Company. When Peacock started to shake, he looked out of the window and saw a light beacon very close on the starboard side. He went up to the bridge, where he found the engine had been stopped, the Second Mate was looking out through the wheelhouse starboard window and the Pilot was out on the starboard bridgewing. He ordered all the deck lights to be switched on, so as to be better able to assess the situation. Peacock was listed four degrees to port and appeared to be hard aground. The engine was put to full astern, but there was no movement and the engine was stopped again after about four minutes, at 0203.

The Mate had arrived on the bridge shortly after the Master, and after the engine had been stopped again he joined the Master and the Pilot in discussing the best course of action. The Pilot suggested going ahead on the engine with the rudder hard over to starboard, in an attempt to pivot the vessel to starboard before going astern on the engine again. The Mate agreed with the Pilot, but the Master preferred to go astern and the telegraph was put to full astern at 0208. Again there was no movement and the engine was stopped at 0219.

The Master discussed the situation with the Chief Engineer, who was concerned about the fact that heavy fuel oil was still in the system, which would cause problems if the engine was to remain stopped for any appreciable length of time. It was therefore decided to run the engine astern and change over to diesel oil and the engine was put to full astern at 0225.

The Master issued instructions for the crew to sound around the vessel, also for the Chief Engineer to sound all of the tanks. These soundings showed that although Peacock was well aground, there had been no penetration of the hull.

Assisted by the Pilot, the Master prepared messages to be telexed to the Maritime Rescue Coordination Centre (MRCC) Canberra and to the Queensland Coastal Pilot Service Pty Ltd in Brisbane. The message to MRCC Canberra was transmitted at 0319.

The change over to diesel oil took until 0332, after which an attempt was made to pivot the vessel to starboard, the engine being worked up to half ahead. However, this was aborted at 0340, the Pilot advising the Master that it would be better to wait for the next high tide, at about 1030, before making further attempts to refloat the vessel.

The engine was again put on full astern at 1016 and run until 1038. As this had no effect, the Master and Pilot concluded that Peacock could not be refloated without assistance. On instructions from the owner, the Master signed a salvage agreement, using Lloyd's Standard Form, with salvors who flew to the vessel by helicopter that same morning.

In compliance with 6.5.12[1] of Marine Orders Part 54, the Pilot was relieved from the vessel on 19 July.

After the failed attempt on the morning high tide, the Australian Maritime Safety Authority issued an Intervention Order, under the MARPOL Convention, stipulating that no further attempts were to be made to refloat Peacock until such time as oil pollution prevention equipment was in place. Floating boom equipment was shipped from Cairns aboard the tug Hamilton, which arrived at Piper Reef early on 20 July, and further equipment was flown to Lockhart River by DC4 aircraft.

The tides were such that there was insufficient water for refloating the vessel for another week. On Friday 26 July, 450 tonnes of bunker fuel were transferred to Pacific Explorer, a landing barge operated by Endeavour Shipping and normally used for transporting aviation fuel and general cargo to Thursday Island. Late that afternoon Peacock was pulled off the reef by the tug Pacific Salvor (brought down from Papua New Guinea for the salvage operation) and was moved to an anchorage position approximately one mile northward of Piper Reef.

No pollution had occurred, either as a result of the grounding, or the slavage operation.

An underwater inspection of the vessel's hull was carried out by divers on Saturday 27 July, and as the various double bottom tanks were

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[1] If a ship under pilotage grounds ... the Manager must as soon as practical after being advised of the grounding ... suspend the licence of the pilot having conduct of the vessel for a period not exceeding seven days.

cleared as being sound, the bunker fuel was transferred back from Pacific Explorer. The underwater inspection revealed that Peacock had suffered very little damage, the maximum indentation of plating being about 50 mm.

Inspection by a classification society surveyor of the main engine and other machinery revealed a problem with one of the vessel's steering motors, which though operable, was not fully functional. As it is a requirement that vessels transiting the Inner Two Way Route have two steering motors operating during the transit, AMSA issued another Intervention Order, requiring Peacock to be towed to Cairns. The salvage company and the owner extended the salvage agreement to cover the tow, Pacific Salvor commencing the towage operation on Sunday 28 July.

Comment and Analysis

Peacock grounded on Piper Reef while the navigation was under the conduct of a pilot with 26 years experience in the Great Barrier Reef and when an alteration of course was not made about six minutes before the grounding. No machinery or equipment failure contributed to the grounding.

It is therefore necessary to examine why the Pilot did not make the necessary course alteration, why this was not detected by the vessel's Bridge Watch and what the circumstances were which led to the situation.

The Pilot had sat in the pilot chair at about 0135 and his last recollection of time, before being startled by the ship vibrating on grounding, was at about 0137 or 0138. From that point, or shortly thereafter, he lost situational awareness and it seems probable that he fell asleep about 15 minutes before the grounding.

The Second Mate absented himself from the wheelhouse for a considerable length of time, taking no part in the navigation of the vessel, with the result that the alertness of not only the Pilot but also that of the Second Mate was impaired to such a degree that the vessel was placed at hazard.

Alertness

Research has shown that nine internal or external factors and stimuli are relevant to the level of alertness in an individual[2]. They are:

1. Environmental light.

[2] Moore-Ede, M., The Twenty-Four Hour Society, Random House Australia, 1993

2. Environmental temperature.

3. Environmental sound.

4. Environmental aroma.

5. Time of day on circadian clock.

6. Muscular activity.

7. Ingested nutrients and chemicals.

8. Interest, opportunity or sense of danger

9. Sleep bank balance.

These factors can be seen as switches that may be in the "on" position, "off" position or in "neutral". Whereas just one individual switch in the closed position may not be sufficient to cause a dangerous loss of alertness or induce sleep, the greater the number of closed switches, the greater the hazard.

Environmental factors

Bright light, cool temperature, irregular sound and certain aromas all act as stimulants, which help keep a person alert. Dim lighting and darkness, warm sultry heat and regular rhythmic noise can all have the opposite effect.

The conditions on any ship's bridge at night, particularly in the tropics, with the darkness, warmth, rhythmic sound of the engines and steady background noise of electrical machinery, are such that the environmental switches are all in the "off" position. However, there is normally sufficient activity to maintain the alertness of those on duty.

There is some dispute with respect to the claimed stuffiness of the atmosphere in the wheelhouse and whether or not the wheelhouse doors were open. Any stuffiness would have decreased the alertness of those in the wheelhouse and made them more susceptible to drowsiness.

Time of day

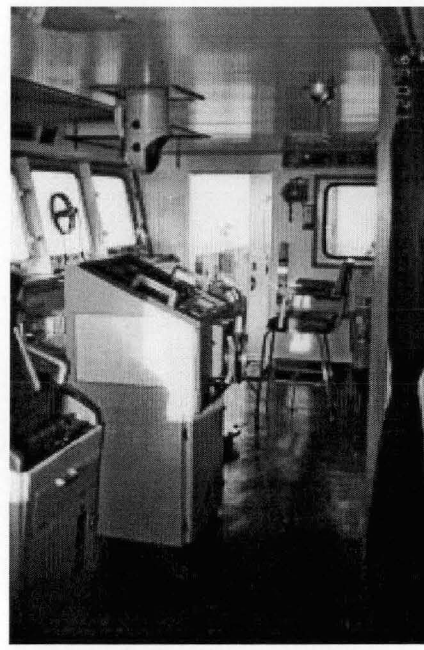
The natural period of sleep is during the hours of darkness, between 2200 to 0600, the brain automatically regulating the body into the sleep mode. People working regular shift work, where the periods of work are not changed, can adapt to the different sleeping period without too much ill effect, their biological clock adjusting to the changed conditions. Thus mariners are able to adjust to their watch regime, the time of day switch being in the "on" position at the required times.

The pilots serving the Great Barrier Reef, however, work a routine where the natural sleep period is seriously disrupted, although generally for periods not exceeding 48 hours at one time. During the natural sleep period, 2200 to 0600, the time of day switch will be in the "off" position.

Depending on the speed of the ship, pilots have conduct of the ship in the Inner Two Way Route for between 34 and 50 hours. However, there are five recognised areas within the Inner Two Way Route where pilots can leave the bridge to take a rest, provided circumstances permit. Also, their schedule is so programmed that after each pilotage they are usually able to get at least one full night's sleep before their next assignment. The pilots are apparently able to adjust to this routine, without ill effect.

Muscular activity

All types of muscular activity, even chewing, act as a stimulant to alertness, the muscular activity switch moving to the "off" position when the body is at rest.



Photograph of interior of Peacock wheelhouse showing position of pilot chair

The inner route pilotage requires the pilot to be on the bridge for very long periods at a stretch and it is not unusual for a pilot to sit in the chair specifically provided for his use. However, in sitting in the pilot chair at 0135 and particularly in cupping his chin in his hand, the pilot caused the muscular activity switch to move to the "off" position, making himself more susceptible to sleep. Also, by supporting his head in his hand, his head could not fall forward as he relaxed and a basic warning mechanism was lost.

Ingested nutrients and chemicals

Caffeine and amphetamines are stimulants, whereas alcohol and some medications are sleep inducing. Although the Pilot had drunk an occasional cup of coffee whilst on the bridge, he had not consumed large quantities.

The Pilot stated that he had consumed two glasses of wine during dinner the previous evening, or some 21 hours before he boarded Peacock. He stated that he had consumed no other alcohol whilst awaiting the vessel at Thursday Island, and the Master confirmed that he had had no alcohol whilst on board.

The Pilot also stated that he was not under any long term medication, and had not taken any short term medication for relief of a cold, influenza or pain.

In the early hours of 18 July 1996, the Pilot's nutrients and chemicals alertness switch would have been in the "neutral" position.

Interest, opportunity, sense of danger

These are all stimulants to alertness - the Pilot was jolted into full alertness by the vibration as the ship ran aground.

As the Pilot was sitting in the pilot chair everything was going smoothly - the vessel was on course, the weather was fine and the passage through the reef presented no special challenge to the Pilot, for whom it was purely routine. The Pilot's sense of risk was therefore reduced. With still some minutes to run to the next course alteration he was relaxed and, whereas it would not have been in the "off" position, this alertness switch would have been in "neutral".

Sleep bank balance

Sleep periods are considered as making deposits in the individual's "sleep bank" and periods of wakefulness make withdrawals. As a general and approximate rule, sleep deprivation occurs, and the alertness switch goes to the "off" position, when an individual expends the total "sleep credits". Sleep credits are considered to accumulate at a rate of two for every hour of sleep and to expend at the rate of one for every hour awake. Hence, after eight hours sleep an individual can be considered to have 16 credits, which are expended over the next sixteen hours.

Summary of alertness switches

From the time the pilot sat in the pilot chair, at 0135, six alertness switches were in the "off" position and two were in the "neutral" position. However, the situation was not remarkably different from any other inner route pilotage situation and could be considered as being normal.

The fact that an experienced pilot succumbed to sleep while having the conduct of the vessel suggests a prima facie case of sleep deprivation, or fatigue, on the part of the pilot.

Fatigue

The Pilot stated that he had had a good night's sleep, between eight and nine hours, in the hotel on Thursday Island, the night before joining Peacock. He also sated that he had also spent the early part of the afternoon sitting down, resting, while waiting to go out to the vessel. Although he had not slept, other than a possible short nap, during his first spell away from the bridge, between 1945 and 2110 on 17 July, he did sleep during his second spell away, between 2225 on 17 July and 0010 on 18 July. The period between returning to the bridge at 0010 and sitting in the chair at 0135 was 85 minutes. Theoretically, with his period of sleep immediately before 0010, the Pilot would not have expended all his sleep credits, although they would have been low, therefore, it is considered unlikely that the Pilot would have been suffering from acute fatigue during the early hours of 18 July.

Chronic fatigue is reached when a 'normal' period of sleep proves insufficient to restore the individuals's working performance to its usual level.[3] It is brought about by sleep disturbance, due to various factors, and or sleep deprivation over a prolonged period.

In 1993, new regulations came into force, administered by AMSA which also licences the pilots, governing pilotage within the compulsory pilotage areas within the Great Barrier Reef Marine Park. The introduction of the new regulations and the opening up of the pilotage to competition, resulted in the formation of two pilotage services, with separate managing companies.

The managing company with the smaller number of pilots was able to secure the larger share of the available business, resulting in those pilots having to take on a greater workload. In the twelve months prior to the split, the Pilot conducted 59 pilotages, whereas in the same 12-month period prior to the incident he had conducted 69 pilotages, an increase of 17%, with a decrease in recreational time of about 7%.

Prior to the introduction of compulsory pilotage under the Great Barrier Marine Park Act, in October 1991, the workload was distributed fairly equally by the secretariat amongst all the Queensland Coast and Torres Strait pilots, although senior pilots had the option of reducing their workload. During the 12 months period July 1990 to June 1991, the Pilot conducted 47 pilotages. Therefore, over the intervening five-year period, as a result of pilotage being made compulsory and the restructuring, the number of pilotages conducted by the pilot has increased by 47%. Much of this increase has been in pilotage of ships through Hydrographers Passage, a pilotage of about 9½ hours duration. However, of importance is the number of nights worked in any period and whether rest periods between pilotages are disrupted by relocation travel.

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[3] Executive Summary of the Procedings of a Research Workshop on fatigue in the Maritime Industry, Seafarers International Reseach Centre, University of Wales, Cardiff, 1996

From	time/date	To	time/date
Blossom Bank	0800, 22 June	Hay Pt	1620, 22 June
Hay Point	0900, 24 June	Booby Island	2310, 26 June
Booby Island	1600, 28 June	Stephen Island	0400, 29 June
Stephen Island	1800, 30 June	Goods Island	0300, 1 July
Booby Is	0940, 2 July	Cape Flattery	1930,3 July
Cape Flattery	1000, 6 July	Booby Island	2000, 7 July
Goods Island	0130, 9 July	Townsville	0700, 11 July
Goods Island	1900, 14 July	Cairns	2359, 15 July
Goods Island	1630, 17 July		

Table1 - Pilots Schedule

A pilot's tour of duty is generally of between 14 and 21 days duration. However, of the six tours of duty the Pilot had undertaken since 1 January 1996, one had been of 26 days duration and that particular tour was into its 27th day.

The Pilot had started that particular tour of duty on 22 June 1996, after a period of 12 days at home and after travelling to Hamilton Island on 21 June. The Pilot was involved in pilotage, with either little sleep or disrupted sleep patterns, during the nights of 25, 26, 28 and 30 June, 2, 6, 8, 9, 10, 14, 15 and 17 July. That is 12 nights out of a total of 26 for the tour and 6 nights out of the last 10.

Tables 1and 2 show the Pilot's schedule over the period.

The major contributing factor to possible chronic fatigue would seem to be irregular hours of work over a prolonged period. However, in addition to the actual hours of work, a number of other factors, such as sleep apnoea, diet and, domestic and occupational concerns, can affect the quality of sleep and an individual's susceptibility to fatigue.

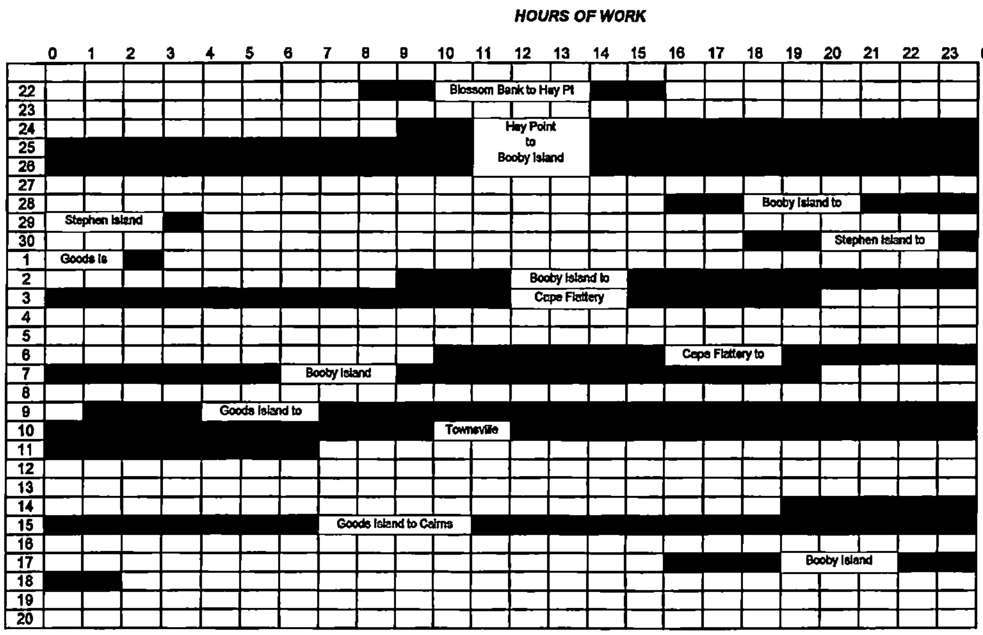

Table 2 - Pilot's Hours of Work

At 64 years of age and heavily built, the Pilot is a prime subject to suffer sleep apnoea. Prior to his weight loss in 1993, the Pilot reportedly was a heavy snorer, an indication of sleep apnoea.

Although he reportedly now snores less, it is possible the Pilot suffers some degree of sleep apnoea, with the resultant effect on the quality of his sleep.

Although not under medication, the Pilot had been diagnosed as being a type 2 diabetic in January 1993 and was under a dietary regime. After an initial weight loss of approximately 26 kg over a two month period, the Pilot's weight had since remained stable at 106 kg.

In the 24 hours prior to the incident, the Pilot had eaten breakfast, consisting of Swiss Muesli with milk and coffee; lunch, consisting of a bread roll with ham and tuna, but with no butter or spread, an apple and a coffee; dinner, consisting of a small amount of a rather fatty and unappetising meat dish and; supper, consisting of a bowl of noodles.

Although the Pilot was obviously well adjusted to his diet, dieting and food intake of insufficient calorific value can reduce both energy and stamina and so make an individual more prone to fatigue, particularly under increased workload.

The formation of competing pilotage services has resulted in changed conditions of service, including a reduction in income for individual pilots and a number of pilots have reported experiencing concern and anxiety as a result of these changes. Such anxieties are acknowledged to cause stress, which can affect an individual's sleep and concentration.

Despite the pilot stating that he had not felt tired, only a little leg weary, taking all the above into account, it is considered that the Pilot, at the time of having the conduct of Peacock, was suffering to some degree from chronic fatigue.

Details of the Pilot's schedule were submitted to Circadian Technologies Inc, of Cambridge, Massachusetts, an institution that is widely consulted on investigating the effects of disruption to the body's natural sleep pattern. Based on an initial appraisal of the information provided, the Institution considered pilot fatigue to be a major factor in the incident.

At the behest of AMSA, the Pilot was examined by specialists at the Airport Health Centre, an accredited rehabilitation provider, and was also referred to a neurologist. The report by the Centre included the comment "All the investigations and reports indicate that there was no underlying medical reason, other than fatigue, to explain the short absence of conscious awareness during which the incident of 18 July 1996, occurred. Certainly there is no underlying medical illness or condition of any significance".

Pilot's roster

Although the regulations allow for pilots performing up to 28-day tours of duty, in that they stipulate that after 28 days a pilot should have a minimum of 10 days rest, generally tours are of between 10 and 21 days duration. However, it is not uncommon for their tours to be longer than 21 days, particularly for those living in the Brisbane and Sydney areas.

The pilots are organised by their managing companies, based in Brisbane, and their work is governed by the shipping demand. However, the length of a particular tour, or tours, can be tailored to an individual's needs. Also, any pilot is at liberty at any time (and it is his responsibility) to request relief if he considers himself for any reason unable to perform his duties to acceptable standards.

In this instance, the Pilot was in a suitable location to terminate the tour in Townsville on 11 July and in Cairns on 16 July, by which time he had completed 20 days and 25 days on duty respectively. However, on both of these occasions he was relocated to Thursday Island to pick up another vessel at the request of the managing company.

Before commencing that tour of duty, the Pilot had advised his managing company that he had a dental appointment in Sydney on 23 July, enabling the managing company to program his movements to suit both the company and himself.

On completing a pilotage at Townsville on 11 July, the Pilot initially received instructions to proceed home, but this was quickly followed by a series of instructions, to remain in Townsville to pick up a north bound vessel, to proceed to Cairns and, to proceed to Thursday Island. Finally, his instructions were to proceed to Thursday Island after overnighting in Cairns, as the managing company was short of pilots at Thursday Island.

After completing the next pilotage at Cairns on 16 July, the Pilot was again requested by the managing company to take one more vessel from Thursday Island. He reminded the company about his dental appointment, but was assured he would be home in time to keep it.

Although the regulatory rest periods between vessels were being maintained, the three consecutive inner route pilotages resulted in a high proportion of nights worked in the latter part of a long tour.

An examination was made of the work schedules of 22 pilots of the Queensland Coastal Pilot Service for the period 1 January 1996 to 21 July 1996. Sixteen pilots had performed at least one tour of duty in excess of 21 days; six pilots had performed two tours of duty in excess of 21 days; one pilot had performed three tours of duty in excess of 21 days and; five pilots had performed a tour of duty in excess of 30 days.

In all cases, the pilots appeared to have had good rest periods between pilotages, usually well in excess of the minimum 24 hours. However, only dates were provided, not times, which could be misleading, as nights with interrupted sleep could be hidden. Early embarkation times and late disembarkation times both impinge on natural sleep patterns. Also, a 24-hour rest period from disembarkation at midnight one day to embarkation at midnight the following day does not provide the same recuperative sleep as midday to midday.

Although the companies monitor the rest periods pilots have between ships and the number of days they work, the number of nights worked do not appear to be taken into account, nor allowance made for the reduced quality of rest. To avoid a pilot becoming over tired, it is imperative that a person does not work an excessive number of nights in any given period.

Bridge procedures and organisation

Pilots are aware that the length of the passage (the longest single pilotage in the world), their irregular hours and disrupted sleep patterns expose them to fatigue. Without counter-measures, strategies and management of their bridge routine the risk of an accident through reduced performance as a result of fatigue is significantly increased.

The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978, requires officers to check the courses steered, the ship's position and speed at frequent intervals to ensure that the ship follows the intended course. Also, on taking over the watch an officer must satisfy himself of the ship's position, course and speed, take note of any dangers that may be encountered and also maintain a proper record of the ship's movements. The STCW Convention also makes specific provision that the presence of a pilot does not relieve the officer of the watch from their duties and obligations for the safety of the ship. (See Annex 1)

These provisions are also recommended in the International Chamber of Shipping's Bridge Procedures Guide, which recommends that officers of the watch should cooperate closely with pilots and maintain an accurate check on the ship's position and movements. It also recommends that, where an officer becomes unsure of the pilot's actions he should if necessary call the master and take action before the master arrives on the bridge. (See Annex 1)

Such cooperation is a two-way street, although it is not easy to implement a standard procedure when piloting vessels of different nationalities and with crews who may have little or no English. However, it should be possible to ensure that every officer of the watch is involved, is told or shown each alteration of course position and encouraged to take an active role in supporting the pilot.

In the case of the Peacock, the Pilot did call the Master's attention to the fact that positions were not being entered on the chart, but it was confined to this basic task. However, as the Second Mate's command of the English language was limited the Pilot had no dialogue with him at all, nor did he indicate the alter course position to him. It is probable the Second Mate felt ignored and irrelevant, rather than an important element in the bridge organisation, which removed the defences against pilot error.

Bridge watchkeeping

When the Pilot started to lay off his courses on the charts, once Peacock was steadied on the East Strait leads, he noted that only one position had been marked on the chart, off Hammond Rock, in the western straits of the Prince of Wales Channel. From this it seems that it was not normal for the vessel's progress to be monitored by the officer of the watch when under pilotage.

After the Pilot had brought this lack of monitoring to the attention of the Master, who in turn brought it to the attention of the Mate, the vessel's position was plotted on the chart at 15 minute intervals until midnight.

At midnight the Second Mate relieved the Third Mate as officer of the watch. The Second Mate had maintained a regular sleep pattern for some days, did not drink alcohol and was not on any medication, therefore, his level of alertness could be expected to have been normal. However, it is apparent the Second Mate took the view that the Pilot was responsible for navigation, that he had little or no role to play and as a result his alertness was seriously affected.

The Second Mate, a Korean, and the Third Mate, an Indonesian, had difficulty in communicating and the hand over consisted mostly of gestures. After midnight, the vessel's position was plotted on the chart at 0010, the time the Pilot was called as the vessel approached the Home Islands, and at 25 minute intervals at 0035, 0100 and 0125.

Based on the above, the Second Mate should have plotted the position at 0150, at which time Peacock should have been on the next course. Had he maintained his 25-minute regime and plotted the position at 0150, he should have realised that the vessel had passed the alter course position. With more than one mile to run before Piper Reef light, there would have been time to avert the grounding. It is evident that, having plotted the position at 0125, the Second Mate did not check the vessel's speed and estimate the time the vessel would be at the next alteration of course position.

As it was, after the Second Mate had plotted the position at 0125, he busied himself behind the curtains closing off the chart table. He stated that he had been checking the courses laid off by the pilot on the next chart. In doing this he was following the Master's instructions, however, such a task should not take very many minutes. The length of time he spent at the chart table, more than twenty five minutes, was excessive and not satisfactorily explained and resulted in him not monitoring the navigation of the vessel and the actions of the pilot, which were his prime responsibilities.

The helmsman said that he had been able to see the light and had realised it would be passed very close, but because the pilot was present, he felt that it must be all right. However, the helmsman was aware that the Second Mate had been absent from the wheelhouse for some considerable time and it would have been prudent, therefore, for him to summon the Second Mate to the wheelhouse as the light beacon was approached.

There is differing evidence as to whether the steering was in manual or in automatic at the time of the grounding. The Pilot thought the helmsman had moved away from the wheel, to the port side of the wheelhouse, after the alteration of course off Moody Reef, and had moved back to the wheel when he ordered "hard a port". According to the helmsman, however, he was at the wheel, steering the vessel manually. Although this had no bearing on the grounding, it is considered probable that the helmsman had changed over to automatic steering and had moved away from the wheel, as this would have been in line with the normal procedure on board.

Conclusions

These conclusions identify the different factors contributing to the incident and should not be read as apportioning blame or liability to any particular organisation or individual.

Peacock grounded on Piper Reef as a result of the vessel's course not being altered, from 175° to 149°, as it approached from the north with the reef right ahead.

The following factors are considered to have contributed to the grounding:

1. The Pilot's loss of situational awareness, the balance of probability being that he fell asleep.
2. The Pilot's sitting with his chin cupped in his left hand, making him more susceptible to falling sleep.
3. The warm, stuffiness of the wheelhouse atmosphere, in association with the sleep inducing factors of time of day and background environmental noises.
4. Chronic fatigue as a result of the Pilot's recent work schedule, particularly the high proportion of nights of disrupted sleep.
5. The lack of a strategy on the part of the Pilot to counter the effects of foreseeable fatigue during periods of reduced activity.
6. The lack of proper bridge management and lack of interaction between the Pilot and the Watch Officer.
7. The lack of proper monitoring of the vessel's progress by the Watch Officer.

8. The attitude of the Watch Officer in assuming the Pilot was solely responsible for the navigation and his prolonged absence from the wheelhouse.

9. The absence of a formal control framework, to monitor a coastal pilot's nights of disrupted sleep, to prevent the development of chronic fatigue.

Submissions

Under sub-regulation 16(3) of the Navigation (Marine Casualty) Regulations, if a report, or part of a report, relates to a person's affairs to a material extent, the Inspector must, if it is reasonable to do so, give that person a copy of the report or the relevant part of the report. Sub-regulation 16(4) provides that such a person may provide written comments or information relating to the report.

The final draft of the report, or relevant parts thereof, was sent to the following:

The Pilot

The Master, Second Mate and Helmsman, m.v. Peacock.

The Australian Maritime Safety Authority

A written submission was received from the Pilot, a joint acknowledgement from the Master and Second Mate, and written comment from AMSA. The text of the report has been amended where it was considered appropriate.

The Pilot's submission also contained the following comments:

"I am not aware of having suffered from the symptoms of sleep apnoea apart from snoring. I have had no sudden waking in the middle of the night for no apparent reason and have never discussed such a condition with any medical practitioner whom I have consulted.

"I question the suggestion that my diet should be considered to be inadequate, given that I have had a regular pattern of eating reduced

sugars and fats for three years. There has been no reduction in my energy or stamina levels during this period.

"I was not aware of any actual fatigue or its symptoms nor did I foresee that I would suffer fatigue (Conclusion no.5) despite the fact that I had experienced a high proportion of working nights during which I had a disrupted sleep.

"Prior to June 1993 pilots had no distractions from their pilotage duties apart from those associated with normal living. However, it is now a different matter as there are continuous concerns felt by pilots with respect to competition currently existing between the pilotage services and the general uncertainty that ensues from this circumstance. Both income and sufficient recreational time are matters of concern noting that the pressure of work is stressful enough without adding these other factors. Pilots today have these distractions to cope with in addition to their pilotage duties. In my view it all adds up to the placement of extra stress on pilots. It is my view that some responsibility for this situation rests with the authorities, in particular noting their obligations in respect of the maintenance of an efficient and safe pilotage system and the integral factor in achieving this, namely the conditions and environment under which pilots are required to earn their livelihood."

Details of Peacock

Former name	Southern Cross
IMO No.	8518819
Flag	Panama
Classification Society	Nippon Kaiji Kyokai
Ship type	Refrigerated cargo/vehicles
Owner	Libero Panama S.A.
Operator	Shunko Shipping Corp, Tokyo
Year of build	1986
Builder	Kochi Jyuko K K, Japan
Gross tonnage	4964
Net tonnage	3036
Summer deadweight	6541 tonnes
Length overall	124.70 m
Breadth, extreme	17.80 m
Draught (summer)	7.317 m
Engine	Mitsubishi 6 cylinder diesel
Engine power	5149 kW
Crew	19 Korean and Indonesian

Annex 1

Bridge Watchkeeping

Regulation II/1.6(b) of the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978:

"During the watch the course steered, position and speed shall be checked at sufficiently frequent intervals, ... to ensure that the ship follows the planned course."

Regulation II/1.8(b):

"On taking over the watch the relieving officer shall satisfy himself as to the ship's estimated or true position and confirm its intended track, course and speed and shall note any dangers to navigation expected to be encountered during his watch."

Regulation II/1.8(c):

"A proper record shall be kept of the movements and activities during the watch relating to the navigation of the ship."

Regulation II/1.10:

"Despite the duties and obligations of a pilot, his presence on board does not relieve the master or officer in charge of the watch from their duties and obligations for the safety of the ship. ... The master and officer of the watch shall co-operate closely with the pilot and maintain an accurate check of the ship's position and movement."

Paragraph 3.10.3 of the International Chamber of Shipping's Bridge Procedures Guide:

"The officer of the watch should co-operate closely with the pilot to assist him where possible and to maintain an accurate check on the ship's position and movements. If the officer of the watch becomes unsure of the pilot's actions or intentions, he should seek clarification and, if still in doubt, should inform the master immediately and take the necessary action before the master arrives on the bridge."

APPENDIX 2

NUDIST® REPORT

An example of the format of a NUDIST® report, in this instance a report on the conclusions of all reports indexed against node (1 2 3) /Fatigue/Fatigue Behaviours/ I.P.deficiencies giving all conclusions coded as information-processing deficiencies.

Q.S.R. NUD*IST Power version, revision 4.0.
Licensee: Richard Phillips.

PROJECT: Proj 98, User Richard, 1:19 am, Dec 16, 2002.

****
(1 2 3)   /Fatigue/Fatigue Behaviours/I.P.deficiencies
*** Definition:
encoding, interpretation, correlation, processing.
++
+++ ON-LINE DOCUMENT: 102ColumbVic/SampHp
+++ Retrieval for this document: 2 units out of 19, = 11%
*Conclusions
13
++ Text units 15-15:
1. The Master and Officers on Columbus Victoria took insufficient account
of the increase in wind strength and the likelihood that pronounced yawing could trip the anchor out of its holding ground.
15
++ Text units 17-17:
3. The 2000 anchor position did not appear to cause concern to the watchkeepers on Columbus Victoria and any ambiguity between the 2000 position and other positions plotted on the chart was not resolved.
17
++
+++ ON-LINE DOCUMENT: 103Nimb/MareskT
+++ Retrieval for this document: 1 unit out of 13, = 7.7%
*Conclusions
6
++ Text units 11-11:
3. With Maersk Tapah's automatic radar plotting aid giving inconsistent
data for the vessels being overtaken, the Second Mate did not use compass
bearings to establish whether the bearings of the vessels being overtaken
were altering appreciably.
11
++
+++ ON-LINE DOCUMENT: 113Osco Star
+++ Retrieval for this document: 2 units out of 29, = 6.9%
*Conclusions.
12
++ Text units 15-15:
2. A proper appraisal of the possible movement of the cyclone was not made, and no account taken of the steady fall in barometric pressure and
lack of wind directional shift, which resulted in Osco Star passing close
to the centre of the cyclone.
15
++ Text units 17-17:
4. Reliance was placed upon the wind conditions being experienced beyond
the immediate area of effect of the cyclone, rather than on the Bureau Of
Meteorology's predicted wind strengths.
17
++
+++ ON-LINE DOCUMENT: 116ExterminUnisina
+++ Retrieval for this document: 1 unit out of 17, = 5.9%

*Conclusions.
9
++ Text units 13-13:
2. A proper appraisal of the situation was not carried out by the
Watch
Officer, by using either visual bearings or radar, before he altered
course to starboard.
13
++
+++ ON-LINE DOCUMENT: 117Tiao Frontier
+++ Retrieval for this document: 2 units out of 15, = 13%
*Conclusions.
7
++ Text units 9-10:
1 The pilot ladder was rigged on the weather side, preventing the
Pilots
from boarding until a lee had been provided.
9
2 The lack of any planning of the approach, with no delineation of
danger
areas or safety limits on the chart, or consideration of possible
contingencies.
10
++
+++ ON-LINE DOCUMENT: 120Dakshine...
+++ Retrieval for this document: 1 unit out of 16, = 6.2%
*Conclusions.
7
++ Text units 16-16:
9. The assumption made by the 3rd Mate that the problem was not the
engine but the steering, and any confusion that caused, occurred at
such
a time that his actions did not alter the outcome.
16
++
+++ ON-LINE DOCUMENT: 123RivYar/Trotter
+++ Retrieval for this document: 1 unit out of 22, = 4.5%
*Conclusions. 11
++ Text units 18-18:
6. The lack of appreciation by the Pilot and Master of the difficulty
in
controlling the directional stability of W J Trotter when towing stern
first at speed.
18
++
+++ ON-LINE DOCUMENT: 126PineTrust
+++ Retrieval for this document: 2 units out of 18, = 11%
*Conclusions.
8
++ Text units 14-14:
2. Inadequate monitoring by the Pilot of the position of the vessel,
prior to passage of beacon No. 10, till the vessel grounded.
14
++ Text units 16-16:
4. Inadequate monitoring of the vessel's position by the Master.
16
++
+++ ON-LINE DOCUMENT: 127NOL Amber
+++ Retrieval for this document: 2 units out of 18, = 11%
*Conclusions.
8
++ Text units 14-15:

5.The Pilot did not fully evaluate the situation regarding River Embley
before deciding which way to turn the vessel.
14
6.At the start of the turn, the Master did not satisfy himself that the
vessel had sufficient room in which to carry out the manoeuvre.
15
++
+++ ON-LINE DOCUMENT: 27Sanko Harvest
+++ Retrieval for this document: 1 unit out of 16, = 6.2%
* Inserted sub-header...
6
++ Text units 9-9:
1. The lack of appreciation by the Master and Second Officer (and other
officers who were aware of the planned approach to Esperance) of the
warnings contained on the charts and Australian Sailing Directions,
Volume 1.
9
++
+++ ON-LINE DOCUMENT: 36Jovian Loop
+++ Retrieval for this document: 1 unit out of 21, = 4.8%
* Inserted sub-header...
5
++ Text units 15-15:
5. When taking over the watch at 0355 the Mate failed to pick up the
discrepancy between the course line drawn on the chart (152∞) and the
course being steered as handed over by the 2nd mate (135∞).
15
++
+++ ON-LINE DOCUMENT: 37TNT Carpentaria
+++ Retrieval for this document: 3 units out of 23, = 13%
* Inserted sub-header...
9
++ Text units 14-15:
3. The Master and Mate failed to fix the ship's position before the
turn to port was made and failed to monitor the ship's position through
the course of the turn.
14
4. The Master and Mate failed to properly assess the option of turning
to starboard.
15
++ Text units 18-18:
7. The Master, having completed a passage plan, did not properly
appraise and appreciate the significance of the transmissions from tidal
stations.
18
++
+++ ON-LINE DOCUMENT: 39Daishowa Maru
+++ Retrieval for this document: 2 units out of 18, = 11%
* Inserted sub-header...
6
++ Text units 11-11:
3. The strong wind and high swell warnings issued by the Bureau of
Meteorology should have indicated to the Master that, under the forecast
conditions, the Twofold Bay Quarantine Anchorage was not safe, placing

the ship on a lee shore.
11
++ Text units 14-14:
6. In his concern to head the ship to the east and pick up the anchor,
the Master failed to fully evaluate the situation and consider alternative actions.
14
++
+++ ON-LINE DOCUMENT: 41Longevity/Blue G
+++ Retrieval for this document:3 units out of 18, = 17%
* Inserted sub-header...
6
++ Text units 11-12:
3. The Master failed to properly ascertain the situation with respect
to the Blue Goose of Arne and whether it was safe to alter course to 180
degrees.
11
4. The Master also failed, having altered course to 180 degrees, to ascertain whether a safe situation existed, before handing over the watch to the Second Mate.
12
++ Text units 14-14:
6. The Second Mate's actions were directed by the recommendations of the Master, not as a result of a correct assessment of the situation.
14
++
+++ ON-LINE DOCUMENT: 48Wyuna
+++ Retrieval for this document: 1 unit out of 20, = 5.0%
* Inserted sub-header...
7
++ Text units 14-14:
5. The Master's conclusion that the radar information was wrong and that the Wyuna had grounded on the northern shore of Mid Pasco Island was erroneous.
14
++
+++ ON-LINE DOCUMENT: 52Malinska
+++ Retrieval for this document: 1 unit out of 24, = 4.2%
* Inserted sub-header...
7
++ Text units 12-12:
3. The Master failed to fully assess the situation before altering course to starboard, placing undue reliance on the ARPA, mis-reading or
misinterpreting the distance to the collision point, and failing to check the ship's position.
12
++
+++ ON-LINE DOCUMENT: 54LibraSankoHeron
+++ Retrieval for this document: 1 unit out of 16, = 6.2%
* Inserted sub-header...
7
++ Text units 14-14:
3. The skipper of the yacht was unaware that he was crossing a major shipping lane.
14
++
+++ ON-LINE DOCUMENT: 65Searoad Mersey
+++ Retrieval for this document: 1 unit out of 17, = 5.9%

* Inserted sub-header...
6
++ Text units 11-11:
3. The Master's conservative use of propeller pitch, giving a
reduced
rate of turn, together with the delay in the commencement of the turn
and wind drift due to the easterly wind, resulted in the turn being
too
wide.
11
++
+++ ON-LINE DOCUMENT: 66Boa Force
+++ Retrieval for this document: 2 units out of 31, = 6.5%
* Inserted sub-header...
13
++ Text units 21-22:
5. The lack of appreciation on board Support Station III of the
problems in manoeuvring an off-shore anchor handling vessel in a
relatively confined area for a prolonged period without an effective
point of reference.
21
6. The failure of the job safety analysis to properly take into
account
the operational safety issues of an unmarked subsea well.
22
++
+++ ON-LINE DOCUMENT: 70Cape Grafton
+++ Retrieval for this document: 1 unit out of 31, = 3.2%
* Inserted sub-header...
11
++ Text units 16-16:
2. There is little doubt that, had those on the bridge and in the
engine room worked together properly, had the Master thoroughly
understood the operation of the propulsion system and the steering,
had
the secondary systems and local controls available in an emergency
been
appreciated and had these been utilised, the grounding could have
been
prevented.
16
++
+++ ON-LINE DOCUMENT: 75Conus
+++ Retrieval for this document: 2 units out of 16, = 12%
* Inserted sub-header...
7
++ Text units 10-11:
1. The Pilot did not plan the undocking and take full account of the
wind strength and direction.
10
2. The Pilot and Master did not jointly consider any sailing plan
for
Conus, taking into account the prevailing conditions, rather they
relied
on a 'standard' departure which did not take into account the
possible
effect of the wind or tide.
11
++
+++ ON-LINE DOCUMENT: 78Bulkazores
+++ Retrieval for this document: 2 units out of 16, = 12%
* Inserted sub-header...
9

++ Text units 12-13:
The grounding of Bulkazores in shoal water off Kendrew Island, Western
Australia, on 24 February 1995, was caused by poor seamanship, in that Bulkazores did not clear the area when the tropical cyclone changed direction and moved towards the Dampier Archipelago, as a result of which
the vessel came within the dangerous semicircle of the cyclone and was trapped on a lee shore.
12
Other decisions and actions, both before Bulkazorres arrived at Dampier
and after it was instructed to leave Dampier Roads anchorage, are considered to have contributed to the incident: The initial recommendation of the weather routing consultant was disregarded, probably in order that Bulkazores would arrive before a competing vessel
and, apparently, without taking into account the known behaviour of tropical cyclones off the north-west coast of Australia and their propensity to curve towards the coast.
13
++
+++ ON-LINE DOCUMENT: 83Iron Baron
+++ Retrieval for this document: 1 unit out of 24, = 4.2%
* Inserted sub-header...
10
++ Text units 16-16:
2. Due consideration was not paid to the effects of the strong northerly wind and south flowing flood tide when manoeuvring to pick up
the Pilot.
16
++
+++ ON-LINE DOCUMENT: 86NewNob/Goonz
+++ Retrieval for this document: 5 units out of 28, = 18%
* Inserted sub-header...
14
++ Text units 20-21:
3. The need to monitor the shipís position from a consistent set of reference marks was not fully appreciated by the Master and officers on
board New Noble.
20
4. The limitations of the anchors was not fully appreciated by New Nobleís Master.
21
++ Text units 23-24:
6. New Nobleís Master was preoccupied with the recovery of the anchor and did not drive the ship ahead, either dragging the anchor or releasing
the bitter end and allowing it to pay out, while the opportunity existed. 23
7. New Nobleís Master undertook no contingency planning regarding recovery of the anchor, nor did he think through his intended action or
make any realistic assessment of how long it would take to recover the anchor.
24
++ Text units 27-27:
10. Goonzaranís Master had the option of slipping his shipís anchor cable and this may have avoided the collision.
27
++

+++ ON-LINE DOCUMENT: 90Carabao 1
+++ Retrieval for this document: 2 units out of 17, = 12%
*Conclusions
7
++ Text units 10-10:
1. Faced with a deviation from the usual operational procedures, the Harbour Master did not fully evaluate the changed circumstances and assess what appropriate action was required.
10
++ Text units 12-12:
3. The phenomenon of tunnel, or narrowing field vision while the Harbour
Master was executing the turn around Old Man Rock.
12
++
+++ ON-LINE DOCUMENT: 91BogDua/Midas
+++ Retrieval for this document: 2 units out of 22, = 9.1%
* Inserted sub-header...
7
++ Text units 18-18:
5. Knowing there was to be a lengthy time at anchor before berthing and
knowing the exposed nature of the anchorage, the Master of Bogasari Dua
did not consider using more anchor cable to improve the holding capability of the anchor, or consider ballasting the vessel down to reduce its windage area.
18
++ Text units 21-21:
8. The Master of Midas did not consider the slipping of his anchor cable
as an option open to him.
21
++
+++ ON-LINE DOCUMENT: 96Niaga
+++ Retrieval for this document: 1 unit out of 18, = 5.6%
*Conclusions
9
++ Text units 16-16:
4. A lack of any realistic assessment by the Master or deck officers of
the risks involved while drifting off Christmas Island, together with the
lack of planning and determination of sensible safety margins.
16
++
+++ ON-LINE DOCUMENT: 98FV Galaxy/Alam Tenggiri
+++ Retrieval for this document: 1 unit out of 18, = 5.6%
*Conclusions
10
++ Text units 13-13:
o The Second Mate on Alam Tenggiri, having seen the light of the vessel
being overtaken, did not keep a proper lookout in that he did not make a
full and effective appraisal of the situation and of the risk of collision.
13
++
+++ Total number of text units retrieved = 47
+++ Retrievals in 28 out of 100 documents, = 28%.
+++ The documents with retrievals have a total of 561 text units,

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    so text units retrieved in these documents = 8.4%.
+++ All documents have a total of 1966 text units,
    so text units found in these documents = 2.4%.
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