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Great Barrier Reef
Pilotage Fatigue Risk Assessment

for

AMSA

Approved by:.....
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1. INTRODUCTION

The Australian Maritime Safety Authority (AMSA) is a Commonwealth Government Authority charged, amongst other things, with responsibility for the regulation of coastal pilotage. AMSA's charter is to enhance efficiency in the delivery of safety and other services to the Australian maritime industry.

AMSA was created on 1 January 1991 under the Australian Maritime Safety Authority Act 1990 (Commonwealth) to supersede the former Marine Operations Division of the Department of Transport and Communications. The function of regulating coastal pilotage was transferred from the Marine Board of Queensland to AMSA as of 1 July 1993.

Two sections of the Great Barrier Reef are defined as areas of compulsory pilotage, namely the Inner Route and Hydrographers' Passage. In addition, the Great North East Channel is an area of recommended pilotage (IMO Resolution 1991). The longest of these is the Inner Route, which takes around 40 hours to navigate. During this time, the pilot spends the majority of his time on the bridge, therefore there is the potential for fatigue to impact on their performance. Following a recent grounding incident, AMSA commissioned the Queensland University of Technology (QUT) to undertake a detailed assessment of the fatigue aspects of the pilot's work.

The QUT report (Ref. 1) made a number of recommendations in relation to better management of pilot fatigue. These recommendations were extensive. Therefore, prior to their implementation, AMSA decided to carry out a risk assessment with a view to establishing whether the magnitude of the risk justified the expenditure required to implement the recommendations. DNV was commissioned to undertake the risk assessment and this document summarises the findings.

2. METHODOLOGY

The study methodology is summarised as follows:

- Literature search to identify any relevant information.
- Collection and analysis of accident data in the reef area and international data sources.
- Workshops with AMSA personnel to discuss the relevant issues and to carry out preliminary analysis of pilot influence on grounding and collision frequencies (fault tree analysis).
- Discussion with the two largest pilot companies on the key issues and to confirm DNV's understanding.
- Interviews with the authors of the QUT report.
- Assessment of the risk attributable to fatigue.
- Recommendations as to the way forward and reporting.

3. RISK PROFILE

This study concentrates on incidents in which the pilot has a significant influence. Thus, the risks of concern are primarily those of collision and grounding. There are other risks, for instance fire, foundering, hazardous cargo events, etc, but the pilot for the purpose of this report has little influence on these. In order to determine a realistic risk profile for collision and grounding events in the Great Barrier Reef (GBR) the risk of collision and grounding was analysed in a number of ways:

- Statistical analysis of actual incidents in the GBR area from AMSA records;
- From worldwide shipping data;
- Using fault tree analysis to estimate the contribution from fatigue.

These methods are described in the following sections.

3.1 Historical Data Analysis

3.1.1 GBR Data

A summary of incidents in the GBR area was provided by AMSA. Further details of each were downloaded from the Internet pages of the Marine Incident Investigation Unit (MIIU). These are available as both summary and detailed incident reports.

Table 3.1 provides a summary of the incidents between 1983 and 1998 (approx. 13 years). Table 3.2 presents the results of the analysis of the raw incident data, including incident frequencies per year and probabilities of damage and hull breach in the event of a grounding or collision incident.

Some of the terminology in the following tables requires clarification:

- ‘Damage’ refers to significant damage to the vessel (not the ‘other’ vessel in a collision). It is difficult to quantify the extent of damage from the incident reports, but this would include what is described as ‘minor damage’ but excludes cases where ‘no significant damage’ was reported.
- ‘Hull Breach’ is self-explanatory and is taken from the incident reports, which usually describe the point of breach, e.g. forward ballast tank, bottom fuel tank etc.
- Where the pilot is described as ‘On Board’, he may be on the bridge or in his cabin.
- The ‘Consequences’ and ‘Causes’ are simplistic summaries of the more detailed information available in the incident reports. It is possible that other readers of the reports would summarise the key issues differently, but we have attempted to be as objective as possible, with the focus on the issues relevant to this study.
- The incident frequencies in Table 3.2 are expressed in two ways: as a simple frequency per year and as ‘an incident every X years’.

Table 3.1: Summary of Incidents

Date	Ship	Ship (Collision)	Type	Pilot Onboard	Area	Consequences	Damage *	Causes	Computory Area
25.03.85	TNT Alltrans		Grounding	N	Bustard Head	Extensive Bottom damage, no pollution	D	Failure to change course, failure of lookout to see danger	No
06.07.85	Iron Cumberland	FV Satfiord = fishing vessel)	Collision	Y	Clack Reef	Minor damage to FV	ND	No passage Plan. No proper lookout, pilot not on bridge	Rec
02.09.86	Alam Indah		Grounding	N	Chapman Is	No significant damage, no pollution	ND	2nd Officer failed to alter course or keep lookout	Rec
24.07.86	Mobil Endeavour		Grounding	N	POW	Bottom damage of the tanker, no pollution.	D	Master ignored prepared Passage Plan and warnings from crew	Rec
03.05.87	River Embley		Grounding	Y	POW (Alert Buoy)	Hull breached, no pollution,	D, B	No passage plan. Inappropriate speed. Incomplete briefing of master.	Rec
03.12.87	Leichardt		Grounding	N	Endeavour Strait	Empty fuel tank breached.	D, B	Poor Passage Planning Poor navigation	Yes
01.07.91	Jin Shan Hai	FV Kikenni	Collision	Y	Low Isles	F V Kikenny sank, minor damage to ship.	D	Crew failed to keep a proper lookout or assess collision risk. Pilot not on bridge.	Yes
03.09.91	Khudozhnik Ioganson	FV Zodiac	Collision	N	Cairns	Damage to FV Zodiac	ND	Failure of ship to monitor FV course.	No
09.09.91	Jovian Loop		Grounding	Y	Unison Reef	Minor damage to ship, no pollution	D	Pilot advised correct course but crew failed to check correct course when onto autopilot.	Yes
01.10.91	TNT Carpentaria		Grounding	Y	POW (Harrison Rock)	Minor damage, no pollution	D	Pilot advised turn wrong direction. Failed to fix position.	Rec
1.09.92	Antares	Yacht	Collision	N	Bustard Head	Major damage to yacht –	ND	Inadequate lookout on both	No

Date	Ship	Ship (Collision)	Type	Pilot Onboard	Area	Consequences	Damage *	Causes	Computory Area
		Champers				de-masted			
03.12.92	Fareast	FV Ronda	Collision	Y	Middle Reef	Sig. Damage to FV only	ND	Inadequate lockout when pilots in cabin, FV lights obscured nav lights.	Yes
02.11.93			Close Quarters	Y					Yes
02.06.94	Cape Grafton		Grounding	N	Whitsunday Islands	No significant damage	ND	Power failure inc. propulsion, inadequate understanding of vessel	No
01.10.94	M Nuri Cerramoglu		Grounding	Y	POW	Vessel just touched bottom, no damage.	ND	Passage plan OK but not updated. Grounded during "timewaste" circle	Rec
09.03.95	Carola		Grounding	Y	South Ledge Reef	Breach of hull, no pollution	D, B	Consume of alcohol and reduced sleep time disabled the mate for his duty on the bridge, pilot was not called	Yes
24.06.95	Svenborg Guardian		Grounding	N	Brook Islands	No significant damage	ND	Bridge unmanned for 5 hrs because fell asleep, fatigue.	No
10.07.96	River Embley	FV Bronze Wing	Collision	N	Little Fitzroy Is.	Minor damage to both	D	FV violation of Colregs, inexperience of FV actions.	Yes
18.07.96	Peacock		Grounding	Y	Piper Reef	Minor damage, no pollution	D	Fatigue, OOW off bridge.	Yes
06.09.96	Alam Tenggara	FV Galaxy	Collision	N	Off Mackay	Minor damage to FV	ND	Poor appraisal of collision risk, over-reliance on ARPA, too close.	No
26.06.96	Maersk Tapah	FV Nimbus	Collision	Y	Low Isles	FV hull damage	ND	Inadequate appraisal by Tapah of collision risk. ARPA faulty, no watchkeeping on FV.	Yes
13.03.97	River Embley	HMAS Fremantle	Collision	Y	Heath Reef	Minor hull damage, no pollution	D	Inadequate passage planning (Fremantle), unaware of traffic, inexperience	Yes
11.06.97	Thebes		Grounding	Y	POW (Larpent Bank)	No damage, no pollution	ND	Error setting autopilot, vessel progress not monitored	Rec

Date	Ship	Ship (Collision)	Type	Pilot Onboard	Area	Consequences	Damage *	Causes	Compulsory Area
12.07.97	Dakshinesshwar		Grounding	Y	POW (Ince Point)	Unknown	ND	Engine failure	Rec
01.11.97	NOL Amber		Grounding	Y	POW (Larpent Bank)	Minor damage to ship, no pollution	D	Pilot and Master failed to ensure location and to check there was room to turn	Rec

*ND = No Significant Damage; D = Significant Damage; B = Breached Hull

Table 3.2: Summary of Collision / Grounding Frequencies

	NO. OF INCIDENTS IN 13 YEARS	FREQUENCY - PER YR	FREQUENCY - ONCE EVERY "X" YRS
Total incidents (grounding + collision)	24	1.8	0.6
Total incidents, pilot on board	14	1.1	0.9
No damage incidents	12	0.9	1.1
Damage incidents (includes breached hull)	12	0.9	1.1
Hull breach incidents	3	0.2	4.4
Groundings, total	15	1.1	0.9
Groundings, piloted	9	0.7	1.5
Damaging groundings	9	0.7	1.5
Damaging groundings, piloted	6	0.5	2.2
Hull breach groundings	3	0.2	4.4
Hull breach groundings, piloted	2	0.2	6.6
Fuel tank breach incidents	1	0.1	13.3
Collisions, total	9	0.7	1.5
Collisions, piloted	5	0.4	2.7
Damaging collisions	3	0.2	4.4
Damaging collisions, piloted	2	0.2	6.6

The following points are noteworthy:

- There are a substantial number of incidents in the MIIU database. As a result, the data can be considered a reliable source of information for frequency analysis. If there were only a few incidents, the data would be considered more unreliable and not as statistically significant – in which case greater reliance would need to be placed on other methods such as extrapolation from worldwide data or fault tree analysis.
- For piloted vessels, there is approximately one collision or grounding incident a year.
- A grounding incident involving a hull breach occurs approximately every 4 – 5 years. Of the three incidents since 1983, all three were in the compulsory or 'recommended' area and one involved the breach of a fuel tank (the tank was empty at the time).
- The frequency of hull breach events should be considered very high for an event that has potentially very severe consequences. In considering the consequences, the public perception of an oil spill on the reef should be taken extremely seriously. This needs to be considered also from a technical point of view where the consequences are unlikely to be severe. (I.e. In comparison to the annual damage to the reef from other causes such as fertiliser run-off and anchor damage).

- There appears to be a general perception amongst the majority of the people interviewed that because the reef is relatively soft, a grounding incident would tend to have a limited consequence. Whilst in many cases grounding produces little damage, 20% of groundings have resulted in a hull breach and there is clearly the potential for loss of containment (e.g. cargo or fuel oil).
- Whilst the frequency of ‘Damage’ events is presented, it should be stressed that in many of these cases the damage to the ship was only minor. Risk is a function of both frequency and consequence of incidents and both parameters need to be considered to properly evaluate the risk.
- Based on the incident history, the consequence of collisions to date, was very minor (i.e. damage to the ship, not to the various fishing vessels etc. which tend to suffer major damage). There have been no collisions involving large vessels. However, the consequences of a major collision are probably more serious than groundings – being more likely to involve loss of cargo containment and a greater chance of total vessel loss. The incident analysis might tend to suggest that grounding presents a higher risk than collision, but this conclusion should not be drawn. The *frequency* of major collisions is clearly lower than for major groundings, but because the consequences of collision are potentially worse, it is not possible to comment on the relative *risks* of grounding versus collision without performing a more detailed assessment.

3.1.2 World-wide Data

The applicability of worldwide incident data to this situation is questionable because the hazards are very specific to the individual passages. Furthermore, because the incident data from MIIU is of a reasonable standard and there are a significant number of incidents in the database, there is no real need to defer to international experience.

The main differences between the GBR situation and the ‘worldwide average’ are that:

- the passage is clearly more complex and difficult to navigate than average; and
- this is offset to a certain extent by the additional safeguard of the pilotage requirement.

Notwithstanding this, it is interesting to see how the safety performance on the reef compares with the ‘worldwide average’. To this end, a simple predictive analysis was carried out using incident rates from DNV’s internal marine risk databases.

Using international data for restricted waters and simplistically assuming that the predicted accident frequencies can be characterised on the basis of the number of ‘vessel hours per year’, the following frequencies were predicted for the Barrier Reef area:

- Groundings – approx. once every 11 years;
- Collisions – approx. once every 15 years;
- Total groundings plus collisions – approx. once every six years.

These figures are approximately an order of magnitude lower than the actual experience on the reef in recent years.

The most likely explanation for this discrepancy is that the passage through the reef is a lot more difficult than 'average' – and that the increase in risk that this presents is not entirely offset by the presence of the pilot. Other explanations are also possible, however, for example the international data could suffer from under-reporting.

An interesting piece of information from the worldwide database is that 24% of grounding incidents result in 'vessel casualty'. This is consistent with the analysis of the reef data, where it was found that 20% of groundings resulted in breach of the hull.

Along similar lines, the worldwide proportion of collisions resulting in vessel casualty is 12%. Once again, this is consistent with the Barrier Reef data, where there have been 9 collisions since 1983, with no cases of serious damage.

3.2 Risk Attributable to Fatigue

For the purposes of this study, it would be useful to be able to establish the amount of risk which is 'attributable to fatigue'. If this were known, this would provide an excellent basis for evaluating how much effort should be expended on reducing the risk. For example, if the risk contribution from fatigue were found to be low, expensive or difficult risk reduction methods might not be warranted. Conversely, if the risk contribution from fatigue were high, this would justify a great deal of effort to tackle the problem.

Unfortunately it is very difficult to quantify the risk which is attributable to fatigue. Some risks are clearly not related to human behaviour and these do not pose a problem in this respect. However where human failure is the primary cause (the majority of incidents), there are a number of complex performance shaping factors which influence the outcome, from which it is impossible to extract fatigue as a distinct element.

Attempts to quantify the contribution from fatigue should therefore be treated with caution and assumed to be rather judgemental. Notwithstanding this, it is possible to make some valuable 'ball park estimates', which can be used as a basis for decision making. To make no attempt to evaluate the fatigue risk on the grounds that it is difficult (the 'too hard basket') does not address the problem. It is better to make a best estimate given all the available information and to acknowledge the uncertainties when evaluating the need for risk reduction measures.

3.2.1 GBR Data

From the MIIU accident reports, it is impossible to make a reliable judgement on the contribution of pilot fatigue to the various incidents as incident investigations have not specifically addressed fatigue as an issue. In some cases, one could reasonably surmise that fatigue was a critical aspect – for instance the Peacock – but in others it is difficult to establish to what extent pilot errors were the result of fatigue. It was the view of one of the pilots interviewed that 99% of his (numerous) mistakes were directly attributable to fatigue. Other pilots would disagree and claim that they rarely suffered from fatigue.

Based on the incident reports only a minority of GBR incidents involved significant fatigue components – 10-20%, as a very rough indication based on the very limited information available.

3.2.2 Worldwide Data

Two studies on fatigue amongst seafarers are of particular relevance. The US Coastguard, which has carried out extensive research into fatigue, estimates that fatigue is a factor in 16% of critical vessel casualties. The research also found that the fatigue contribution for groundings was 36% and 25% for collisions.

A Japanese study produced somewhat higher values: 53% for groundings and 38% for collision.

It should be noted that in both cases the studies have looked at general shipping incidents and as such *they represent incidents on ships without pilots*. In the GBR situation there are essentially two officers on watch for the period when the pilot is on the bridge (pilot plus officer-on-watch). From this point of view, one would expect the risk from fatigue to be less for piloted vessels because there is an extra person providing a checking function. Evidence from the nuclear industry shows that the risk reduction of having two people performing the same task, rather than one, is 27% [Irwin et al 1964 - p 152 of human reliability and safety analysis handbook].

However the risk reduction afforded by the pilot's presence on the bridge is offset by the fact that the Barrier Reef passages are much more complex than the 'average voyage' and are not as forgiving of errors.

The percentages from the US and Japan quoted above are useful in evaluating the proportion of the risk which may be due to fatigue. It should be acknowledged, however, that they only provide an approximate indication of the magnitude of the problem and hence of the potential for risk reduction.

3.2.3 Fault Tree Analysis

Fault tree analysis is a formal risk assessment technique for the identification of causal mechanisms for hazardous incidents. It can also be used to evaluate the frequency of incidents. In this study, fault trees were developed in a workshop environment with DNV and AMSA participants. Separate trees were generated for grounding and collision events. The trees were used to estimate the relative contributions in percentage terms of the various causal factors. The trees are presented in Appendix 1.

It should be stressed that whilst the structure of the fault trees should be robust, the estimates of percentage contribution were derived purely from the experience of the AMSA personnel. It was the initial intention that these percentage contributions be developed with input from the pilots but this did not occur because the direction of the project changed (a better methodology became apparent).

The fault trees were quantified for two scenarios: the first case was the current situation, where there is pilot fatigue; the second case represents a hypothetical situation where there is no significant fatigue. The difference between the two can be viewed as the portion of the

risk which is attributable to fatigue. Based on the AMSA workshop, the percentage of risk attributable to fatigue is :

- Approx. 20% for collisions;
- Approx. 24% for groundings.

These values appear reasonable and are of the right order of magnitude.

3.2.4 Overall

Considering each of the above factors, it is considered that the percentage of the accidents which are attributable to fatigue would lie in the range 10-25%. This should be treated as indicative only, since the reality is that the relationship between fatigue and human performance is not one that is explicitly understood and fatigue is only one of a number of complex performance shaping factors which cannot readily be 'disentangled' from each other.

4. QUALITATIVE ASSESSMENT OF FATIGUE MANAGEMENT STRATEGIES

Fatigue, as an issue, within the marine pilotage industry in the Great Barrier Reef, was highlighted by the grounding of the Peacock in 1997. This led to the commissioning of a study by QUT looking at the work practices of marine pilots in the Great Barrier Reef. The report includes recommendations for Fatigue Management Strategies to be implemented by AMSA and the pilotage companies. It is the intention in this section of the report to assess the likely benefits of implementing these Fatigue Management Strategies.

In order to assess the benefits/risk reduction of the QUT recommendations it is important to have an understanding of the nature of the work GBR pilots undertake. This is reported in detail within the QUT report [ref. 1], and is summarised below. The factors influencing fatigue and fatigue effects on performance have also been discussed in more detail within the QUT report, and a summary again provided below. The recommendations for Fatigue Management Strategies made in the QUT report are then discussed in detail.

4.1 Introduction

Long working hours, stress and fatigue are well known risks to occupational health and safety. In much of society and in many industries there are now rules and regulations which provide limits to the numbers of hours worked. The maritime industry has also begun to recognise and address the issue of fatigue in its industry. Two key international agreements have been produced: the 1995 amendments to the Standards of Training, Certification and Watchkeeping Convention (STCW) and ILO Convention 190 on Seafarers' Hours of Work and the Manning of Ships. Additionally, many flag states now have their own national regulations. However, despite these regulations fatigue continues to contribute to marine accidents and incidents.

Marine accident investigators have recently begun to systematically assess the influence of working hours upon accidents and incidents. Notably, the US Coast Guard have developed a 'Fatigue Index' to estimate the contribution of fatigue to marine incidents. They estimate that fatigue is a factor in 16% of critical vessel casualties and 33% of personal injury cases.

4.2 Summary of GBR Pilots Work Practices

Using a combination of discussion with current GBR pilots and the QUT report [ref. 1] it has been possible to put together a summary of the work practices of this group of mariners.

The essence of the GBR pilots' job is to help the master of the ship they are onboard safely navigate through the compulsory pilotage areas of the Great Barrier Reef. The Marine Orders [ref. 2] state in paragraph 7.1 that "*the function of a pilot on board a ship is to provide information and advice to the master of the ship to assist the master and the ship's navigating officers to make safe passage through the pilotage area or areas for which the pilot is engaged*".

Traditionally the GBR pilots tend to have high levels of local knowledge, ship handling skills and navigational experience. The minimum requirements for gaining a coastal pilots licence are [ref. 3]:

- Be an Australian citizen or be entitled to permanent residence in Australia.

- Hold a valid Australian certificate of competency as Master Class 1.
- Have completed not less than 36 months service – of which 18 months must have been with in the previous 5 years – as navigating officer in charge of watch, or Master, on ships 35 meters or over in length while holding Master Class 1 certificate.
- Have satisfactorily completed an approved programme of training.

The demand for marine pilots is determined by the shipping traffic through the Great Barrier Reef. Due to the irregularity of this traffic the work schedules of the pilots is necessarily irregular as well. Work can be undertaken at any time of day or night. Night work is common, with the findings of the QUT study [ref. 1] indicating that 54% of the 'ship time' is undertaken between the hours of 18:18 and 05:25.

The rostering of work between the pilots varies, one system used is designed to ensure that all the pilots get equal numbers of assignments and income throughout the year. The pilots having had the most number of assignments are put at the bottom of the list and those having had the least at the top. Pilots perform tours of duty, during which time they are on call to perform one or more assignments. The time between work assignments is spent ashore at home or travelling to the start point of the next assignment. After a tour is finished an extended period of time spent at home is normal.

The duration of tours of duty and work assignments tends to vary due a number of factors including the irregularity of the work, the shipping route being travelled, the type, size draught and speed of the vessel, the prevailing weather and tidal conditions, and the amount of other traffic. Research [ref. 1] shows that on average pilots undertake just over 9 tours of duty per year, with each tour last approximately 17 days and involving around 5 work assignments. Work assignments average 40.5 hours in duration, while time between work assignments is typically around 53 hours. Research shows that some work assignments can mean an excess of 60 hours on duty [ref. 1], however, discussion with the pilots shows that this is not common, occurring in total 3 or 4 times per year.

Not all of the time spent onboard a ship is spent navigating, however, pilots are on call at all times. There are no predetermined rest breaks, however, there are periods in the navigational passage when the pilot can go below to take a break. Research shows that 31% of pilots report that they attain an average of less than 4 hours sleep per day, while 65% reported between 4 to 6 hours sleep per day [ref. 1]. The sleep obtained on duty is also reported to be considered of poor quality, with over 55% of the pilots rating their sleep as fair, poor or very poor. This has been shown to be a function of the work conditions.

By comparing the average sleep duration of the pilots when at home and on duty it has been found that during work assignments pilots incur an average sleep debt of 2.8 hours per night [ref. 1]. This has been found to be more than double the figures reported for other Australian seafarers and American merchant marine personnel. Thus, pilots are susceptible on longer working assignments to exhibiting fatigue related performance decrements induced by a cumulative sleep debt.

Discussions with current GBR pilots have also highlighted possible problems with chronic fatigue (i.e. fatigue compounding over the period of a tour of duty). This seems to be influenced by numerous factors including:

- the length of time between assignments;

- the environmental conditions of the place where the rest break is taken (e.g. pilotage station); and
- the nature of the work assignments.

Sometimes the pilots will get what can be called a ‘dream run’, where each assignment is onboard a clean and comfortable ship, with crew the pilot believes are competent, the weather is calm and the pilot manages to get a reasonable amount of rest and sleep. On a run such as this the problem of chronic fatigue is not an issue. On a ‘nightmare run’ the ships living conditions are less than desirable, the pilot may not place a lot of faith in the competence of the crew and the weather may be difficult. The pilot will spend the majority of the passage on the bridge with little opportunity for rest or sleep. This type of tour can leave the pilots feeling physically drained.

In summary, it can be seen that the nature of pilotage work means that pilots are often working during times when circadian rhythms suggest that the pilots should be resting, and that due to the irregularity of the work there is little if any circadian adjustment. The irregularity is both in terms of the time worked during a 24 hour period and in terms of when and how long duty periods and rest periods are scheduled. There are many factors which influence the nature of the work, including the rostering of work, the length of passages and shipping demands.

4.3 Fatigue in the Marine Industry

As an international industry supplying global markets, shipping is of necessity a round-the-clock industry. The need to maintain 24-hour operations is undisputed. Safe operations in the context of the complex nature of ships’ cultures, equipment and systems require high levels of training, experience, qualifications, alertness and concentration. This is true of not only the ships’ crew but also, in the compulsory pilotage areas of the Great Barrier Reef, it applies to the pilot.

The problem of fatigue is not simply one of long hours. In 1989 the UK Department of Transport report [ref. 4] highlighted the relationship between fatigue and the length of continuous duty periods, the time available for continuous sleep and the arrangement of the duty, rest and sleep within 24-hour periods. These findings have been supported by research such as the AMSA Survey of Health, Stress and Fatigue of Australian Seafarers in 1997 [ref. 5] and the research workshop on Fatigue In The Maritime Industry in 1996 [ref. 6]. The results of this research demonstrate how these factors can interact to adversely affect seafarers’ ability to obtain sufficient high quality rest. The results of the International Transport Workers Federation (ITF) survey [ref. 7] demonstrates that there are also other factors which negatively impact on seafarers’ performance:

- Disruptive work patterns
- Long tour lengths
- Noise and vibration
- Alarms and safety drills
- PA announcements
- Poor shipboard conditions
- Weather
- Cargo working

The working patterns experienced by seafarers run in direct conflict with the body's natural rhythms and, combined with the additional factors of the working environment, can leave them suffering almost permanent 'jet lag' type symptoms. This can mean a constant struggle to perform safely and efficiently at times when their 'body clock' has significantly reduced their mental and physical capabilities. The ITF survey produced extensive evidence of seafarers suffering from such effects as 'microsleep' and lapses in concentration or attention. In some cases this led to very serious consequences. The grounding of the Peacock and discussion with some of the GBR pilots shows that these effects are also apparent within the pilot groups.

4.4 Fatigue and Performance

The physical and psychological effects of long hours and fatigue are well documented and include the following:

- Loss of concentration and diminished decision-making abilities
- Loss of alertness and extended reaction times
- Impaired co-ordination of control skills
- Tiredness, depression and irritability
- Poor sleep quality and disrupted sleep patterns
- Increased accident and mortality rates
- Increased dependence on drugs, tobacco and alcohol
- Loss of appetite, gastro-intestinal problems
- Increased risk of infection
- Higher incidence of cardiovascular disease

Research performed by the University of Adelaide showed that the performance of people who had been awake for between 18 and 24 hours is similar to those with a blood-alcohol level of 0.05. Subjects who went without sleep for between 25 and 26 hours performed similar to people with a blood-alcohol level of 0.1 (more than twice the US Coast Guard limit for seafarers and well above the 0.08 limit laid down in the STCW Code). This research shows just what a serious effect fatigue can have on performance.

When looking at marine pilots in particular the job factors that influence fatigue include:

- irregular work schedules;
- long periods on duty;
- the on call nature of the work; and
- the unpredictability of the sleeping environments.

Table 4.1, taken from the QUT report [ref. 1], summarises some of the recognised fatigue-induced performance decrements and how these decrements may affect piloting performance. These factors have been used to help develop the fault trees used to aid the decision making process in this report.

Table 4.1: Fatigue-Induced Performance Decrement and Pilotage Examples

Type of Decrement	Pilotage Examples
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Lowered levels of vigilance	<ul style="list-style-type: none"> • Lack of position monitoring • Incorrect reading of navigational equipment • Failure of identify relevant information
Slowed reaction time	<ul style="list-style-type: none"> • Failure to respond to situations quickly enough to avoid adverse consequences
Impaired decision making	<ul style="list-style-type: none"> • Inappropriate navigational actions • Inaccurate calculations
Memory difficulties	<ul style="list-style-type: none"> • Forgetfulness in communicating information to the crew • Forgetfulness in checking the ship's position at critical times
Narrowing of attention	<ul style="list-style-type: none"> • Failure to fully appraise situations or to recognise the risks of situations • Increased perseverance with inappropriate responses
Lapsing or microsleep	<ul style="list-style-type: none"> • Delayed or no response to relevant information
Time on task decrement	<ul style="list-style-type: none"> • Slowing in response time to unexpected information as work period continues • Increased errors in judgement and decisions as work period continues
Adoption of simpler but riskier strategies	<ul style="list-style-type: none"> • Over-reliance on radar and other automated equipment

As stated in the QUT report [ref. 1], due to the nature of pilotage work there is a high probability that pilots will suffer from fatigue at various times in their work schedules. Most pilots would probably agree that at certain times on certain assignments they feel tired. In the vast majority of cases the consequences of the pilot being fatigued will be insignificant. A course change may be made fractionally late, the crew will notice that the pilot has indicated a change to port but meant to say starboard, etc. However, what this report is trying to identify is the probability that the fatigued performance of the pilot leads or contributes to an incident or accident.

As stated earlier, the US Coastguard has identified that fatigue contributed to 16% of critical vessel casualties and 33% of personal injuries that occurred in US coastal waters between 1 July and 31 December 1995. Of the incident evaluated by the US Coast Guard 36% of groundings and 25% of collisions were found to have a significant fatigue contribution [ref. 8]. The Japan Maritime Research Institute notes that 'lack of awareness' and 'dozing during navigation' accounted for approximately 53% of groundings and 38% of collisions occurring between 1985 and 1991.

4.5 Discussion

It can be seen from the work patterns and environment of the GBR marine pilots that they are subject to conditions which can produce fatigue-related performance decrements. That pilots get fatigued at times during their work cannot be disputed.

Pilots themselves feel that the influence this has on their general performance is not significant. They tend to assert that they get used to the nature of the work, the work and rest periods and the conditions that they are subject to. To a large extent they probably do. The industry is one that self-selects those that can adjust to the unique demands of the job. Those that cannot adjust either do not consider the work in the first place or they choose to leave.

However, the research shows that circadian rhythms do not adjust, or adjust very little to the irregular hours worked. This means that the pilots are susceptible to fatigue, especially during periods when their circadian rhythms suggest they should be resting. This is something which is particularly difficult to manage within the framework of GBR pilotage duties. Most pilots will have coping strategies, or personal fatigue management strategies that will in general help them to deal with fatigue, be that drinking coffee, setting an alarm to wake them up, taking showers, resting when they can, etc.

The pilots believe that the introduction of a compulsory night time sleep period into their rest periods between assignments will have a significant impact on reducing fatigue. Some of the other issues they feel would also contribute to an improvement are:

- Improving the living quarters/environmental conditions on some of the ships they work on;
- Improving the scheduling of work assignments to give even distribution of work and rest periods at home;
- The lack of economic regulation in relation to pilotage services is perceived by some pilots as adding to workplace stress.

In the light of this information it is possible to see that the QUT recommendations which address work scheduling are likely to have a significant impact on the reduction of fatigue. It would require an international standard to improve the living quarters on ships, and while this would significantly improve the quality of rest that pilots get, it is also impossible to see that this would happen overnight.

4.6 QUT Recommendations

We will not reproduce word-for-word the recommendations made by QUT, they can be found in the report [ref. 1], but a summary of each point set out is given below, with a discussion of each of the points and an assessment of the likely benefits.

Recommendation 1: Reassessment of the present guidelines for minimum rest breaks between work assignments and develop guidelines which will minimise fatigue potential.

- 1.1 Rest breaks allowing 2 full nights sleep during optimal hours (2200 – 0800)
- 1.2 Specific wording of the guidelines to include hours and timing of sleep and where rest breaks should be taken
- 1.3 AMSA and pilot companies working together to develop guidelines on rest breaks with endorsement by an expert panel
- 1.4 Develop a predictive model for probable fatigue status of pilots

1.5 Develop a predictive model for recuperative value of sleep periods

Recommendations 1.1 and 1.2 are the only parts of the QUT recommendations acted on already by AMSA. They have produced guidelines on rest breaks which includes a requirement to have *one* full nights sleep during 2200 and 0600 as part of the 24 hour minimum rest break between assignments. The 2 full nights sleep recommended by QUT would obviously give more recuperative rest than the one nights sleep that AMSA have so far recommended, however whether this would be practical given the nature of the pilotage business and the limited number of pilots available is debatable. The next important step for AMSA is to work with the pilot companies to develop more detailed rest break guidelines (1.3). This does not seem to have been achieved thus far, but based on DNV's discussions with the pilot companies it seems likely that they would agree with AMSA that one night is all they would want to see in the guidelines.

DNV recommends that AMSA works with the pilots to implement QUT's recommendation 1.3, although the expert panel may not be required.

The predictive models, as recommended in 1.4 and 1.5, would require a large amount of development, and would require the pilots to record and report certain aspects of their tours. They could be used to help the pilot companies to assign tours to the least fatigued pilots. There is a system for allocating work within the pilot companies which takes some this into account already, although it is much more crude than what QUT has in mind. Certainly one of the companies operates an informal system which involves scoring on the number of tours, money earned, length of rest breaks, etc and this has a lot of merit. Those with the least tours go to the top of the list and those with the most go to the bottom. New tours get assigned to those who have done the least so far that year. This may mean that the pilots have periods where they will do a lot of tours, and then periods when they do only a few.

QUT may also have recommended these measures for AMSA's use. This would allow AMSA to monitor the potential fatigue levels of the pilots. AMSA would then be able to insist that those pilots who they feel are too fatigued do not perform the next tour. It is considered that this would be very difficult for AMSA to implement directly, but if guidelines can be agreed within the pilots' Code of Conduct, AMSA could then audit for compliance with the Code.

The recommendation's ability to reduce fatigue or impact on safety will be dependent on how the information is used, but assuming that it is used to ensure that the pilots are not fatigued when they are assigned tours then it will improve the ability to ensure this. However, although crude, the current system of assigning tours does provide some way of ensuring that assignments go to the pilots who have had the most rest breaks.

DNV believe, in light of the risk assessment findings, that the costs associated with Recommendations 1.4 and 1.5 may outweigh the risk reduction benefits gained. A more informal system, developed jointly between the pilots and AMSA is likely to be equally effective.

Recommendation 2 : Implementation of revised guidelines – self regulation with minimum prescription.

- 2.1 Minimum prescription guidelines developed based on studies, by AMSA, companies and pilots combined with self regulation through formal fatigue management programs targeting companies and individuals.
- 2.2 Auditing of the formal fatigue management strategies at regular intervals.
- 2.3 AMSA to monitor/audit guideline compliance.
- 2.4 Ability for the companies to request changes to guidelines where they are felt to be too limiting.

This recommendation suggests that prescribing working hours or resting hours may not tackle the issue of fatigue in the most effective way (e.g. in the road transportation industry stating that drivers must have 8 hours rest in every 24). QUT suggest that by developing the guidelines in the manner suggested in Recommendation 1.3 (i.e. AMSA, pilots and experts together) and keeping the prescriptive element to a minimum, that these guidelines are more likely to be implementable. If the guidelines and fatigue management strategies are agreed by all parties, they should also require little policing and therefore AMSA would only be required to audit/monitor compliance rather than being responsible for policing compliance. This is consistent with the approach being taken in the UK to regulations. The authorities are taking a goal setting approach, with self regulation or verification of compliance.

DNV does not see that this recommendation has a direct effect on safety or fatigue, but it is a sensible approach to the development and implementation of any guidelines on fatigue management, and therefore support the implementation of Recommendation 2.

Recommendation 3 : Development of a system enabling companies to allocate work to pilots in a way that is consistent with guidelines for rest breaks.

- 3.1 Review of each pilotage company on the criteria currently used to allocate work to pilots.
- 3.2 Develop a systematic approach to allocating work to pilots that minimises fatigue, maximises safety and complies with rest guidelines.
- 3.3 Aim to make the distribution of work and rest more even.
- 3.4 Investigate the way work is allocated currently vs. other industries (e.g. airlines).
- 3.5 Review existing practices with the aim of making optimal use of the limited workforce and minimising fatigue in non-alterable situations (e.g. pilots onboard during non-compulsory areas of the route, use of reserve group of pilots, optimised use during busy periods, optimise sleep opportunities at sea).

The development of a system for optimising the allocation of work to pilots with respect to fatigue and safety is obviously a recommendation that will improve the management of fatigue and therefore impact favourably on safety. It is felt that all of the recommendations made as part of Recommendation 3 should be undertaken. 3.4 is a low priority, however, since the nature of the work is very different to other industries. A joint AMSA / pilots working group, as in 1.3, would seem to be an appropriate forum, implemented via the pilots' Code of Practice.

Recommendation 4: Upgrade reporting procedures of work schedules

- 4.1 Upgrade the reporting procedures of work schedules to enhance work schedule files with additional information (including: total duration of bridge periods; total duration of bridge periods during an assignment and during critical hours; travel to and from the ship).
- 4.2 Refine the reporting of work schedules using a 6 month trial of the enhanced reporting system, extending the current model to include more temporal aspects of work and sleep patterns, development of predictive fatigue status model of pilots.
- 4.3 Upgrade the reporting procedures of work schedules to monitor fatigue potential in a more timely fashion at (a) regulatory/company level, and (b) at a personal level.

QUT are recommending in 4.1 and 4.2 that, in addition to the information that the pilots already provide on their work schedules for each tour, they should provide supplementary information related to the study of fatigue. This links in with Recommendation 1 and the predictive fatigue modelling.

DNV agrees that the issue of fatigue requires further study before the impact of fatigue on performance can be rigorously defined and that this work would be of value to not only the marine industry but to all industries where fatigue is an issue. However, we believe that improving the scheduling of work will have a more immediate and significant impact on the reduction of fatigue than the use of predictive modelling.

Recommendations 4.1 and 4.2, as with 1.4 and 1.5, are, in light of the risk assessment findings, 'nice to have' rather than essential.

The recommendation 4.3(a) would require AMSA to maintain an active role in updating the rest guidelines to ensure the regulations are in line with current findings and best practice. This is a sensible, low cost, recommendation which DNV supports.

However, the rest of recommendation 4.3(a) is linked to the requirement for AMSA to police the fatigue levels of individual pilots and to have the power to intervene if they felt a pilot is overly fatigued. In order for this policing to take place the recommendations linked to predictive fatigue modelling and monitoring would need to be set in place. This is something that AMSA may like to work towards, but is not seen as a high, immediate priority.

Recommendation 4.3(b) relates to pilots monitoring their own fatigue levels using a checklist which could be incorporated into the passage planning.

This is considered to provide a low cost method for improving the pilots understanding of their personal fatigue issues, which may lead to improved personal fatigue management. The pilots should be encouraged to adopt such practices via the Code of Conduct or company procedures.

Recommendation 5: Implement an education programme on the nature of consequences of fatigue.

- 5.1 Develop a fatigue education programme targeting pilots, company personnel and AMSA officials involved in pilotage matters.
- 5.2 Examine the appropriateness of fatigue training programmes from other industries (e.g. NASA and transportation) which could be used as a general introduction to fatigue to go along with pilot specific material.
- 5.3 Incorporate a fatigue education/training programme within the existing area of Pilot Professional Development
- 5.4 Use knowledge gained from marine accidents investigations to enhance the content of the programme.
- 5.5 Consider a distance learning programme to take account of the scattered home bases of the pilots and the nature of their work.
- 5.6 Develop a system to regularly and systematically distribute fatigue updates to pilots based on the latest findings from scientific and industry literature.

This recommendation links with parts of Recommendation 4 regarding personal fatigue monitoring. Having a practical based programme which will teach the pilots about the issues and how they can personally improve their fatigue management strategy will have a long term impact on safety.

We believe that the provision of a fatigue management education programme for pilots would be very beneficial and feel that recommendations 5.1 to 5.5 should be implemented, possibly sponsored by the pilot companies and required for all relevant staff via the Code of Conduct. Recommendation 5.6 regarding provision of fatigue information updates is less essential, although nice to have, but it should be ensured that any update material is included in revisions to the fatigue education programme.

Recommendation 6: Review the current medical screening procedures for pilots

- 6.1 Review the type and frequency of assessment
- 6.2 Review medical assessments for other groups (e.g. airline pilots) for applicability to marine pilots
- 6.3 Develop most appropriate screening procedures in consultation with occupational physicians to consider age, fatigue consequences of work and sleep patterns.
- 6.4 Promote a preventative approach to health.

This is linked to Recommendations 4 & 5. Incorporating fatigue related issues into the medical screening and monitoring of pilots will improve the pilots' knowledge of fatigue related issues and will monitor the effects of fatigue on health and performance.

This issue is related to the health of the pilots in the long term, rather than being directly related to the risk of accidents on the reef. It is an OHS issue. DNV does not wish to comment on this, but instead recommends that it be taken up with OHS authorities if necessary.

Recommendation 7: Implement a healthy lifestyle education programme to complement Recommendations 5 & 6.

- 7.1 Implement health and lifestyle education programmes which include stress coping strategies, exercise and nutritional issues especially for those in home-and-away work situations.
- 7.2 Liaise with QUT regarding the suitability of existing programmes for application, with modification, to the pilotage workforce.
- 7.3 Incorporate health and lifestyle education into the Pilot Professional Development structure and encourage pilots to be proactive in this issue.
- 7.4 Investigate the availability of such programmes for delivery and monitoring using a distance learning approach.
- 7.5 Trialing and evaluating health and lifestyle programmes with GBR pilots.

As with Recommendation 6, this is more of an Occupational Health and Safety issue. It would be impractical to develop such a programme for the small group of reef pilots, however, a wider seafarer healthy lifestyle programme would benefit the entire marine community. This type of programme can help to improve general health and fitness which will in turn help to reduce fatigue and therefore have an impact on safety.

In the immediate sense this programme will not have a significant impact on safety, and it is with this in mind that we suggest that implementing Recommendation 7 is not presently essential.

Recommendation 8 : Enhance the accident / incident reporting procedures with respect to fatigue

- 8.1 Provide information from the QUT report to upgrade the human factors investigation and reporting procedures.
- 8.2 Review the current procedures for accident investigation to assess the adequacy of this collection and access to information concerning human factors issues.
- 8.3 Consider the use of the present work schedules in an investigation of chronic fatigue problems during accident investigations.
- 8.4 Establish or maintain investigation of the contribution of human factors to accidents/incidents as a priority.
- 8.5 Establish a close working link between MIIU, AMSA and the pilot companies with a view to a proactive rather than reactive approach to fatigue issues.

Improving the knowledge of what role fatigue can play in incidents will lead to improving the fatigue management strategies used within the industry, and therefore DNV supports the implementation of Recommendation 8.

AMSA should also consider implementing the US Coastguard 'Fatigue Index'. This method is used to classify incidents in relation to the fatigue contribution to the incident. The

analysis undertaken by the US Coast Guard so far indicates that a number of conditions significantly contribute to fatigue, these contributors could be included in the incident reporting and investigation to improve the knowledge of fatigue contribution. These contributors include:

- Number of consecutive days worked prior to the incident
- Number of day worked in the 30 days prior to the incident
- Hours on duty prior to the incident
- Hours worked in the past 24, 48 and 72 hours prior to the incident
- Change from the normal working schedule on the day of the incident
- Absence of company or union policies governing working hours

5. POTENTIAL RISK REDUCTION MEASURES

From the frequency analysis discussed in Section 3, it is concluded that the frequency of an oil spill from fuel tanks would have to be considered high. Given the sensitive nature of the reef, the consequences of any size of spill should be considered serious and the risk would therefore also be considered high (risk being a combination of both frequency and consequences).

It is therefore appropriate to consider whether that risk can be reduced to more acceptable levels. Whilst better fatigue management could clearly reduce the risk, so could numerous other measures. The objective of a modern risk management approach should not be to reduce the risk to *as low as possible*, but rather to *as low as reasonably practicable* – i.e. to optimise, rather than minimise the risk, having regard for cost implications and practicability.

To this end, rather than blindly implementing the various QUT recommendations as discussed in the previous section, a more considered, holistic approach is recommended. This would involve the identification of all potential risk reduction measures, and their evaluation based on cost, practicability and the risk reduction afforded. Risk can invariably be reduced by ‘throwing money’ at the problem, but the essence of good risk management is to recognise that there is a limit to how much can be practically expended, and to ensure that the available resources are deployed in the most cost effective way.

Clearly some of the fatigue management strategies recommended by QUT would be quite costly (whether to AMSA, pilots, or ships). It would not be sensible to go ahead with these until other strategies have been evaluated. In Section 3, it was concluded that only 10-25% of the total risk was attributable to fatigue and hence no matter how good the measures are, there is only limited potential for risk reduction. If other potential measures are more effective and cost less, they should be implemented in preference.

The following approach is recommended:

- Continue to work with the pilots towards better fatigue management, as in the previous section, but do not insist on the more costly ones.
- Conduct workshops with the aim of identifying all possible risk reduction measures.
- In the workshop forum, evaluate the approximate risk reduction afforded by each potential measure and estimate the cost (or difficulty).
- Rank the various risk reduction measures in terms of their cost-effectiveness and in the light of this, decide on an appropriate course of action.

DNV has carried out a very crude exercise of this kind to illustrate the process and to demonstrate that fatigue is by no means the most important issue. A matrix approach was utilised. For each potential risk reduction measure, the cost/difficulty was estimated, as well as the likely risk reduction. This information was plotted on a matrix, allowing the measures to be ranked in order of cost effectiveness. This is illustrated below.

Table 5.1: Cost/Benefit Factor

		Risk Reduction Benefit		
		Low	Medium	High
Cost	Low	3	4	5
	Medium	2	3	4
	High	1	2	3

The most cost effective risk reduction measures would be those with a Cost-Benefit Factor of 5 – these are low cost but produce the greatest risk reduction. The lowest Cost-Benefit factor is 1. Table 5.3 illustrates how this works for some of the potential risk reduction measures identified by DNV. Note the categorisations are only provisional at this stage. They should be refined with more expert input from AMSA and the pilots.

The definitions of High/Medium/Low are presented in Table 5.2:

Table 5.2: Category Definitions

	Cost / Difficulty	Risk Reduction
High	\$1M+ or virtually impossible	>10%
Medium	\$100K - \$1M, or difficult	1 - 10%
Low	<100K, or quite straightforward	<1%

Table 5.3: Evaluation of Risk Reduction Measures

Risk Reduction Measures	Cost / Difficulty	Risk Reduction	Cost/Benefit Ratio
Portable GPS location alarm	L	H	5
Electronic passage planner inc. time + location alarm	L	H	5
'X weeks on Y weeks off' type requirements	L	M	4
Regulate maximum no. of tours per year	L	M	4
Wristwatch - alarm at time to change course	M	M?	3
Pilot competency req'ts (selection and training)	M	M	3
Fatigue reduction as per QUT recommendations	M	M	3
Commercialism - fixed fee per tour	H	M	2
2 pilots per tour	H	M	2
Change pilots half way on inner route	H	M	2
Improve sleeping conditions	H	L	2
Use pilots for spill emergency response	M	L	2
Pool of pilots for peak load management	M	L	2
Fairway Channel charting (extra sleep break)	M	L	2
Require certain vessels to use Outer Route	H	Requires QRA*	?

* Quantitative Risk Assessment – a more detailed analysis of the risk.

Whilst the analysis in Table 5.3 above is only indicative at this stage, it illustrates the methodology nicely and it can be clearly seen that there are some potential risk reduction measures which are more cost effective than the QUT recommendations.

In particular the possibility of pilots carrying portable, GPS-based alarms seems to be a promising risk reduction measure (ideally pre-programmed with the passage plan so that there could be a time-based alarm as well). Whilst this is by no means infallible, it has the potential to reduce risk significantly more than fatigue management, for a reasonable cost. It is possible that several of the recent incidents on the reef could have been avoided had this sort of safeguard been used.

6. CONCLUSIONS

The following conclusions are drawn:

- Based on analysis of the incidents on the reef over the past 13 years, the frequency of damaging groundings and collisions is significant. The frequency of a hull-breaching grounding is about once every 4-5 years. A program of risk reduction is highly desirable.
- In working towards risk reduction, it is important to note that fatigue is just one of numerous potential causes. It is estimated that the proportion of accidents attributable to pilot fatigue would lie in the range 10-25%. Improved pilot fatigue management should reduce the risk, but there is greater potential for risk reduction by addressing other causes. A multi-faceted, ongoing program to reduce risk is therefore recommended.
- A simple risk management method is recommended, involving a risk matrix approach which incorporates the cost of potential risk reduction measures. It is suggested that workshops be held to identify such measures, and that these are then evaluated systematically to identify the most cost-effective solutions. External input to this process would help provide a balanced and objective viewpoint.
- Notwithstanding the above, the QUT recommendations have been assessed and comments made as to their merit. Some of the recommendations are supported because they represent good practice and are reasonably straightforward. Others are of less value, or would be expensive and it is suggested that AMSA need not implement these, pending the resolution of the broader risk management workshops recommended.
- Pilot fatigue management methods would be very difficult for AMSA to dictate. Instead, DNV would encourage the promotion of a greater shared vision of environmental protection issues. It is recommended that fatigue management strategies be implemented via the pilots' Code of Conduct, rather than by prescriptive regulation. It would be hoped that, in the light of the results of this risk assessment, all parties will recognise the need for risk reduction and take a more proactive approach. There is currently a (mistaken) impression that the risks are very low and hence that costly risk reduction is not justifiable.
- It is worth noting that some of the pilots have a strong view that competency standards are falling as a result of the commercialisation of pilotage services and that the increased commercial pressures compound the fatigue problem. This is a complex issue which goes beyond the scope of this study, but which should nevertheless be given consideration when AMSA embarks on the risk reduction program recommended above.

7. REFERENCES

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APPENDIX I
FAULT TREE ANALYSIS

I.1 INTRODUCTION

The fault trees presented in this appendix are a summary of the results from the workshops held with DNV and AMSA participants. They illustrate the causal mechanisms required for a grounding or collision incident.

To interpret the trees, the reader should start at the top event (e.g. 'grounding') and work downwards. Where the path is marked 'And', all of the subordinate events are required to occur simultaneously. Where it is marked 'Or', either one of the subordinate events can result in the event in question.

The event descriptions in the trees are accompanied by two percentages. The percentage not in brackets represents the team's estimate of the contribution of the event in question to the top event frequency (for example, 'gyro wanders' represents 1% of the total grounding causes). The numbers in brackets indicate how these contributions might be reduced if fatigue were to be totally eliminated. This then provides an indication of the maximum risk reduction achievable through fatigue management.



