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MCA RP545: Development of guidance for the mitigation of human error in automated ship-borne maritime systems

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Executive Summary

Background

As with other high hazard domains, the use of automation is increasing within maritime systems. Although automation can be beneficial to operators of complex systems in terms of a reduction in workload or the release of resources to perform other on-board duties, it can also be detrimental to system control if errors are introduced through its use. In the maritime area, human errors related to the use of automated ship-borne maritime systems have been identified as possible contributory factors to accidents and incidents at sea.

This report is produced in response to the Maritime and Coastguard Agency's (MCA) contract MSA 10/9/210. The MCA has a requirement for a research programme aimed at developing guidance for the mitigation of human error in automated ship-borne maritime systems. It is envisaged that this guidance material will be used by industry to assist in understanding how complex automated systems should be used on-board ships.

Maritime automation issues identified

A review of maritime incidents, accidents and related literature identified the following human element issues:

- Over-reliance on automation
- Lack of in-depth understanding
- Sub-optimal ergonomic design
- Sub-optimal Human-Computer Interface design
- Inherent system latency interfering with error recovery efforts
- Lack of awareness of automation failsafe modes
- Maintenance and calibration errors
- Poor support to development and maintenance of situation awareness
- Information overload issues
- Display inconsistencies between different manufacturers
- Poor appreciation of automation characteristics and limitations by operators
- Automation not designed around operators' abilities and limitations
- Standardisation
- Human Factors
- Training
- Subsequent changes made to original automated system designs

The current taxonomy adopted for grouping maritime incidents may mean there are further cases involving automation that cannot be retrieved with a standard search of the databases.

Standards and guidelines

Automation issues are well recognised within the general Human Factors and Ergonomics field. The number of standards and guidelines specifically directed at automation is low; rather there is indirect coverage of wider topics (e.g. human error). Human Factors Integration plans provide a good source of guidance on the means by which requirements can be achieved. A User-Centred Design philosophy can also be integrated in the procurement of automated systems to reduce the incidence of automation issues.

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Other industries with regulations and guidelines for automation include the aviation, chemical and nuclear industry. The Aviation industry is at the forefront of regulation aimed at certification of operators. The Chemical industry is driven by a framework of requirements; to a large extent, the guidance to achieve the requirements is not available. The Nuclear industry requires licensees to undertake a Human Factors Engineering plan of work. Confidential report systems are another common feature for identifying operator problems retrospectively.

Training requirements to address automation issues

A review of maritime Crew Resource Management (CRM) training found only one course that specifically addresses 'automation awareness', whilst a further two encompass Human Factor topics covering human error. All courses have been developed to satisfy different customer needs and therefore direct comparisons are problematic. The effectiveness of CRM training is as dependent on selection of appropriate delivery channels as it is on the course content material.

Development of critical thinking skills and other non-technical Crew Resource Management (CRM) skills requires provision of an environment where the student can practise these skills.

Guidance for automated maritime systems

Based upon the literature research, guidance was developed for use of automated maritime systems. The guidance is tailored for three stakeholder groups: shore-based company management; shipboard management (e.g. Ship's Master); and automation users (e.g. seafarers). The guidance is summarised as follows.

- Promote the greater use of existing standards and guidelines relating to the mitigation of human error in automated ship-borne maritime systems.
- Verify any assumed savings in manning levels anticipated with the introduction of automation.
- Involve users in the procurement of new equipment.
- Question commercial-off-the-shelf (COTS) suppliers on the level of Human Factors involved in their products.
- Encourage operators of automation to share experiences involving misunderstanding and confusion during operation. This experience should be collected and disseminated to other users.
- Ensure automated systems do not interfere with manual control and monitoring of the vessel.
- Ensure automated systems provide an overview of systems being monitored and controlled by the automation.
- Support ship crews in maintaining their skill sets.
- Provide training in understanding the limitations of automation.
- Avoid COTS equipment that is heavily reliant on modes for operation.
- Ensure crew handover periods are sufficient to allow the old crew to pass on their knowledge to the new watchkeepers.
- Encourage crew communication to support shared awareness and understanding.
- Encourage crew to report any concerns with the function and operation of automation.

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- Ensure crew conduct regular cross-checking of information provided by automated systems.
- Consider using periods of low workload and benign operating conditions to practise the procedures involved with reverting from automatic to manual control.
- Increase operator awareness of mode errors.

Training recommendations include:

- Elevate resource management training to mandatory status as part of the STCW Code.
- Endorse the use of trainers with pedagogical and human behaviour training, in addition to being subject matter experts.
- Develop courses with the customer needs in mind, based upon Training Needs Analysis.
- Develop courses based on sound, current pedagogical theory (e.g. student centred learning).

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1 Introduction

1.1 Background

As with other high hazard domains, the use of automation is increasing within maritime systems. Although automation can be beneficial to operators of complex systems in terms of a reduction in workload, or the release of resources to perform other on-board duties, it can also be detrimental to system control if errors are introduced through its use. In the maritime area, human errors related to the use of automated ship-borne maritime systems have been identified as possible contributory factors to accidents and incidents at sea.

1.2 Requirement

This report is produced in response to the Maritime and Coastguard Agency's (MCA) Contract MSA 10/9/210. The MCA has a requirement for a research programme aimed at developing guidance for the mitigation of human error in automated ship-borne maritime systems. It is envisaged that this guidance material will be used by industry to assist in understanding how complex automated systems should be used on-board ships.

1.3 Structure of report

The requirement has been met through a number of work packages that cover the following areas:

- A review of accidents, incidents and near misses in commercial shipping.
- A review of literature in the field of marine bridge design and ergonomics.
- A review of existing regulations, codes of practise and mitigation measures in other safety-critical industries.
- An assessment of decision making and Crew Resource Management in safety-critical systems.
- A review of current maritime training courses that address resource management issues including human interaction with automated systems.
- An assessment of human factors design standards and guidelines.

The output of the work packages are reported in the following chapters:

- Identification of automation issues in commercial shipping and from other high-hazard industries.
- Review of standards and guidelines to address automation issues.
- Review of training course requirements to address automation issues.

Guidance to minimise the risks posed by automation issues were produced on the basis of the six work packages. The guidance is based around three target audiences identified with the customer. The three target audiences were as follows:

- Shore-based company management, particularly with regard to those responsible for equipment and vessel purchasing and operational issues
- Shipboard management (i.e. ship's master)
- Automation user (i.e. seafarers)

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Guidance relating to training as a mitigation activity is also presented in the form of curriculum components that can be incorporated into existing training programmes.

2 Identification of automation issues in commercial shipping and other high-hazard industries

2.1 Review of accidents, incidents and near misses in commercial shipping

A recent review [1] of the accident databases from the USA, UK, Canada, Australia and Norway confirms that human error continues to be the dominant factor in maritime accidents. The following conclusions were drawn:

- While the total number of accidents is declining, human error continues to be a dominant factor in 80 to 85% of maritime accidents.
- Failures of situation awareness and situation assessment overwhelmingly dominate.
- Human fatigue and task omission seem closely related to failures of situation awareness.

In their review of 150 accident reports from the website of the Australian Transportation Safety Bureau (ATSB), causal factors were classified in root cause groupings, which included a situation awareness group (27.5%), management group (24.5%), a risk group (30%) and a non-human error group (15%). Although the authors acknowledge that these root cause groupings are subject to interpretation, the results correlate well with their survey of the UK Marine Accident Investigation Branch (MAIB) database. However, the management group refers almost entirely to on-board management factors, with only 4.5% of these factors being ascribed to organisational influences, such as the level of manning or business management [2].

A search of the UK Marine Accident Investigation Branch incident database, using a number of search queries related to human error and automated ship-borne maritime systems, has been undertaken. From this search a number of incidents have been identified where human error during interactions with automated ship-borne maritime systems *may* have been a causal factor of the incident (See Appendix A). However, because there is no standard taxonomy of terms referring to incidents related to human error in ship-borne automated maritime systems, it is very difficult to determine from the results of the incident database search whether such errors were involved or not. In order to confirm that human error during interactions with automated ship-borne maritime systems was a causal factor in these incidents, reference would have to be made to the full text of each incident report and possibly even to the primary data of the investigation. Recent European research [3] suggests that other databases also do not have taxonomies that relate specifically to interactions with the automated systems.

In a review of the 169 hazardous incident reports that have so far been submitted to the Confidential Hazardous Incident Reporting Programme (CHIRP), no incidents can be identified, using the publicly available data, that have reported human errors related to automated ship-borne maritime systems. As with the MAIB data, this could only be confirmed by reference to the full text of each hazardous incident report.

In order to determine the human element issues related to the interaction with automated ship-borne maritime systems, a number of case studies have been reviewed. These case studies have been chosen because the causal links between the human errors whilst interacting with automated systems and the incident, are clearly established. Together, these

cases highlight the main issues relating to human error when interacting with automated ship-borne maritime systems.

2.2 Case Studies involving accidents, incidents and near misses in the commercial shipping industry

2.2.1 The Grounding of the “Royal Majesty” [2]

The circumstances

In June 1995 the passenger vessel “Royal Majesty”, with 1509 passengers aboard, went aground near Nantucket Island on a voyage from Bermuda to Boston [4]. The vessel was fitted with an integrated bridge system including an autopilot which, when engaged, was capable of steering the vessel along a pre-programmed route using the vessel’s GPS system as a primary source of positional information. In the case of insufficient satellite data, the GPS was designed to default to a Dead Reckoning (DR) mode. The autopilot, however, was not capable of recognising any change in GPS status and thus, with the GPS in DR mode, was able only to continue navigation without correction for wind or current.

The autopilot was set on departure from Bermuda, but after about an hour the GPS defaulted to DR mode (probably as a result of a loose connection on the receiver cable) and for the next 34 hours the vessel was navigating on DR through the autopilot. At no time during this period was this situation detected by the bridge team, so that when the vessel eventually grounded, she was 17 miles off course.

The official National Transportation Safety Board report gave as the probable cause of the grounding:

“The watch officers’ over-reliance on the automated features of the integrated bridge system, Majesty Cruise Line’s failure to ensure that its officers were adequately trained in the automated features of the integrated bridge system and in the implications of this automation for bridge resource management, the deficiencies in the design and implementation of the integrated bridge system and in the procedures for its operation and the second officer’s failure to take corrective action after several cues indicated the vessel was off course.” (NTSB, 1997). [4]

The analysis

This case illustrates the problems of over-reliance on the available technology by the bridge team. All the officers have been lulled into a false sense of security by a modern system that appears to be protecting the vessel but is vulnerable. Their understanding of the system and its weaknesses is incomplete and their reliance on technology has led the team to use only a limited number of sources of information to determine the vessel’s position. Other sources are ignored and not used for crosschecking. This deviance from normal watch keeping practise has gradually become the accepted norm by all members of the team.

There were several opportunities when both the Chief Officer and the Second Officer on their respective watches could have avoided the grounding through the observation of buoys visually and by use of the radar. However, because of their over confidence in the GPS, the team is in a “mind set” where conflicting evidence is not analysed critically and assumptions are not questioned. The result is that the individuals remain confirmed in their bias towards the information from one source and remain in blissful ignorance of the real situation.

2.2.2 Pollution from the “Randgrid”

The circumstances

Randgrid arrived in the area of the Tetney monobuoy at 0055 on 20 December 2000, where she was met by the service boat *Spurn Haven* and the tug *Lady Debbie* [5]. Berthing was carried out safely and *Randgrid* was secured at 0135. Both berthing masters confirmed that the chain stopper was fully closed on to the chain before arranging for the messenger rope to be slacked back as usual. The chief officer discussed the discharge with the cargo surveyors and went to supervise the pump and line set-up. The first discharge hose was connected at 0210 and discharge started at 0245 with a line pressure of 11 bar. A small leak caused a delay, but by 0350 the discharge pressure was back to 11 bar. At that time the bridge berthing master became concerned about the vessel’s movements under wind and tide, so arranged for the steering control to be changed from DP to manual. The chain stopper was also checked. Between about 0415 and 0430, the chief officer went to the bridge and shut down the hydraulic pumps controlling the power systems forward.

Before going to his cabin, he told the duty AB to check the mooring at regular intervals. This was carried out between 0500 and 0730; the mooring being confirmed secure. By 0715, with the flood tide due, the berthing master arranged for the tug astern to maintain a slow astern speed.

At 0753, the aft discharge hose pulled away. The duty cargo officer stopped the pumps and started to close the valves. Shortly afterwards, the forward hoses broke away. On the bridge, the berthing master became aware that something was wrong with the mooring, looked up and saw the first of the hoses pulling free. Tetney Terminal was informed and the standard terminal emergency arrangements were implemented. The astern tug was brought into play while *Randgrid*’s main engines were started and by 0812 the vessel was able to manoeuvre under her own power. *Randgrid* then went to an anchorage, while terminal vessels contained and dealt with the oil spillage.

An investigation revealed that both spool pieces and flanges were damaged on the hoses, with slight deformation and cracking in weld flanges. The chain stopper was found in the closed position, but the chafing chain was missing. Subsequently, it was established that the chafing chain had been released from the chain stopper because the chain stopper controls had been operated accidentally. The pickup rope held the vessel until the lashing, securing the chafing chain to the pickup rope, failed at about 0750.

No staff were injured, but an estimated oil spill of about 12 tonnes occurred.

When connecting or disconnecting the monobuoy mooring, the bridge screen showed an appropriate message with the screen background varying in colour to emphasise the condition:

GREEN chain stopper closed
YELLOW chain stopper operating
WHITE chain stopper open

Like many other computer systems, the bridge monitor had been installed with a multi-functional screen system, i.e. No 1 screen would show a number of differing controls and systems, some of which could be operated using the function keys, F1, F2, etc. When switched to No 2 screen, a different set of systems and controls would be displayed, but using the same set of function keys: F1, F2, etc.

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- SCREEN 1 chain stopper open/closed
chain stopper operating
coupler valve open/closed
crude line valve open/closed
loading on/off
buzzer off
- SCREEN 2 hydraulic pump No 1 on/off
hydraulic pump No 2 on/off
hydraulic pump No 3 on/off
dog clutch engaged
pressure selection for pump station
buzzer off

An example of the dual operation of the function keys is as follows:

SCREEN 1 chain stopper open F9

SCREEN 2 hydraulic pump No 1 off F9

Using this installation it is important, therefore, that the operator is aware at all times through which screen interface he/she is currently operating.

The analysis

This incident was the direct result of human error in opening of the chain stopper, which was activated from the bridge. This human error was the primary factor in the release of the vessel from its mooring. The operator most likely meant to turn off a hydraulic pump, but had the wrong screen for this task displayed. Without looking at the screen for verification that it was the correct screen, the operator depressed the function key and the chain stopper “open” command was sent. Alternative, but similar causes of the release of the chain stopper proposed in the incident report are that the operator could activate the chain stopper release in error while trying to silence one of several routine engine room alarms sounding on the bridge, or by accidentally depressing the emergency mooring release button, as this button was not covered.

The chain stopper claw would have opened sufficiently to allow movement of the chafing chain within 2 to 3 seconds of the start. Allowing for a system change delay of about 1 to 2 seconds, any immediate error correction is unlikely to prevent the claw opening enough to allow chain slippage. Allowing for the slackness in the pickup rope, there would be a forward movement of about 2 to 3 metres. This would be sufficient for the chafing chain to pull clear of the chain stopper.

The MAIB report stated that one of the key requirements of a control station is that it, together with the equipment within it, is ergonomically designed to minimise the risk of error during operation. The design of the control system on-board the Randgrid, whereby the same function key controls two different but interrelated systems, depending on what screen level is selected, did not meet this key requirement.

Anecdotal evidence from many shipboard users of screen-based distributed control systems (DCS) indicates that many of these systems have confusing graphical user interfaces (GUIs).

2.2.3 Grounding of HMAS Ballarat (description of incident taken from a news report)

The circumstances

On 22 January 2005 the Royal Australian Navy's newest \$500 million warship was driven backwards onto Christmas Island after crew error caused computers to take control of the frigate [6]¹. A series of human errors prompted the computer control system to over-ride the manual commands being given by the ship's officers. The ship's company then had to stand by and watch as HMAS Ballarat backed onto the rocky shoreline.

The incident damaged both propellers and the rudder, with the cost of repairs in the order of \$2 million. The incident began when the ship was conducting a boat transfer during a planned U-turn manoeuvre. It was operating in "port echo" or economy mode at the time. The manoeuvre was supposed to take the warship inside a buoy that had another ship's mooring line attached to it. As the ship approached the buoy it became clear to the crew on the bridge that it would not make it and would pass over the line, so they attempted to make an emergency turn.

Because the ship had only one of its three engines running, the crew tried and failed to run one propeller forward and one astern to conduct the emergency turn. Such a move is impossible with just one engine running. At this point the control system froze, the ship's computer took over and placed both propellers into reverse. It shut down the engine soon afterwards, but by that stage the ship was travelling in reverse at a couple of knots and ran aground.

The analysis

This incident highlights the problems that can arise when a vessel's crew are unfamiliar with the operation of a complex control system and unaware of the automatic actions the control system is programmed to take following a set of circumstances that initiate the control systems built in "failsafe" functions.

2.2.4 Collision of the "Bright Field"

The circumstances

On December 14, 1996, the fully loaded Liberian bulk carrier *Bright Field* temporarily lost propulsion power as the vessel was navigating outbound in the Lower Mississippi River at New Orleans, Louisiana [7]. The vessel struck a wharf adjacent to a populated commercial area that included a shopping mall, a condominium parking garage and a hotel. No fatalities resulted from the accident and no one aboard the *Bright Field* was injured; however, 4 serious injuries and 58 minor injuries were sustained during evacuations of shore facilities, a gaming vessel and an excursion vessel located near the impact area. Total property damages to the *Bright Field* and to shore side facilities were estimated at about \$20 million. This incident raises the issue of the adequacy of the ship's main engine and automation systems.

The *Bright Field* owners' oversight of testing and maintenance of the vessel's engineering control systems was inadequate and led to unreliable performance of the engineering plant and contributed to the shutdown of the main propulsion engine on the day of the accident.

According to statements from the Chief Engineer and other engineering crewmembers, the normal practice for the *Bright Field* while operating in restricted waters was to have the No. 1 lubricating oil pump running and the No. 2 pump on automatic standby and that the vessel was operating in this configuration on the day of the accident. On January 4, 1997, Safety

¹ Caveat: This description of the HMAS Ballarat incident is taken from a news report rather than an official statement or investigation report.

Board investigators tested the oil pump automatic changeover feature by reducing the lubricating oil pressure sensed by the device. During these tests, the pressure switch failed to activate the standby pump. The original pressure switch was removed from the vessel for laboratory testing. Test conclusions were that, “the contact resistance is abnormally high,” and could, under certain conditions, “cause a problem; i.e., giving erroneous ...or faulty readings.” The probable cause of the main engine trip that led to the incident was the failure of the standby main engine lubricating oil pump to start automatically following a partial loss of lubricating oil pressure from the running main engine lubricating oil pump. When this standby pump failed to start, because of the faulty pressure switch, the loss in main engine lubricating oil pressure was sufficient to initiate the automatic main engine low lubricating oil pressure trip.

The analysis

The poor maintenance of the automatic control equipment on-board the Bright Field was one of the root causes of this incident. Maintenance and calibration errors when setting up control systems can lead to catastrophic consequences.

It was a poor risk management culture within the shipping company that led to the errors in maintenance and calibration of essential automated systems.

2.3 Other automation issues identified from maritime literature review

2.3.1 Inconsistency in automation design

Although performance standards exist, many bridge systems, engineering consoles and cargo systems vary greatly in their user interface (layout of controls, displays and symbology) and functionality beyond what is required as a minimum (added features requiring extra controls, menu options or customised symbology). The result of non-standardised controls and displays is an increase in the amount of training needed to make a seafarer familiar with and effective in, the use of the equipment [8].

The navigation, engine and cargo systems installed on merchant vessels can vary significantly from one ship to another. Variations in symbology, layout and presentation of data are common. For example, an Officer may be competent in the use of a particular type/make of integrated bridge; however when faced with a totally different system on-board another vessel, it may require a period of adjustment or familiarisation before a satisfactory level of competence is achieved. Greater opportunities for human error exist during this period, especially if accompanied by low manning levels [9].

Existing requirements include; SOLAS chapter V regulation 15 [10] (see Appendix B) that describes such features as bridge design, the arrangement of navigational systems and bridge procedures, as well as International Maritime Organisation (IMO) resolutions and recommendations. Examples of related incidents (see Appendix A) where ship-borne technological / automated systems may have been amongst the causal factors, suggests that these requirements are not sufficient; and, or sufficiently enforced.

The need for an overall standard for navigation displays has been recognised and is the focus of ‘Working Group 13’ set up in association with the International Electrotechnical Commission (IEC)’s Technical Committee 80 (Maritime navigation and radio-communication equipment systems) to examine ‘displays for the presentation of navigation related information’. Currently, the working group is drafting a technical standard to support the removal of current inconsistencies in the display of navigational information and provide harmonisation of definitions, abbreviations, units, symbols, colours and controls [11].

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At the Nautical Institute's 'Integrated Bridge and Navigation Systems' conference held in London in November 2002; Capt. Taylor, senior vice chairman of the International Marine Pilots Association, presented the case for 'information overload' for pilots, noting that;

"...at least each watch and sometimes several times in the same watch pilots will be presented with a new bridge layout and possibly radically different class and nature of vessel."

(Card, 2002.) [12]

The purpose of taking a pilot must be to strengthen the existing bridge team. This can be achieved only if the pilot integrates with the bridge team and each bridge team member continues to be involved to the same extent as prior to the boarding of the pilot. It is often noted that advanced integrated navigational bridges remain unused during pilotage, because many pilots lack the familiarity, technical knowledge and skills to use the equipment. Therefore it has been known for some Port Authorities to insist on the pilot being allowed to conduct the pilotage using traditional techniques. This is an unsatisfactory situation that defeats the purpose of having the equipment, reduces safety margins and is a potential cause of conflict between the pilot and the bridge team [13].

The development of the Portable Pilot Unit (PPU) potentially overcomes the problems relating to unfamiliarity. The PPU consists of a carry-aboard laptop computer linked to a Differential Global Positioning System (DGPS). This enables pilots to receive all important information via radio data, including radar, on their own computer screen. Using this system allows pilots to become accustomed to the technology and identify its advantages and disadvantages. Subsequently pilots become confident in using the system [12].

Although the PPU systems attempts to address the problems of unfamiliarity experienced by pilots, in reality the PPU system may not necessarily be usable. In order for the pilot to receive ship data such as AIS and Radar, the interfacing sockets / computer ports must be available and working. This is likely to be a problem considering the wide variation in age, type and make of equipment installed on merchant vessels. Therefore standardisation of designs is necessary to create an environment where seafarers and pilots, working within the natural constraints of their trades, can operate technological and automated systems safely and effectively.

The literature research suggests that little attempt has been made to help other seafarers with familiarisation problems. The issue of whether one standard can apply to all seafarers is another concern; ergonomics, anthropometric factors, cultural differences and even whether the users are left or right handed have an effect. It is felt that it may be impossible to design one system that fits all; however a balance needs to be achieved to suit the majority of the users. A simple common standard could help to overcome differences and increase usability [14].

Although compulsory retrofitting is a regulatory option and standardisation has received more attention recently within the industry, in general, any harmonisation achieved is likely to be more effective when applied to new technology. Retrofitting does bring its own disadvantages and therefore satisfactory standardisation is likely to be a long-term aspiration.

2.3.2 Poor design and layout of controls and displays

The P&O 'Roll on, Roll off' (Ro-Ro) ferry 'Pride of Portsmouth' collided with the moored frigate HMS St Albans, in Portsmouth harbour in 2002. The U.K. Marine Accident Investigation Branch (MAIB), investigation stated that the cause of the accident was human

error [15]. An incorrect helm order was given by the master resulting in the collision. Other factors that had an influence were the fact that the Master and bridge team were new to the vessel and may still have been unfamiliar with controls etc. Bridge Resource Management (BRM) was poor and the ergonomics on the bridge were lacking; rudder angle indicator was not clearly visible from the central conning position.

A major contributory factor in the cause of the 'Torrey Canyon' accident was because the autopilot lever was on 'disengage', perhaps due to an inadvertent knock by the helmsman. This meant that the ship had sub-optimal controls. Optimisation is where the displays and controls must be carefully designed to eliminate machinery-assisted error and be user-friendly [16]. Such accident investigations have illustrated that ergonomics can have significant qualitative consequences for human work with advanced technology and automation.

Anecdotes from the maritime domain describe how placing of a piece of equipment was described not by standards, rule or human factor requirements but by the length of electric cable available to the installer. On one ship, which was built as a containership in the 1960s, rebuilt as a cruise liner in 1990 and visited as part of a study in 2001, there were 15 different manufacturers' names on the navigation, control and communication equipment. This in itself leads to many inconsistencies for the mariner to overcome. Furthermore when new equipment is installed, in many cases the old equipment is left in its place, creating a cluttered, sub-optimal layout [17].

In a paper by Hadnett [18], written for the Royal Institute of Navigation, it was noted that ergonomic issues often affect where antennas, etc, can be mounted. It has been observed that Automatic Identification System (AIS) heading information transmitted by many vessels are often inaccurate due to misalignment during installation, as well as potential faulty input data from the compass and Global Positioning System (GPS) [18].

There has been a notable trend over recent years towards increasingly complex shipboard systems. Modern vessels now rely on a high degree of automation and supervisory control that adds considerably to the complexity of the total installation. The major driver for change has been to achieve greater competitiveness through reduction in through-life costs [19].

The options available to the systems designer have expanded as the capability of electronic and automated ship-borne maritime systems has increased. The possibility to develop systems with an increasing level of functionality encourages the design and construction of ever more complex systems. The downside of this trend is that the user is left with a system that may possess unnecessary properties; the resulting system may be beyond the understanding of the average, well-trained user. The situation is made more complex by the interconnection of systems using networking, so that the possible interactions and dependencies are no longer as obvious as with older non-automated systems [19].

A typical modern bridge arrangement, aimed at providing safe operation with a reduced bridge team, presents a high information load to the team. Since a human operator is unlikely to understand all the characteristics of the total hybrid system, it follows that the designer must ensure that the system hardware is usable by the average competent operator. Moreover, when the system is procured from many individual equipment suppliers the problems are compounded. Each supplier uses its own standards, particularly for user interfaces; the total system consequently lacks consistency. Often the user is left with manuals and instructions for the component parts and receives little assistance in understanding the operation of the complete system [19]. Further information on problems and incidents related to Integrated Navigation Systems and Integrated Bridge Systems can be found at www.maresig.org.

The Maritime Safety Committee at its seventy-third session (December 2000) adopted the Guidelines on Ergonomic Criteria for Bridge Equipment and Layout, which have been developed to assist designers in realising a sufficient ergonomic design of the bridge, with the objective of improving the reliability and efficiency of navigation. These guidelines have been prepared to support provisions of the revised regulations V/15 of the SOLAS Convention – ‘Principles relating to bridge design, design and arrangement of navigational systems and equipment and bridge procedures’ (appendix B). The guidelines cover factors such as, inter-alia; alarm management and display and positioning of information [20].

Process Contracting Limited, Human Factors Consultancy, published in 2004 a document referring to ‘Bridge Ergonomics – Anthropometric Consideration for ISO TC8 / SC5’. This document illustrates the variation in the physical attributes of seafarers and the measures necessary to ensure that satisfactory bridge ergonomics are achieved [21].

It may appear obvious that systems must be usable by seafarers, but this demands more than the systematic conformance of the working environment to ergonomic principles. Having said that, there are examples of modern ships where the background noise, vibration and lighting levels do not provide an ideal working environment for the crew. It is possible for the basic ergonomic requirements of the installation to be addressed but for the system to become unstable under certain circumstances, notably during abnormal operations and emergencies. The design of bridges and control rooms should reflect the operating procedures, both routine and emergency and suit the characteristics, capabilities, experience and training of the crew. Errors can often be traced back to a misunderstanding of the information supplied by the machine interface or to an overload of information, rather than a mistake in operation per se [19].

When advanced systems and automation fail, the operators need to revert to manual systems; this can be problematic. Automated ships are often not well designed for manual operation and mariners can also be unfamiliar with the manual systems; the reduced manning levels typical of modern ships may mean that crews are not physically capable of operating the system manually [9].

SOLAS chapter V, states that:

“In case of failure in one part of an integrated navigational system, it shall be possible to operate each other individual item of equipment or part of the system separately.” (International Maritime Organisation, 2004) [10]

Unfortunately, not all advanced, automated or integrated systems on-board can be operated separately; the major concern is that many vessels today cannot be operated manually if the automation fails. Vessels in the past have traditionally been built with manual bypasses, which can be used to get the vessel safely home if the automation fails. An example would be the new common fuel rail slow speed engines that do not utilise a camshaft. If the engine computer fails the engine cannot operate and there is no way of bypassing the computer. The only way to remedy the problem is to fix it; there is no other option. The major challenge and responsibility for the modern seafarer are constantly to upgrade and renew their training. Having personnel on-board who are competent and able to repair complex systems is a requirement in today’s modern vessels [9].

2.3.3 Human-system interaction issues

It is apparent that the marine industry is undergoing the same evolution in automation as the aviation and other transportation industries. Accidents involving automated systems, like the

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grounding of the 'Royal Majesty', highlight the importance of considering the abilities of the human operator in automated systems.

The U.S. National Transport Safety Board concluded;

Automation is becoming more prevalent on commercial ships, affecting such areas as engineering, bridge and cargo operation. When designed properly and used by trained personnel, such automation can be helpful in improving operational efficiency and safety. However, when designed poorly or misused by undertrained or untrained personnel, automated equipment can be a contributing cause to accidents.

(National Transport Safety Board, 1997). [4]

In a study of 100 marine casualties, published by the U.S. National Transport Safety Board (NTSB) inadequate knowledge about equipment was found to be a contributing cause in 35% of the casualties. Lack of training is not the only problem. Poor equipment design can induce the mariner to make mistakes. In the same study, one third of the accidents were found to be caused partly by poor human factors design of the equipment (National Transport Safety Board, 1997. Online).

When humans and technology have to work together, the human has to coordinate resources, cooperate with devices and compromise between means and ends. What mariners have to integrate as part of their job includes: representations of data and information, rules, regulations and practise. What the developer and manufacturers of the systems choose to integrate into the screens is not always what the mariner would choose [17].

Similarly the NTSB investigation into the Royal Majesty accident noted that inadequate training and poor human factors design are often the result of applying a technology-centred philosophy to automated systems. This approach seeks to replace mariner functions with machine functions without considering the mariners' capabilities and limitations. As a result, the approach has the effect of leaving the mariner without meaningful control or active participation in the operation of the ship. A human-centred philosophy towards automation recognises that the mariner is the central element in the operation of the ship. Consequently, the philosophy emphasises designs that fully utilise human capabilities and protect against human limitations, such as unreliable monitoring and bias in decision making. [4]. Although this principle may appear obvious, implementing such a philosophy is easier said than done.

Despite the plethora of maritime studies, the topic of integration has received little attention and when it does, the strategies usually suggested to improve work on the bridge are to add more technology and increase automation. One equipment manufacturer at the Nautical Institute's 2003 Integrated Bridge Systems and Human Element conference said:

"Officers perceive integrated bridge systems as 'scary' but the individual components are the same as before, the system is easy to use." [17]

If some officers perceive integrated bridge systems as scary, it would be more valuable for the manufacturer to find out why. Many problems experienced with technological systems today are perceived by designers and engineers to be of a technical nature; consequently they are translated into design solutions. This philosophy does not appreciate the role that cognitive and social factors play in the 'end user failure'. Technology alone cannot solve the problem that technology has created [17].

Research used by the IMO for STW 34/INF.6 “Issues for training seafarers resulting from the implementation of on-board technology” indicates that humans are poor monitors of automation and operators will monitor less effectively when automation is installed and even more so if it has been operating acceptably for a long period of time. Evidence also suggests that the more robust a system is in its design to prevent human intervention, the more difficult it is to have knowledge of and control of what is going on inside its boundaries. Under these circumstances, the human operator has no means of checking the accuracy or fidelity of instrument readouts and thus may well revert back to heuristic decision making [22].

The crew of the ‘Royal Majesty’ knew that when the chart on the radar screen was ‘chopping’ (jumping), this meant it was unstable and not to be trusted. Consequently when there was no chopping they believed that the radar chart must be safe and stable. Unfortunately this assumption was incorrect. [4].

Trust in technology is an important factor influencing the impact of automation in safety-critical systems. Trust is defined here as confidence or reliance upon the actions or information of another in an exchange. Technology that is reliable, accurate and useful may nevertheless not be used if an operator believes that it is untrustworthy. Initially, user’s trust is dynamic and will change depending upon user experience with the automation. Users will weigh each experience with the technology differently, depending upon the “risk” involved. The result is that trust will affect the way in which operators use technology and automation [23].

A variety of factors can influence an operator’s reliance on automation, including; the system’s accuracy and reliability; the complexity of the tasks being supported; the operator’s workload, skills and abilities; operator’s perception of risk in the system and their trust in the automation; as well as the nature of the environment in which the automation is deployed. Other contributing factors to the reliance on automation may be the ease with which failures can be detected and the ability for the automation to be enabled and disabled [23].

Trust in automation is not always advantageous; in fact some technology can be over-trusted, in the sense that operators may come to rely uncritically on it without recognising its limitations, or failing to monitor its inputs. Automation trust can lead operators to erroneous conclusions, to rely on single sources of information and fail to monitor displays and instruments; as cited by maritime accidents such as the ‘Royal Majesty’ grounding in 1995 [23].

If the ‘Royal Majesty’ accident illustrates one thing about automation, it is that increasing automation to reduce the influence of human weaknesses can be limited. Automation is not a panacea for removing human error at a stroke. Automation creates new human weaknesses and it amplifies existing ones. Human error does not vanish; automation changes its nature. The more autonomous the machine, the more the consequences of error get displaced into the future, further compromising opportunities to recover. The question for successful automation is not “who has control”; giving the automation more control as technological capability grows or economic imperative dictates; the question is “how do humans and automation get along together”. What designers need guidance on today is how to support the co-ordination between people and automation. The key to a successful future of automated systems lies in how they support co-operation with their human operators, not only in foreseeable situations, but also during novel, unexpected circumstance [24].

2.3.4 Training issues

IMO guidelines [8] recognise that automation has qualitative consequences for human work and safety and does not simply replace human work with machine work. Automation changes the task it was meant to support; it creates new error pathways, shifts the consequence of error further into the future and may delay opportunities for error detection and recovery. Automation creates new kinds of knowledge demands. Operators must have a working knowledge of the functions of the automation in different situations and know how to co-ordinate their activities with the automated system's activities. This manifests itself in situations whereby seafarers do not understand the weaknesses or limitations of systems they rely upon. Training in this respect will become more important as systems become more integrated and sophisticated.

The competence-based approach at the heart of the 'Standards of Training, Certification and Watchkeeping of Seafarers' (STCW) convention seeks to identify those skills that are key to safe and efficient shipboard operations. The convention does not and could not, identify all of the myriad of competences that are required in every situation on every type or size of ship. It concentrates on the core competences and establishes the specification of the minimum international standard for those competences. The training requirements in the STCW convention almost certainly require amplification to meet the demands of many sectors of the shipping industry and undoubtedly lag behind the technology [25].

Protection & Indemnity (P&I) Club experience shows that maiden voyages are often times of high risk, presumably because of relatively untried equipment with which the operators are unfamiliar. The same is often noted after a refit [26]. In general the shipping industry is not keen to spend more money than necessary on training; consequently where the money is not invested, crews are often not adequately trained in relation to the new equipment [9].

There are many challenges encountered when assessing the training needs for seafarers in using technology-based systems on-board; some are cultural and others are practical, but these issues need to be addressed if seafarers are to be able to utilise technology-based systems on-board to make good decisions.

The IMO STW sub-committee, 34th session, agenda item 13; 'Issues for training seafarers resulting from the implementation of on-board technology' highlighted that, in many cases, crews of new ships or ships fitted with new equipment may be trained ashore in accordance with a manufacturer's recommendation or model course criteria, but those initial crews may be required to train their reliefs, in situ, in the proper use of the equipment. This procedure is often known as 'cascade' training. This leads to a situation where the initial crew might receive 3—5 days of specialist training for a system, but are required to pass this knowledge on to other watchkeepers during a brief turn-around period in port. Additional aids such as Computer Based Training (CBT) modules, used either on-board or prior to joining a ship have the potential to improve the situation. Technical manuals can, however, be poor training tools. The issue of who should bear the costs of developing equipment specific training (simulators, CBT or book based) is a further problematic issue [8].

At the Nautical Institute's conference on 'Integrated Bridge and Navigation Systems' held in London in 2002, concerns about training were high on the agenda. There was a consensus that an Integrated Bridge System (IBS) will require as much training as when the equipment is used in its separate parts. Some delegates suggested that it would require more.

Type-specific training was one suggestion, with many believing there should be a statutory requirement for training of the various new technologies on the bridge, particularly Electronic Chart Display Information Systems (ECDIS). Some believed that this training should be obtained from the manufacturer while others thought it should be up to the owner to invest more in additional training [12].

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Because technologies such as ECDIS are not a carriage requirement under regulation 19, Chapter V of the 'Safety of Life At Sea' (SOLAS) convention [10], this has an effect on the provision of statutory training. Training for many new technologies is not covered by 'Part A' of the STCW code; it is usually incorporated into 'Part B', which is non-mandatory 'recommended guidance', if at all. Therefore many new technologies are not subject to mandatory training. The IMO model courses can be valuable guidance for training in the use of these systems; however the industry often makes its own interpretation [9].

The Nautical Institute's conference also highlighted the importance of training in relation to a perceived 'dumbing down' of seafarers, with some delegates questioning whether technologies such as ECDIS and AIS were too difficult for seafarers to use. Captain Peter Woods noted that;

"Little thought appears to have been given as to how such large amounts of information can be managed. High technology equipment is often placed in the hands of watchkeepers who have had no training in the equipment they are expected to use. In many cases watchkeepers are not even computer literate."

Card, 2002. [12]

The Nautical Institutes conference emphasised that although there is a necessity to train in new technologies and automation, effective basic training should be the initial focus of future training programmes [12]. Although this may be true, the investigation into the 'Royal Majesty' grounding determined that the officers were familiar with the basic operation of the automated navigation equipment, but no one appeared to be fully proficient with the systems; illustrated by the lack of knowledge about the GPS receiver's Dead Reckoning (DR) mode capability. The crews' automated navigation equipment training consisted mainly of 'on the job' training; the type that the industry has historically relied upon. Since the introduction of sophisticated technology and automated systems, 'on the job' training alone is unlikely to be sufficient [4].

Technology on-board merchant vessels has increased the quantity of information available to the seafarer, thus increasing the task of managing the information. The information on the bridge of a ship can include information pertaining to navigation, collision avoidance, communication, cargo, engineering, ship management, ship safety and security. A single watchkeeper will have great difficulty monitoring this quantity of information. Training in information management is essential; information overload is a significant hazard [8].

The IMO guidance for the operational use of IBS highlights the need for operators to have adequate knowledge of system functions for 'mode awareness', 'situation awareness' and 'workload management', in addition to traditional seamanship. These skills apply equally to engine and cargo control systems.

Often rules and regulations lag behind technology and when this happens, mariners have to devise work strategies themselves [17]. A small number of accidents have occurred as a result of failures in operational procedures on ships with automated cargo control systems; an example of which is the 'Coral Acropora' accident in August 2004 where a tank was overfilled leading to loss of cargo.

These accidents are essentially the result of the following failures:

- Alarms accepted but not cancelled - in some systems this results in the disabling of audible alarm indicators; future alarm conditions go unnoticed.
- Reliance on remote digital read outs - if gauges stick or sensors malfunction the absence of on site checking, particularly during topping off operations on

tankers, inevitably leads to problems such as over-filling or over-pressurisation of cargo spaces.

- Deviation from set procedures - many systems require actuating events to occur in strict sequence, variation from this often leads to unforeseen effects, such as the wrong set of valves being opened or closed, or safety interlocks being bypassed.
- Erroneous assumptions concerning system characteristics - some cargo control systems, including automated shut down arrangements, may vary widely from ship to ship and with the type of cargoes carried. Accidents may occur if the officers in charge of loading and discharging the cargo are not completely familiar with the control and emergency arrangements of each system.

These findings indicate that it is imperative for seafarers who are operating automated and computerised cargo control systems, to receive thorough training in the limitations and operational use of such systems [27].

Bainbridge identified in a paper 'Ironies of Automation' that; if there are frequent alarms throughout the day then the operator will have a large amount of experience of controlling and thinking about the process as part of normal work. Perhaps the final irony is that the most successful automated systems, with rare need for manual intervention, may need the greatest investment in human operator training [28].

The literature reviewed indicates that new technology and automation, whether on the bridge, in the engine room or for cargo operation, requires seafarers to possess a modified knowledge and skill set. Training is a strategy for mitigating human error with automated ship-borne maritime systems; however current training for new technology does not appear to be particularly effective at developing competent operation [9].

Although training is a significant factor it cannot be viewed in isolation. A quote by Bell, D, 2000, in the Marine Engineer's Review is very apposite:

"...in short, a badly designed interface encourages mistakes that no amount of training or management intervention can completely mitigate."

Bell, 2000 [29]

2.3.5 Risk Homeostasis

There has been a notable trend over recent years towards increasingly complex shipboard systems. Modern vessels now rely on a high degree of automation and supervisory control that adds considerably to the complexity of the total installation. The major driver for change has been to achieve greater competitiveness through reduction in through-life costs [19].

Risk homeostasis relates to a perverse situation where improvements in system safety have a tendency to be cancelled by increased risk taking in other activities of the system. As an activity is made safer, system factors can conspire to make it riskier, e.g. by conducting the task faster to improve productivity. Perrow [30] makes the point that whilst technology may confer safety advantages, the same technology is seen to encourage increased speed and risk-taking in the face of production pressures and hence effectively erode any increased safety advantages. One instance within the maritime industry relates to the use of navigational instrumentation:

Instruments for course keeping, position finding, depth recording, have all improved very considerably over the last several years and the twin radar sets now commonly fitted in tankers mean that there is data readily available on the position of all other vessels in contact, regardless of visibility; yet ships continue to collide, to strand and occasionally to founder. It appears that one must conclude that improved instrumentation is being used to enable navigators to prosecute their voyage with greater economic efficiency and certainly with greater ease, but the risk per ship would seem to remain about constant.

Captain A. F. Dickson, "Navigational Problems (Tankers)". International Tanker Safety Conference (London: International Chamber of Shipping, 1971, 2).[31]

The effects of risk homeostasis may conversely reduce overall system safety in some cases and increase risk unnecessarily if it gives rise to mistaken beliefs concerning its efficacy. For example, Gardenier [32] studied the effectiveness of Collision Avoidance Systems (CAS) on preventing a corpus of collision accidents. From a large sample of ships and assuming favourable conditions (i.e. CAS working correctly and correctly interpreted by the operator), Gardenier calculated that only 13.1% of the collision accidents would have been prevented with CAS. Whilst a reduction of this magnitude could justify the installation of CAS, the problem arises when higher operating speeds are adopted by ships fitted with CAS in the mistaken belief that CAS will effectively resolve many more potential collisions than in actual performance.

2.3.6 Organisational Factors [2]

Organisational factors play a significant part in accident causation. The analysis of human factors in accident causation is still relatively immature in the maritime world. Although databases held by the MAIB and other parties interested in the causal factors of accidents – e.g. insurers and classification societies – do include human error taxonomies, little analysis is undertaken to identify trends or patterns. Even less analysis has been attempted in assessing the significance or frequency of organisational factors such as the incidence of commercial pressure or the effects of organisational culture on accident causation.

The differences in organisational culture between shipping companies are a well known phenomenon, but there has been little work on understanding the effects of organisational culture on safe and efficient performance. In much the same way as we are striving to identify a set of behavioural markers to assess the competence of individuals, so there is a need to establish a set of organisational metrics to determine the competence of shipping companies to perform safely.

Not enough is known about the parameters governing functioning and performance of management systems. There is little research evidence to indicate what makes a management system work or indeed what prevents it from working. Equally, not enough is known about the metrics that enable the status of a management system to be determined. Ideally, what is required is a set of "leading" indicators that will predict future performance so that interventions can be made before accidents occur.

2.4 Automation issues identified from other industries

In instances where there is poor installation of automation (in the majority of cases, through poor awareness of human element factors), there is a risk of detrimental consequences. The detrimental effects of automation are discussed below.

2.4.1 Out-of-the-loop syndrome

Operators monitoring automated systems commonly have diminished capability for detecting failures and problems and have a reduced capability to intervene effectively when operator intervention is required (e.g. in event of automation malfunction).

Endsley *et al* [33] proposes the following primary mechanisms whereby the out-of-the-loop syndrome occurs:

- Changes in vigilance and complacency associated with monitoring,
- Assumption of a passive role against active role in processing information for controlling the system and
- Changes in the quality or form of feedback provided to the human operator.

Wickens [34] proposes that a further cause of the effect is the exponential increase in the number of variables that need to be monitored (i.e. operators must monitor the automated systems in addition to the parameters of the original task), combined with the inevitable increase in system complexity through the proliferation of system components.

2.4.2 Mode blindness and automation understanding problem

Commonly operators experience difficulties in understanding the automation's current activities. Endsley [33] attributes this to the inherent complexity in automation, poor interface design and inadequate training.

Mode blindness occurs when the human operator incorrectly perceives the current mode of the automation and therefore incorrectly understands display values and ascribes the wrong actions to multi-function controls (e.g. the 'function' keys found on personal computer keyboards). One example of a mode blindness error already discussed is the case of the 'Randgrid' (see Section 2.2.2); the operator believed he was on a different computer operating screen from the actual screen and therefore ascribed an incorrect action to the function key.

Automated understanding problems commonly arise because the state of the automation and its current functioning are often poorly presented through the system display. Additionally, the display of projected (i.e. near future) equipment actions can be insufficient or absent altogether.

2.4.3 Decision support dilemma

Decision-aiding automation can inadvertently interfere with the operator's attention and information evaluation processes, i.e. automation can interfere with the human's normal decision making process. In the worst cases, *expert systems* or *decision support systems* may not only fail to deliver any improvement to human decision making, but may also lead to decision biases resulting in an increased probability of making an error (when the decision support system is wrong) compared to a condition of no system advice. Endsley [33] concludes there is evidence to suggest that operators are not conducting decision making independently of the decision support, but rather are highly influenced by the decision support advice. One approach that appears to side-step the programme is the use of critiquing systems that provide advice to operators *after* they have made a decision [35].

2.4.4 Skill fade

The long term consequences of human operators being removed from direct control of a system is typically a loss of proficiency in the skills required to exercise control. This is

particularly true of the aviation industry, where high degrees of automation have meant that the skills pilots need to intervene when there are failures associated with automation are often in danger of being degraded through lack of application and use (i.e. skill fade or de-skilling). Furthermore, the pilot can often be disoriented when called upon to intervene with relatively little notice. Long periods of passive monitoring can make operators unprepared to act in emergencies.

2.4.5 Explaining the causes of automation confusion and misunderstanding

Automated systems often perform tasks and conduct decision making in a radically different way from their human counterparts. Mosier notes [36] that automation expends fewer resources on gathering information from the environment (i.e. situation assessment) than humans and greater resources on choosing between alternative actions. As a result, humans are more adaptable in generating, monitoring and modifying plans in response to feedback. By comparison, the automation's relatively small repertoire of information inputs has led some to describe automation as the 'novice' stage of human expertise development [37]. Automated systems are based around rule-based reasoning (e.g. If event X, then action Y) based upon an atomistic perspective of the situation, whilst human experts attempt to understand the situation as a whole (i.e. gestalt approach), allowing humans to take account of non-analytic factors in arriving at a decision.

Unfortunately, the users of automation are largely unaware of these significant departures between automation and human approaches to operating. This is commonly exacerbated by poor interface design, inadequate training and lack of familiarity. As a result, many users of automation have misguided notions of what the automation can and cannot be expected to do [38].

Mosier identifies five myths of automation that are commonly held by their human operators:

Myth One: Automated decision aids can make experts out of novice users.

- Automation focuses on monitoring a relatively small set of factors, compared to the human expert.
- Automation can give novices much greater confidence in decisions than is warranted. Inexperienced human operators are likely to lack the knowledge to recognise the limitations on automation.
- Automation can prevent the novice user from gaining the experience necessary to develop expertise (e.g. by unwittingly hiding cues in the environment required to recognise a situation).

Myth Two: Humans can easily ignore automation and revert to using traditional cues in the outside environment.

- Automation changes the way that humans make decisions. Humans learn that the automation is the 'best cue' for making a decision and therefore will check the automation in preference to traditional cues, especially when time is short.
- Automation is designed to be salient, difficult to ignore and quicker in operation than traditional methods. The ready availability of information will satiate the 'satisficing' nature of human decision making (e.g. humans will take the route of least mental effort).
- Automation may diminish human operator access to traditional cues (e.g. vibration cues in diagnosing machinery state).

Myth Three: Automation aids take into account more factors than human experts.

- Automated aids only take account of factors they have been programmed to compute; otherwise automated aids are blind to the context.
- Automated aids offer consistency, accuracy and speed on the set of factors they have been programmed to compute and therefore give the impression of greater competency than human experts.

Myth Four: Human experts can tell when automation is in error.

- Research has found that human experts are no more likely than novices to spot flaws in a defective automation aide, although they do express greater confidence in the 'wrong' answer [38].
- Automation provides poor feedback on its activities [39]. The most common reported queries pilots have on automated glass-cockpit flight systems are 'what is it doing?', 'why is it doing that?' and 'what is it going to do next?' [40]
- Humans are recognised as being poor monitors of infrequent and unpredictable events, especially the longer they are on station.
- Long term extensive use of automation denies experts the opportunity to exercise their skills, leading to deskilling [41].

Myth Five: Ultimate responsibility for decisions remains (and should remain) with the human operator.

- In the vast majority of instances, automation is correctly perceived to be the most efficient way to make decisions, especially under conditions of high workload.
- Explicit reasons for installing automation include reducing human error and manning requirements; therefore, by installing automation, the organisation can be said to be conveying the message that the automation *should* have primary responsibility for decisions.
- Increased introduction of automation subtly erodes the role of the human in decision making, fostering an abdication of responsibility. Deskilling of the human operator undermines their capability to judge when automation is malfunctioning and to competently monitor the automation. [42]

2.5 Summary of automation issues identified

A number of human element issues can be derived that are related to the way in which ship's crews interact with automated ship-borne maritime systems. These issues are detailed below:

- There is sometimes an over-reliance in the automation by the ship's crew leading to a false sense of security that the automation will always handle the situation safely;
- Ship's crews are often over confident in the data presented to them by automated control systems and this leads to a lack of crosschecking of data;
- There is often a lack of understanding by the ship's crew of automated control systems and any inherent weaknesses they may possess;
- Automated ship-borne maritime systems do not always have the best ergonomic design considerations.

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- On some screen-based automatic control systems, the human-computer interface can be very confusing to the user.
- Due to the inherent latency in some control systems, it may not always be possible to recover an error, even if it is very quickly realised.
- Serious consequences can arise if ship's crew are unaware of the failsafe actions that a control system can take automatically following an operator error.
- Maintenance and calibration errors when setting up automatic control systems can lead to catastrophic consequences.
- Some current automated systems do not adequately augment the situation awareness of the system operators.
- A typical modern bridge arrangement can present the crew with information overload issues.
- Poor bridge design and ergonomics can have detrimental effects on human performance and increase the incidence of human error.
- Inconsistencies exist in the display formats of Navigational Information between manufacturers. Greater standardisation is required.
- Human operators rarely understand all the characteristics of automated systems; system weaknesses and limitations can remain hidden from the operator.
- Designers do not design automated systems with the range of competence of the automation user community in mind.

2.5.1 Development of a taxonomy of human element issues

In order for these to be translated into a taxonomy of human element issues related to automated ship-borne maritime systems a more extensive analysis of accident and incident primary data would need to be undertaken. In the case studies used above, the causal link between the incidents and human errors related to interactions with automated ship-borne maritime systems are very clear. In many other incident and accident reports, the only way such causal links could be established would be through the analysis of primary data sources. The current taxonomies and investigating philosophies used by maritime incident investigating authorities for categorising incidents are inconsistent, which can lead to the failure to establish the complete causal chain of some incidents. This in turn could mean that, for some incidents, where human error related to automated systems was a causal factor, this is not being clearly established. Currently it is suspected that incidents and accidents that have human errors related to ship-borne automated systems are being categorised using limited taxonomies, leading to these incidents being categorised using a causal factor "catch all" such as "loss of situation awareness".

It is therefore suggested that a much larger study of maritime incident and accident primary data sources be undertaken in order to develop the human element issues raised above into a detailed taxonomy to assist in the categorisation of maritime incidents and accidents.

3 Standards and guidance for addressing automation issues

The International Maritime Organization has itself produced some guidance relevant to the mitigation of human error in automated ship-borne maritime systems. During the 23rd session of its Assembly, it adopted a resolution [43] that provided the vision, principles and goals for the organisation with respect to the Human Element. This resolution calls for adequate safeguards to be in place to ensure that a single human error will not cause an accident. The application of this principle, during the development of regulations, standards and guidance related to the design, manufacture and utilisation of ship-borne automated systems, would help to ensure that such errors did not lead to accidents.

The International Maritime Organization, through a Maritime Safety Committee Circular [8], has also given specific guidance on the issues to be considered when introducing new technology on board ship. This circular gives guidance on the standardization of new technology, the training needs for seafarers using technology-based systems on board and taking the human element into account when introducing new technology. The IMO calls for the wide dissemination of such guidance by member governments.

Apart from the IMO, there are a number of other organisations that have produced standards and guidelines relevant to the mitigation of human error in automated ship-borne maritime systems and these will now be discussed.

3.1 Human Factors Integration plan

Human Factors Integration (HFI) plans provide assistance for managing potential human factors issues within the context of a procurement programme. The HFI plans include reference to user-directed activities including style guides to ensure consistency across human-computer interfaces and target-audience descriptions to assist designers in developing equipment compatible with the capabilities and limitations of the users.

3.1.1 Sea Technology Group publications

The Sea Technology Group publications (especially STGP 10 and 11) [44 and 45] advocate a Human Factors Integration philosophy to the procurement of maritime vessels. STGP 10 and STGP 11 outline an approach to the procurement of a naval vessel. The philosophy overview can be briefly described as follows:

- Devise a plan of Human Factors activities (i.e. Human Factors Integration plan) that support procurement of a new vessel or refit.
- The Human Factors Integration plan should provide a route map detailing the HF activities, when they occur, their purpose, inputs to the activity (including outputs from previous HF activities), method and steps and outputs from the activity.
- Begin conducting HF activities early in the procurement programme.
- Explicitly allocate responsibilities and identify stakeholders for HF activities.

The STGP prescribes the establishment of implications for automation at the concept stage using Human Factors Trade-Off Analysis. For example, the crew positions may become de-skilled through greater use of automation. Consequently knowledge vital to the successful management of equipment may become diluted.

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The guide recommends the following to ensure operability of systems:

- Users should be presented with a common working environment defined in a Human Factors Style Guide. For example, display features and symbology should be used consistently and control devices and actions should be standardised to ensure a high degree of interoperability across the system.
- The design of equipment interfaces should support the user during recovery from system failures.

Furthermore the guide makes the following observations on marine engineering equipment. Marine engineering equipment must be highly operable. The equipment interface to the platform management system needs to be developed to be compatible with the operating demands placed upon it, the task context and the needs of the users. The task context will concern vessel control and the generation and distribution of power. Emphasis should be placed on the safe execution of tasks rather than the speed and accuracy of performance. The following design issues are relevant to the operability (i.e. ease of operation) of platform management systems:

- The Human Factors Style Guide for platform management should include marine engineering conventions and symbology, whilst following basic display and control rules used consistently across all control systems (e.g. bridge systems) to improve interoperability.
- A platform management alarms and warnings policy should be applied within the context of the whole vessel. A large number of variables can go out of range in the platform management system and the alarms and warnings need to be considered.
- Operation of systems needs to take into account reversionary modes. The operator should always be informed in which mode he is operating.
- Manning levels reduced through the predicted enhanced capabilities of platform management systems need to be of sufficient size to ensure that:
 - Alarm avalanches can be handled within a shift team.
 - The operating team can deal with simultaneous failures in several vessel services.
 - Improved automation does not lead to user de-skilling.
 - Situation awareness is maintained so that the user can intervene following a failure.

User capabilities and the tasks to be performed must drive the basic requirements for physical displays and control devices. For display devices, screen size, colour capability and resolution must be appropriate. Control devices must be usable in the range of conditions experienced on-board vessels and be appropriate for the speed, accuracy and other characteristics of the tasks to be performed.

If the interface uses a “windows” software operating environment, a careful balance is needed to balance the flexible use of windows against the need to preserve displays in consistent locations on the screen without occlusion of important data. The design process therefore needs to identify how windows can be organised and provide default arrangements appropriate to the tasks facing users.

Consistency is a central requirement for achieving operability and interoperability. The guide identifies three types of consistency that should be strived for:

- Internal consistency – use the same display and control types for similar functions within equipment e.g. the operation of valves using the machinery control and surveillance system should be consistent across different platform systems.
- External consistency – the same control action on different equipments should be achieved in the same way e.g. acknowledging an alarm on the bridge system or the platform management system.
- Cultural consistency – use of display formats or control types should meet accepted conventions e.g. move control forwards to increase revolutions.

A Human-Factors Style Guide is required in order to document the general principles for operability (consistency, compatibility between control actions and effects, co-location of controls and displays etc.). The style guide also describes the conventions used for each display and control element (shape, colour, digital read-out, scale etc.).

Equipment interface prototyping with representative subject matter experts, e.g. instructors, should be performed to test the operability and the validity of the various displays and controls provided.

The STGPs also provide support to ensuring the compatibility of equipment to the capabilities and limitations of the users through the Crew Characteristics technical area. Specifically, a Target Audience Description (TAD) document is produced to provide a repository for information on the following user characteristics:

- Body size and strength (anthropometric) characteristics
- Physical skills
- Knowledge and mental skills
- Educational background
- Experience

Whilst the resources involved in producing a TAD may be prohibitively expensive for all but the most expensive maritime procurement projects, there maybe scope for the industry as a whole to consider the production of generic TADs to describe the major categories of seafarers. Such readily available information may encourage automation designers to consider more fully the requirements of the users.

3.1.2 American Bureau of Shipping Guidance notes on Ergonomic Design of Navigation Bridges

American Bureau of Shipping (ABS) has constructed ‘Guidance notes on Ergonomic Design of Navigation Bridges’ [46]; the majority of the guidance is similar in nature to that produced by IMO [20] and incorporated into SOLAS V. However, ABS has also produced guidance relating to ship bridge procedures for human interaction with automation. Section 3.6.2, states that the following principles should be applied to ensure compatibility among the bridge staffing complement, the task to be performed, the environment (time of day, weather conditions, congestion of waterways, etc) and bridge design and its automation.

- i) Determine staffing for all modes of operation, based on high workload operations.
- ii) Consider whether staffing levels, skills and experience will be sufficient for all known operational and failure conditions.
- iii) Consider staffing implications for worst-case scenarios

- iv) Consider staffing for normal conditions.
- v) Allocate tasks according to skills and experience.

(American Bureau of Shipping, 2003) [46]

The above principles when incorporated into bridge procedures should help to prepare for unforeseeable situations and mitigate their effects. If such principles were implemented on-board, it is likely that human error in the use of automation would be reduced.

In its own words, the guidance this document provides is:

1. *General ergonomic design guidance* (design principles) for navigation bridges;
2. *Specific bridge design guidance* gleaned from international sources, such as the International Maritime Organization (IMO) and the International Association of Classification Societies (IACS);
3. A *process* to identify individual vessel bridge requirements to guide application of ergonomic design principles.

Potentially the most interesting section is the final section which comprises a 'New bridge design process' and 'Processes for improving design aspects of existing navigation bridges'. The latter, however, is somewhat disappointing in terms of what it offers. The section on 'New Bridge Design Process' describes a typical process, supported by suggestions for HF activities. The steps that are described include:

1. Requirements determination (what the vessel must do);
2. Functional analysis, allocation and task analysis (generally how it will do it);
3. Development of design concepts (specifically how it will do it);
4. Design validation (based on evolved concepts) and generation of build specifications

The guidance recommends consultation with the user community, development of task analysis, workflow analysis and HMI rapid prototyping, in addition to using HF specialists.

Whilst this guidance is not as extensive as the STGPs, nevertheless its appropriateness and relative brevity may make it more suited to adoption as recommended process for designing automation.

3.1.3 Identification of HF issues with COTS equipment

Selection and adoption of COTS (Commercial-Off-The-Shelf) equipment is a decision commonly based upon economic consideration. Adopting COTS equipment also has the advantage of allowing systems to integrate the latest technological safety systems, in comparison with bespoke systems where requirements to freeze the design specification may mean the technology utilised is older generation even before the system has been accepted into service (e.g. the rapid pace of Information Technology systems).

Systems that constitute a single COTS solution are easiest in terms of managing HF issues. By definition, the constituent parts should be well integrated by design and there should be greater consistency in HMI. The manufacturer can be questioned directly on the level of compliance to HF standards. By comparison, systems that consist of a number of COTS products from different manufacturers constitute a greater challenge to managing HF issues. Invariably, further work will be required to integrate the different COTS systems. HF issues may arise from the COTS equipment, the integration work, or a combination of the two.

The MOD provides some limited pointers on use of COTS equipment in procurement [47]. With major components of COTS contributing to the system, HFI analysis should be conducted before the COTS equipment is selected, since rectification of HF issues not caught early will inevitably involve costly equipment modification, or additional training and manning to accommodate poor design. The latter carries the risk that any savings from use of COTS may be exceeded by the lifetime costs of training and manning and overall human performance may still fail to reach anticipated levels. In general, the greater the extent of proposed COTS, the more important is the role of HFI in informing the selection decision. The following guidance is provided:

- Identify all HF issues prior to the selection of COTS equipment;
- Obtain evidence of human performance levels with the COTS equipment in the current operating context;
- Predict any human performance degradation (e.g. through reduced manning) within the new operating context;
- Identify the need for remedial action (e.g. modifications, additional items, changes to other systems, procedural work-arounds, modified training, additional skills) to guarantee the required human performance level with the proposed equipment;
- Identify the feasibility of the remedial action with respect to the organisational and manning implications necessary;
- Predict the full, lifetime costs of all the above.

Therefore, the adoption of COTS equipments without systematic consideration of the potential HF issues carries a high risk of introducing automation issues. The selection of COTS equipments purely on the basis of immediate financial savings without consideration of all implications (including the human element) should be strongly discouraged. Rather, the implications of the adoption of COTS equipment should be considered in a systematic manner, following the MOD process described above as closely as possible.

3.2 Standards and guidance from other high-hazard industries

3.2.1 Regulations and guidelines in other industries

It is quickly apparent from even a cursory familiarisation with existing regulations that the issue of automation is not often addressed directly by regulatory bodies, but more commonly, indirectly through human factors guidelines regarding HMIs and training requirements. Often the focus is on raising awareness, rather than prescriptive measures directed explicitly at automation issues. The degree to which automation issues are addressed directly to some extent reflects the levels of automation operating within a particular safety-critical industry. For example, the chemical and nuclear industries, in which the automation of processes has been an inherent part for many years, appear to have most directly relevant information. The rail industry has probably the least amount of directly relevant standards, perhaps because the introduction of automation is beginning to accelerate only now, with the imminent introduction of ERTMS², for example.

The greatest focus has been on HMIs. However, it is important to be mindful of the fact that the operator's interaction with automation represents a socio-technical system: it is not solely about the interaction with machine interfaces, but also about the impact of organisational and management factors. Hence mitigation measures can be introduced

² European Rail Traffic Management System

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through the promulgation of design standards, but also by staffing and training recommendations. This area is revisited in the chapter on training to mitigate automation issues

Another major instrument of mitigation is the implementation of reporting systems, which raise awareness but also provide data for analysis. This is very prevalent in aviation, where issues concerning automation of flight decks occupy the major portion of confidential reports made to reporting systems.

The nature of commercial shipping means that there are lessons to be learnt from a number of industries. Large tankers, for example, can be likened, to some extent, to mobile chemical plants, so regulations relating to the chemical industry are likely to be very relevant, but regulations relating to transport systems involving complex navigation systems, such as aviation, are likely to be equally pertinent. For this reason, the discussion will focus largely on these two industries. They also happen to be the safety-critical industries, along with the nuclear industry, that have given most consideration to the safety issues surrounding automated systems.

3.2.2 Aviation industry

The Federal Aviation Authority (FAA) produced a major report [48] covering problems with pilots' interaction with automated flight decks. A series of recommendations ensued. A key recommendation on the management of automation is shown in Table 3-1. There are numerous other recommendations covering issues such as vigilance, hazardous states of awareness, etc.

Recommendation Automation Mgt-1:

The FAA should ensure that a uniform set of information regarding the Manufacturers' and operators' automation philosophies is explicitly conveyed to flightcrews.

Discussion of Recommendation AutomationMgt-1:

The information provided to flightcrews should include:

- The manufacturer's higher level design philosophy (e.g., the reasons for automating particular functions) to the extent that this philosophy could affect operational use;
- The operator's automation philosophy, which should be used as the basis for operator policies, procedures and practises related to automation use;
- The principles of operation (e.g., operating assumptions used in the design, such as the basis for the computation of vertical flight profiles);
- A description of the envelope protection features, including specific capabilities and limitations and the situations or flight conditions for which envelope protection is or is not available; and
- Guidance (including rationale) relative to selecting the appropriate level of automation for routine use and for non-routine situations (e.g., when confused by automation response, engine failure in different phases of flight, unusual attitudes, speed excursions (high or low), terrain or collision avoidance, flight path deviations, or unexpected or difficult air traffic clearances or requests).

Table 3-1 Recommendation Automation Management 1

In response to the growing number of pilot's concerns with automated flight decks, a dedicated web-site has been set-up solely for the dissemination of these problems. The issues number of the order of 100 [49].

FAA automation design principles

One of the most useful documents in terms of guidelines for automation that impact upon error prevention is the United States Federal Aviation Authority automation guidelines document [50]. This document, produced by the FAA, contains guidance under 15 headings with high level design guidance provided within each:

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- General: highlights 25 general points relating to automation;
- Design and evaluation: highlights nine design and evaluation principles such as user-centred design;
- System response and feedback: provides four principles relating to appropriateness and type of user feedback;
- Interface: proposes seven principles relating to the design, navigability and consistency of automation interfaces;
- User acceptance and trust: highlights seven principles relating to human trust and acceptance of automation;
- Modes: covers status of functions when automated functions change in different modes of operation;
- Monitoring: highlights 13 principles relating to the task of users monitoring automation;
- Fault management: provides 15 principles on how the system recovers from failures;
- False alarms: covers two general principles on the occurrence of false alarms;
- Training: proposes 12 principles on the training of users to work with automated systems;
- Function allocation/levels of automation: covers nine principles on the suitability of functions for automation;
- Information automation: highlights 16 principles on acquisition and integration of information in automated systems;
- Adaptive automation: covers nine principles relating to the allocation of tasks to users or automated systems;
- Decision aids: highlights 34 principles relating to automated systems that are used to support human decision making;
- Control automation: highlights eight principles that relate to automation controlling tasks with some degree of autonomy.

Within the document many of the principles are discussed further. The document itself takes the basis of a review of existing guidelines and principles for the use and application of automation. The advantage of [1] is that the guidelines and principles can be traced back to the original reference sources which are taken from across a variety of industries including flight and nuclear.

Each of the statements in [50] is either a “shall” statement (principles that should be adhered to) or a “should” statement (principles that represent best practise applicable in most cases, but may require trade-offs or be influenced by context-specific factors).

The document represents the only dedicated human factors automation guideline available within the public domain. In addition to material drawn from the aviation industry, other sources include academic references (e.g. journal publications), the Institute of Electrical and Electronics Engineers (IEEE), the defence industry, the National Aeronautics and Space Administration (NASA) and the nuclear industry. Examination of the method adopted in developing the guidelines reveals considerable work and effort has gone into the document, including an extensive expert review.

The guidelines are expressed in generic terms and a brief review suggests that all of the guidelines are potentially of use within the maritime industry. Like many guidelines of this ilk, the guidelines are largely using HF and psychology constructs that mean design

engineers may not be able to apply and evaluate design concepts against the guidelines without HF expertise. In a related vein, the guidelines assume a corpus of HF knowledge exists for the specific function and context for the role of the automation, e.g. task analysis. As a result, the guidelines are likely to have optimal effect only when used within as part of a raft of HF activities, i.e. within the scope of a HF Integration plan. It must also be stressed that this document provides guidance for design and therefore does not contain anything of value to the users of automation, nor to the maintainers, trainers or management once the automation is in service.

Many of the other documents found and used as reference sources during this work echo the principles found in [50]. Reference sources [28 and 51 to 54] are in good support of [50].

3.2.3 Chemical industry

The chemical or process industry is largely governed by HSE regulations, with the HSE conducting assessments, inspection and assessment of reports. Human factors in general are discussed in COMAH (Control Of Major Accident Hazard regulations) produced in 1999. There is a recently published HSE publication on Human Factors aspects of remote operations in process plants; and the HSE has produced a proposed framework for addressing human factors in IEC 61508 [55]. Specific requirements include:

- All accident initiating events, including procedural faults and human errors, should be identified
- The system should be tolerant to operator errors
- The system should be designed to cover all reasonably foreseeable misuse
- Particular attention should be given to abnormal or infrequent modes of operation
- Consideration should be given to the availability of skills and resources needed for operation and maintenance of the system
- Maintenance requirements should be specified
- Operating rules should be specified for use during normal, degraded, abnormal and emergency states of the system
- Safety requirements should identify user requirements

How these requirements should be met, however, is not specified.

The chemical industry also produces its own independent codes of practise and guidelines generated by Institutions such as the Energy Institute. One such organisation has published a book that directly covers the issue of automation in the chemical industry. The 'Guidelines for Safe Automation of Chemical Processes' published by the Centre for Chemical Process Safety (CCPS) deals directly with the issue of automation [56]. This has chapters on design philosophy, interface design and general safety evaluation techniques. There is some discussion of risk assessment, but otherwise little reference to Human Factors.

As a response to the widely held misconception that the introduction of automation will necessarily mean fewer staff will need to be employed, the HSE commissioned work to produce a methodology, published in a readily available book form, assessing the safety arrangements for process operations in chemical and allied industries.

Feedback on this book solicited by The Energy Institute (EI) identified the need for guidance setting out a best practise approach [57]. The EI also identified a need for supplementary guidance on how best to apply the methodology to automated plant equipment. This led to the development of a methodology that facilitates the assessment of manning requirements for automated plant (see EI paper [57])

Whether the manning is adequate is assessed with reference to the following issues:

- Situation awareness
- Teamworking
- Alertness and fatigue
- Training and development
- Roles and responsibilities
- Management of operating procedures
- Management of change
- Continuous improvement of safety
- Management of safety

On the whole, the existence of guidelines such as those expressed in IEC 61508 [55] above and the development of the tools sponsored by the EI [57] such as that outlined, suggest that the process industries are relatively well covered from the human factors regulations perspective.

3.2.4 Nuclear industry

As a result of high profile accidents involving human factors and human error, such as Three Mile Island and the extent of automation adopted, the nuclear industry, at least in the US, has probably the best record of addressing human factors issues in general and as they relate to automation. This is reflected in regulations that require operators and builders of nuclear installations to undertake a complete programme of human factors engineering before being licensed [58]. Applicants' Human Factors Engineering (HFE) programmes are subjected to a review that addresses twelve elements:

- HFE programme Management
- Operating Experience Review
- Functional Requirements Analysis and Function Allocation
- Task Analysis
- Staffing
- Human Reliability Analysis
- Human-System Interface Design
- Procedure Development
- Training Programme Development
- Human Factors Verification and Validation
- Design Implementation
- Human Performance Monitoring

Automation issues are specifically addressed within these reviews.

In addition to these regulatory procedures, the International Atomic Energy Agency produces useful and authoritative guidance documents that cover the issues surrounding automation (e.g. [59]).

3.2.5 Road and rail industry

The Road and Rail industries have been grouped because they are in a relatively similar status as regards the implementation of automation. In road transport, there is little legislation yet as automated systems such as collision avoidance are still in early stages of development, although there is plenty of research warning of potential problems [60].

The railway's use of automation has been steady and incremental. No standards address the issue of automation directly, but some standards are addressing human factors issues that involve automation to some extent within specific systems (e.g. TPWS³).

Guidance on identification of human error from the rail industry

An application note produced by Railway Safety [61] discusses the identification of hazards, assessing and reducing risk. In order to do this it proposes a four-stage approach. In stage 4, three strategies are defined for reducing the probability of human error. These three strategies should be considered carefully.

1. Identify, model and control human error and risk

For identifying, modelling and controlling human error there are a variety of human reliability techniques that enable the identification of human contribution to hazards, risk assessment and methods of risk reduction. One should ensure that appropriate human reliability techniques are used correctly.

For identifying, assessing and reducing the risk associated with human error one should address the human contribution to risk and how it may be mitigated. The objective should be to reduce the risk as far as reasonably possible.

2. Error identification

Identification of the sources of human error requires a good understanding of the tasks that are conducted. Failure to comprehend these tasks will impact significantly upon the ability to identify the origin of risks. Task analysis should be applied in order to determine error sources.

3. Error representation and quantification

Human error is not necessarily a standalone issue and should be combined with other safety aspects. Error often has both human and technical aspects to it and so both require consideration. The probability of an error occurring can be represented in terms of a human action being performed incorrectly.

Some human errors can have a knock-on effect and cause others. For example, where the same value needs to be entered into multiple systems if it is entered incorrectly in one then the chances are the human will enter it incorrectly into others.

4. Error reduction

Some risks can be avoided, or mitigated, by changing procedures. This is often a more effective solution than making a technical change. However, one should exercise caution and show that a procedural change is more appropriate than a technical change.

In general, there are three strategies that can be adopted for reducing probability of human error:

- Improve the design of the task and the equipment to avoid provoking the operator into error.

³ Train Protection and Warning System

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- Improve the working environment, e.g. by improving procedures, removing distractions, attending to factors which might cause fatigue.
- Improve the performance of the individual, e.g. by paying attention to training and competence, fitness, motivation, safety culture.

Again, several other sources support what is said in the Railway Safety report. Other sources are complementary to these. The most basic principle taken from US Nuclear Regulation 0700 [62] is that “error-mitigation approaches should not be the sole means for achieving error tolerance, but should be used in conjunction with other means for error prevention and system-assisted detection.” Although this would appear to be stating the obvious, it is a useful maxim to bear in mind because all too often error mitigation is considered in isolation from other aspects.

Guidance on shift patterns from the rail industry

Shift patterns can result in fatigue which in itself can result in an increase in human errors. Evidence of this can be found in incidents such as the Clapham Junction rail accident (1988). The investigation into the accident, conducted by Sir Anthony Hidden QC, found that during the thirteen weeks before the accident 28% of the workforce had worked 7 days a week and another 34% had worked 13 days out of 14.

According to the Health and Safety Executive [63] some shift patterns are known to lead to fatigue more than others. The HSE has produced a Fatigue Index based on five factors that have an impact upon fatigue. The Fatigue Index allows the user to determine where fatigue is a particular problem.

The best type of shift pattern is the fast forward rotation (two mornings, two afternoons, two nights) with the worst being weekly backward rotation (nights, afternoons, mornings). Fewer consecutive night shifts result in less disturbance of circadian rhythms. Permanent night shifts should be avoided [64].

3.2.6 Conclusions on high-hazard industry mitigation strategies

Section 3.2 has identified the mitigation strategies used by other high-hazard industries. These are summarised below.

The strategies used by the aviation industry include the following:

- Briefing procedures (in terms of content, e.g. explicit information set on automation ‘philosophy’) for crew on handover;
- Use of websites to disseminate automation issues to the wider user community;
- Dedicated automation design guidelines (i.e. FAA);
- Training regulations and certification, including checking procedures on operator’s proficiency (discussed in Chapter 4);
- Crew Resource Management training;
- Confidential reporting systems (e.g. CIRAS).

The strategies used by the chemical and nuclear industries include the following:

- Statutory bodies responsible for regulation (e.g. Health and Safety Executive);
- Assessment and inspection by regulatory bodies and/or independent bodies;
- Provision of framework guidance by industry-recognised authority, i.e. implementation left to private organisation;
- Industry codes of practice;

- Method to assess minimum manning levels for automated plant;
- Bespoke and/or adapted Human Factors Integration plan (mandatory in the nuclear industry);
- Development of guidance documents.

The strategies used by the rail industry include development of Human Factors standards for specific systems (i.e. there is no integrated approach to addressing automation issues). In common with other industries, the rail industry also provides indirect support through guidance on human error management (within the design phase of development) and guidance on shift patterns.

Within the high-hazard industries discussed above, no evidence was found within the public domain of any evaluation studies aimed specifically at assessing the effectiveness of any mitigation strategies to prevent the occurrence of automation issues. This may reflect upon the relatively indirect nature in which automation issues are generally addressed.

What can be gathered from this review is that many of the mitigation strategies adopted by other industries are already in force within the maritime industry to some extent. The differences between industries appear to be in the degree to which the strategies are mandated.

Whilst no two industries are the same in their requirements and context, the maritime industry appears to have the closest parallels with the aviation industry, in particular in terms of the international cross-border nature of the work domain and the degree to which the work-system (i.e. aircraft and ship) has to be responsive to factors outside its immediate control (e.g. the external environment).

Arguably, one of the most significant differences between the aviation and maritime industry is in the extent to which there is a general awareness of automation issues and therefore recognition of the problems it can pose. In this respect, a strategy to raise general awareness of automation issues within the maritime industry may be appropriate. Other routes to go some way to bridging the gap (e.g. adoption of aviation design guidelines) are discussed elsewhere in this report.

3.3 Standards and guidance from the general human factors and ergonomics field

The review of standards and guidelines has found that there are few documents dedicated to automation. Automation would appear to be covered by employing good Human Factors principles from the outset and particularly by developing a good Human-Computer Interface. To this end, one should adhere to principles and guidelines that are covered in ISO 9241 [65].

3.3.1 Design guidelines for automation to support good operator situation awareness

Forming an accurate assessment of the current situation is the foundation for good quality decision making. Conversely, if the decision-maker misunderstands the current state of the world, he is unlikely to arrive at a decision that defuses a developing incident and may in fact worsen the situation through directing actions that place the crew and vessel in greater peril. Unfortunately, automation can lead to degradation of situation awareness, for example, through the relatively impoverished display 'real estate' area available in comparison to manual-operation systems. Endsley *et al* [33] have formulated a number of principles for designing automated systems to maintain good situation awareness for human decision-makers. These include the following:

Automate only if necessary. Alternatives to automation that maintain the operator in control of the system should be considered preferable. Increased operator effectiveness may be achievable through improvements to the user interface to better support him in maintaining his awareness and in arriving at decisions. Improvements to the user interface may also reduce data and operator overload.

Use automation for assistance in carrying out routine actions rather than higher level cognitive tasks. By ensuring that the operator maintains responsibility for executive control of the system, the operator will maintain a high level understanding of the situation.

Design the task to ensure the operator maintains an active role in managing the automation's activities. Automation should be restricted to lower and intermediate intervention to maintain the involvement and control of the operator at the executive level.

Avoid the proliferation of automation modes. The use of automation modes can increase the level of automation complexity, increase the workload of operators in maintaining an accurate assessment of the current situation and increase the risk of human error. Endsley *et al* [33] suggest that designers should aim to produce a flexible tool that allows users to customise the automation controls and displays, rather than providing preset modes. By virtue of being active in configuring the automation control and display, the user will have a much greater understanding.

Make modes and system states obvious. If automation modes cannot be avoided, the automation display should clearly indicate its current mode of operation, including a clear indication of the control associated with any function keys. Similarly, any system states should be made highly visible to the operator.

Aim for automation consistency. Consistency in the terminology, information placement (i.e. display layout) and functionality of the automation across modes should be encouraged. The production of an automation style guide is one means of ensuring consistency in design. At industry level, guidance could be laid down for the layout of displays for automation devices across the range of manufacturers and models (e.g. for GPS equipment).

Avoid advanced queuing of tasks. Queuing of tasks removes the operator from the executive management function. In addition, the operator's awareness of the task schedule will deteriorate the longer the time between when the task queue is entered and when the automation performs the next task step. In the aviation domain, incidents have arisen when humans have incorrectly entered waypoints and subsequently failed to detect these errors when the automation performs them.

Avoid the use of information cueing. In drawing the user's attention to particular information sources, the user may fail to notice information that is not highlighted and introduce issues with attention biasing. Displays should instead a philosophy that allows the user to use their own senses more effectively. For example, the display could enable the operator to declutter unwanted information (i.e. remove information under the control of the user).

Provide automation visibility. Automation should clearly display its current activities and those to be performed in the near future. Greater automation visibility may be achieved through designing the interface to communicate its goals, in addition to its current activities.

3.3.2 Designing automation to support human decision making

The design of automation to support decision making should be focused upon providing situation awareness support to the crew rather than dispensing decisions (Endsley *et al*, [33]). The automation should be designed to present the operator with information relating to all the factors that could influence his decision (i.e. ensure that the operator has good

situation awareness upon which to arrive at his decision). The automation should not provide a decision or advice, as this is likely to introduce decision biasing and slowing of decision making (especially if there are other factors beyond the scope of the automation that the operator must also factor into his decision).

Decision support aids should be designed to support an effective human/system symbiosis. Rather than presenting the operator with a suggested solution, other approaches to improving the quality of decision making should be explored, such as:

- Provision of critiquing systems
- Supporting ‘what-if’ analysis
- Supporting alternative interpretations of data
- Provision of systems that directly support understanding/comprehension of the current situation and projection to the near-future.

Designing to support human decision making requires significant information about the nature of the decision itself, the context under which it is taken and the relationship of the decision in the context of the overall system performance. This is beyond the capability of any generic design standards and guidelines and HF methods may be more appropriate, for example HF Integration, which is discussed later.

3.3.3 Adoption of user-centred design process

In instances where the HFI plans described above maybe considered inappropriate, for example, for the procurement of a relatively inexpensive system, principles of User Centred Design (UCD) may still be effectively configured and employed to improve the overall effectiveness of the combined man-machine system.

EN ISO 13407 [66] identifies the benefits of adopting a human-centred design (or UCD) process include minimising the health and safety risks to operators; reducing training and support costs; improved user satisfaction; and improved productivity. Not mentioned specifically by the standard are improvements in human error. The philosophy can be adapted to deal with the procurement process in most respects.

The UCD activities identified by the standard are:

- Understanding and specifying the context of use – including the characteristics of the intended users, the tasks to be performed and the environment in which the system is to be used.
- Specifying the user and organizational requirements – create explicit statements of user and organizational requirements and, where necessary, identify trade-offs between different requirements.
- Production of design solutions – make use of existing knowledge, produce mock-ups, present proposed solutions to users and allow them to perform simulated tasks and alter the design in response to user feedback and iterate if necessary.
- Evaluation of designs against requirements – to provide feedback that can be feed into the design, to assess whether user and organization requirements have been met and to monitor long-term use of the system (e.g. to inform equipment upgrades).

The only activity that would not appear appropriate to the procurement of automation equipment is the production of design solutions. Even here, though, there are likely to be

options that can be explored with users, e.g. selection of specific COTS equipment, options for integration with existing systems, location of controls and displays.

3.3.4 General mitigation strategies

The human factors issues associated with automation may be synthesised into four key problem areas:

- Complacency or over-reliance
- Trust and transparency
- Loss of Situation Awareness
 - Reduction of vigilance and monitoring
 - Adoption of passive role in controlling system
 - Poor feedback to operator
- Skill fade

Likely mitigation measures for these areas are:

Manning – It cannot be assumed that automation will always result in a lower level of staffing. Careful assessments are required regarding allocation of function and staffing needs.

Training – Training required in soft everyday problems that may appear after system is in service. Reporting systems need to be in place to capture these. Sufficient training must be given when introducing automated systems in the first instance. To avoid skill fade, operators must be given regular practise at operating in the absence of automation.

Design – Systems need to be designed with the user in mind. To avoid a lack of trust in a system, it should be designed so that its operation is transparent to the user: so that why something is happening is easy to follow and explained; so that feedback is given. A key design driver must be an understanding of the potential effects of the system on situation awareness, in order to avoid complacency and loss of SA in operation.

4 Training requirements to address automation issues

Chapter 4 opens with a description of the training regime relevant to the use of automation within aviation. The maritime industry has learnt considerable lessons on Resource Management training from the aviation industry. Subsequent sections describe the development of this form of training in the maritime industry, raise pedagogical issues relating to the mode of delivery and give examples of current maritime resource management course syllabi in which automation are addressed. The chapter includes a comparison of these syllabi and comments on their commonalities and differences and concludes with some recommendations for improvement. The research conducted for this study concludes that the training mitigation of human error in automated ship-borne maritime systems is currently embedded in existing maritime resource management training.

4.1 Training in the aviation industry

Amongst the organisations responsible for regulating the aviation industry are the FAA, Civil Aviation Authority (CAA), Joint Aviation Authority (JAA) and ICAO. The FAA operates within the US, the CAA in the UK and JAA throughout Europe. In addition the ICAO also issues guidelines and information world wide.

The JAA is an associated body of the European Civil Aviation Conference (ECAC) representing the civil aviation regulatory authorities of a number of European States who have agreed to cooperate in developing and implementing common safety regulatory standards and procedures.

JAR-FCL 1 [67] covers regulations for training. It was first issued in 1997, with amendments in 2002 and 2003. In a review of training regulations conducted for the CAA [68], it is suggested that there has been little change in philosophy over the years despite the acknowledged changes in the operational task facing pilots as a result of the introduction of automation.

Appendix 1 to JAR-FCL 1.470 sets out the knowledge requirements for the ATPL (A) licence. Wood [69] suggests that students learn only what is required for the exam of the individual module and that at present, there is little consideration given to the introduction of automation as an integral component of the flight deck task. Rather the topic is treated as a system and as such is consigned to the same format as hydraulics, electrics etc. Thus, once the student has gained his ATPL (A) Theoretical Knowledge credits he has acquired a limited level of declarative knowledge (knowing what to do) but very little procedural knowledge (knowing how) that is relevant to working with the automation of a modern flight deck.

A similar situation exists with regard to type training. Wood [69] suggests that theoretical knowledge for the type rating is presented and assimilated as declarative knowledge. Some procedural knowledge is introduced in the form of practical training in the use of autopilot, autothrust and flight management systems. However, the training is limited to the use of systems in normal mode and with hardware failures only. Interviews with ground training personnel yielded comments that the normal procedures and non-normal situations, for which there was a published procedure, were covered but there was little, if any time allocated to the human performance limitations and the management of the automation in realistic settings.

These findings are corroborated by work conducted by the author and other colleagues from QinetiQ on the ECCOTRIS project [70], on pilot transition training. Traditionally, training for new aircraft has been in step with regulations and certification programmes that cover only major abnormal problems such as engine failure. The so-called ‘soft’ problems that occurred particularly when pilots had to get to grips with new glass cockpits were not specifically trained for. So pilots had to learn from bitter experience about everyday routine problems, which none the less could lead to catastrophic effects. More recently, following several accidents and problems, there has been a growing awareness of the need to address these soft problems in training: Airbus has been active in this area.

One obvious mitigation measure is the conduct of regular checks on the proficiency of the pilot. However, the requirements for the skills tests contained within JAR-FCL [65] and amplified in Standards Document 24 [68] are heavily weighted towards the checking of the manual flying skills of the pilot.

In summary, Wood [69] view is that the current regulations covering licence and type rating issues prescribe standards and experience in the procedural knowledge of manual control of the flight path but that there are no similar requirements to ensure appropriate standards and experience for the procedural knowledge of control of the flight path using automation.

Another mitigation measure that has been introduced via legislation is that of Crew Resource Management (CRM). Initially based on concepts adapted from business management behaviour programmes in the US, CRM was introduced into commercial aviation during the late 1970s. Since then the emphasis for CRM has strengthened, resulting in the recently published Standards Document 29 [71] and accompanying CAP 737 [72]. In the view of Wood [69], CAP 737 [72] and [71] contain good information, but it is believed that much of the cognitive aspects of CRM and the application of Human Performance and Limitations to the use of automation may not be fully understood nor implemented as anticipated.

The situation in the US, covered by the FAA, is that since 1978 there has been a requirement for training in human factors, but the precise content of this has again not been specified (FAR Part 61, sec 61.155 [73]).

4.2 Development of Maritime Resource Management (MRM) training

The use of simulation in providing solutions to the problems of risk and crisis management and the optimal use of crew resources has a long established pedigree in maritime training. The first simulators were introduced for radar training over thirty years ago. Training in the proper interpretation of radar information started as a result of a number of radar-assisted collisions in the 1950s, notably the collision between the passenger ship “Andrea Doria” and the “Stockholm”. Those early simulators consisted of real radars, located in a set of cubicles and fed with simulated signals. Individuals or teams could learn the skills of radar plotting under the guidance of an instructor working at a separate master console. Other navigational aids in the simulator were fairly basic and certainly did not include a visual scene.

Bridge simulators with a nocturnal visual scene made their appearance in the 1970s and allowed teams to conduct simulated passages in a realistic environment but with only a few lights available to indicate other vessels and shore lights. It was apparent from the casualty of the Very Large Crude Carrier (VLCC) “Metulla” in 1974, in which the vessel grounded in the Magellan Straits with two pilots and watch keepers present on the bridge that bridge teams were not working effectively in supporting each other or the pilot. Simulator-based training courses were introduced primarily to train the skills of passage planning and the importance of the Master/Pilot relationship [74]. This training initiative developed into the Bridge Team Management (BTM) courses that are conducted today on many simulators

worldwide and contain many of the elements to be found in Crew Resource Management (CRM) courses developed in other industries, such as aviation. These CRM courses were developed to focus on the non-technical skills of flight operations and include group dynamics, leadership, interpersonal communications and decision making [75]. Bridge Resource Management (BRM) courses are a more recent maritime initiative, adapted directly from the aviation model for training the non-technical skills of resource management and are not always based on the use of simulators.

The 1980s saw the introduction of Engine Room simulators and, towards the end of that decade, cargo operations simulators also became available. These types of simulator have primarily been used to train officers in the handling of operations, including fault finding and problem diagnosis and increasingly to train teams in the skills of systems, resource and risk management. Many types of simulators (bridge, engine and cargo control room) have tended to emphasise a physically realistic environment in which these exercises occur, although the use of PC-based simulators for training some tasks is increasingly widespread. In some parts of the world, simulators have been developed that emulate very high levels of physical fidelity, for example, multi-storey engine room mock-ups and bridge simulators including features such as 360 degrees day/night views, pitch and roll and full vibration and noise effects.

The only mandatory requirements in the maritime domain for the development of the non-technical skills of crisis management are those of the International Maritime Organization's (IMO) Seafarer's Training, Certification and Watchkeeping Code [76] Table A-V/2 of this code specifies the minimum standard of competence in crisis management and human behaviour skills for those senior officers who have responsibility for the safety of passengers in emergency situations (See Appendix C). However, within this competency table, no mention is made of human error related to automated ship-borne maritime systems. The IMO has produced a model course for training the competencies of crisis management and human behaviour skills [77].

The competence assessment criteria detailed within the Code are not based on specific overt behaviours, but rather on generalised statements of performance outputs and as such are highly subjective and open to interpretation. Although these standards of competence indicate that IMO recognises the need for non-technical management skills, both the standards and their assessment criteria are immature in comparison with the understanding of non-technical skills and their assessment, within an industry such as civil aviation.

In summary, maritime resource management (MRM) training to mitigate risk has become established in the curricula of many maritime training establishments. Courses take a variety of forms and cover both deck and engine room disciplines. The courses are often simulator-based, but not always and their syllabuses reflect CRM training in other industries. As can be seen from the history of this development, most major training initiatives have resulted from the lessons learnt from a succession of casualties.

4.3 Pedagogical Issues in MRM training

In pedagogical terms, there is an important distinction between knowledge and skill. Full competence in the use of automated ship-borne maritime systems involves both knowledge and skill, i.e. there is a requirement for both understanding the system as well as developing the skill to deal with it. Consequently, the most effective ways of imparting knowledge and enhancing skills need to be addressed in the development of the curriculum. For example, it may well be that knowledge is learnt in a classroom setting, whereas some skills may require the full environmental context that a simulator provides. This section outlines some of the pedagogical issues that arise from this competence requirement and proceeds to give

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examples of actual curricula, which have emphasised either the knowledge or the skill aspect and the corresponding optimum mode of delivery.

Learning is a difficult concept to define, let alone gauge. Yet, to facilitate, even to engineer, student learning, is, one could argue, the primary role of teachers of ships' officers. Unfortunately, research in education suggests that the learning that students are doing is often ineffective [78]. Large numbers of students have no greater understanding of their subject come the end of their course than they did at the start of their course and this is true whether the students are studying to become accountants [79] or veterinaries[80]. While the students are learning, their learning is far from ideal or what the lecturers had intended:

"..very large numbers of students appear to be learning an imitation of at least some of the disciplines they are studying, a counterfeit amalgam of terminology, algorithms, unrelated facts, 'right answers' and manipulative skills that enables them to survive the process of assessment"[78]

Ramsden's [78] findings suggest that there are different levels of learning and that the majority of students are not attaining the level that lecturers judge to be of value. What is true for higher education students is also likely to be true for ships' officers enrolled on resource management courses. In many instances at maritime colleges, course participants are not assessed and thus the lecturers have no knowledge of what has, or has not, been learned. Attendance is all that is required to obtain a certificate and attendance does not necessarily equate with learning.

The clear message from pedagogical research is that passive students are not learning students. Accordingly it follows that the lecture, whereby students sit and listen to the transmissions of the lecturer, is unlikely to be an effective teaching practise, especially if it is the sole technique employed. If the accounts of pedagogical researchers are correct and evidence would suggest they are, then what is needed is a more student-centred teaching style wherein students engage in problem solving.

Another message is that understanding is achieved as the penultimate step in a series of cognitive development steps. The implication is that students who have not progressed through the initial steps will not be achieving understanding of a subject or discipline if presented with, or expected to produce, materials at a higher level of abstraction.

The implications of pedagogical research for resource management training are twofold:

1. Course participants are unlikely to learn much more than a few unrelated facts if the course is dominated by lectures, or if the simulator is used as no more than a demonstration tool; and
2. Resource management based training has to be matched to level of development of the course participants.

Expecting students to engage in the kinds of problem-solving and theorising expected in many resource management courses when they are only able to grasp simple concepts is likely to result in limited learning at best and the 'wrong' learning at worst. Borodzicz and van Haperen [81] argue that simulation is a training methodology that should be used 'when people are ready for [it]' (p 16). They support their assertion by referring to the work of Lagadec. Lagadec [82] found that students who undertake simulations involving crisis too early in their development become anxious and defensive. Lagadec also found that 'undertaking [crisis simulations] too late might merely set in-house attitudes in concrete' (p 331), suggesting that there is a time window for learning using simulations.

The other message from pedagogical research is that it is *how* a teacher teaches that has considerable implications for the effectiveness of learning. Research suggests that teachers

should adopt a teacher-centred style to start with and move to a more student-centred style as students' mastery with a concept develops; and for adult learners at least, there must be opportunity for reflection on experiences and active experimentation with new concepts for learning to take place.

Therefore, the implications for resource management training are as follows:

1. Students need to be weaned off reliance on the instructor through the gradual introduction of the more complex aspects of the course, as it progresses
2. The opportunity for interaction between junior and senior officers needs to be encouraged as much learning occurs through dialogue with one's contemporaries
3. As adult learners, ships' officers need to be encouraged to reflect on their actions in order to process this information to develop new theories.

Ultimately, therefore, resource management course designers need to pay as much attention to the design of the interactions in the classroom, staging of the delivery of classroom and simulation components and debriefing post the simulation exercises, as they do to the simulation exercise itself.

4.4 Current MRM courses

Current maritime training courses that address resource management issues, including human interaction with automated systems, tend to be delivered in three forms:

i) Bridge Resource Management (BRM):

These courses deal with the interactions between navigating officers, their bridge/navigational sea area environment.

ii) Engine Room Resource Management (ERRM):

These courses deal with the interactions between engineer officers and their engine room environment.

iii) Maritime or Crew Resource Management (MRM/CRM):

These courses deal with the interactions between both navigating officers in their bridge/navigational sea area environment and engineer officers in their engine room environment and the interaction between these two groups of officers on-board a vessel.

There are also some training institutions that use the title Maritime Resource Management to mean the same as Bridge Resource Management, i.e. for resource management courses that are used only to train navigating officers.

The Bridge Resource Management Courses and those Maritime Resource Management courses that are only used to train navigating officers usually state that they train officers to be competent with respect to the bridge resource management principles outlined in Section B-VIII/2, part 3-1 of the STCW Code (see Appendix D).

The Engine Room Resource Management Courses do not as yet make reference to the STCW Code as the IMO Maritime Safety Committee only approved the guidance on Engine Room Resource Management principles in May 2005 and a new amendment to the STCW Code, Section B-VIII/2, part 3-2 paragraphs 8-1 and 8-2 will not be issued until late in 2005, after the IMO General Assembly (See Appendix E).

The syllabi of Bridge, Maritime, Engine Room and Crew Resource Management training courses have been derived mainly from two sources, Section B-VIII/2 part 3 of the STCW

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Code and various Crew Resource Management courses that have been developed in the civil aviation industry.

For comparison, examples of the descriptions and syllabi of each of the three course types are detailed below. These descriptions are taken directly from the training organisations' own literature.

4.4.1 Bridge/Maritime Resource Management (The Swedish Club, 2005)

The Maritime Resource Management (MRM) Course is a further development of the original SAS Bridge Resource Management Course. The original course was developed in close co-operation by the following eight organisations: Dutch Maritime Pilots' Corporation, Finnish Maritime Administration, Norwegian Shipowners' Association, SAS Flight Academy, Silija Line, Swedish Maritime Administration, Swedish Shipowners' Association and The Swedish Club. The first Course was launched in June 1993.

It is about the use and co-ordination of all the skills, knowledge, experiences and resources available to the crew to accomplish or achieve the established goals of safety and efficiency.

Course Objectives:

To motivate the crew – if necessary – to change its behaviour to good resource management practises during everyday operations. This includes understanding of the importance of good management and teamwork and the willingness to change behaviour. The use of common terminology is also emphasised.

The MRM course is:

- Changing attitudes – not skills
- Focusing crews as intact teams, not a collection of competent individuals
- Addressing crewmember attitudes and behaviours
- Providing two sets of objectives:
 - Training Objectives
 - Specific Behavioural Objectives
- Providing Computer Based Training for transfer of facts
- Utilising case studies and human interaction to change attitudes
- Originally based on the airline industry Crew Resource Management

Entry Standards:

This course is open to ships' officers and engineers, maritime pilots and shore-based personnel.

Minimum number of participants is four (4) and maximum is eight (8).

Duration:

4 days (32 hours)

Course Syllabus:

Introduction

In this part, a short background to the course is given and its relevance to all types of ships and personnel categories, such as ships' officers, maritime pilots and engineers.

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i) Attitudes and Management Skills

The human nature and its weaknesses are discussed. The trainees learn to be aware of “hazardous thoughts”, that can induce accidents and the opposite, “safe thoughts”. The concept of Common Terminology is introduced.

ii) Cultural Awareness

Cultural differences and how to deal with them. The following characteristics are used to describe cultural differences: Group-Individual, Power Distance, Uncertainty Avoidance, Feminine-Masculine and Short-Long Term.

iii) Communication and Briefings

This module deals with common errors in communication, the importance of “closed loop communication” and how to achieve a good communication climate. The importance of briefings is highlighted, by describing how briefings and debriefings are mandatory in aviation and should be applied also on ships. Practical guidelines are given on how to perform briefings and debriefings.

iv) Challenge and Response

The importance of a Challenge and Response environment is emphasised, defined as a “supportive environment”, in which everybody feels free to question assumptions and actions and in which positive responses are the norm.

v) Short Term Strategy

Short Term Strategy is a practical method for dealing with any type of task, but especially useful in abnormal or emergency situations when use of all available resources is necessary.

vi) Authority and Assertiveness

In this module, behaviour in terms of authority and assertiveness is discussed. Reasons for and the dangers of extreme combinations of authority and assertiveness are analysed.

vii) Management Styles

Different leadership styles are discussed and how to deal with them. The performance/human relation management grid is used.

viii) Workload

The dangers of low and high workload are discussed and systematic ways to avoid them. Methods like task analysis, delegation and rotation of tasks are addressed.

ix) State of the Ship

The state of the ship is generated by the combination of the team members’ personal states of mind. The underlying reasons for different states of mind are discussed, as well as the importance to detect and take action on state extremes and differences between the crew members.

x) Human Involvement in Error

Here, underlying causes of accidents in terms of externally and internally induced errors are discussed and the importance of responding to and learning from errors.

xi) Judgment and Decision Making

Factors affecting judgment and decision making and the process of decision making are addressed. The importance of detecting and avoiding hidden pressure is emphasised.

xii) Leadership in Emergencies

Transferring an emergency situation from the unanticipated, fast reaction type toward the anticipated, slow reaction type is discussed and the necessity to apply different leadership styles in different emergency situations.

xiii) Crisis and Crowd Management

Together with the above modules, this module meets the STCW requirement for theoretical training in Command and Control management. It covers mental and physical reactions in a crisis situation, how to deal with them, how to deal with a crowd and finally a method for personal crisis debriefing.

xiv) Automation Awareness

This module addresses the consequences of increased automation on ships' bridges. It discusses different levels of automation, characteristics, advantages and dangers with automation and some guidelines for learning to work in automated environments."

4.4.2 Engine Room Resource Management (STAR Centre, 2005)

The objective of this course is to complete the learning objectives of individual lecture and discussion modules (e.g. communications, team building) and successfully participate in the simulator and team exercises. The simulator is used as a tool for resource management training and not the subject of the training. The training ideas and their sequence are based on the "discovery method" of teaching. Mature students with established leadership roles are presented with and/or observe information and facts that motivate their own conclusions and learning.

Students are first introduced to the engine room simulator and the procedures for starting and operating various plant components (e.g. diesel generators, steam boiler). A review of own company organization, procedures and check lists is also conducted. Lecture material and group discussion prepares the students to operate the full mission engine room simulator as a team. The only assistance provided is what individuals have briefly learned and shared with their team members as well as their own experience and engineering knowledge. Additional lecture material prepares the engine room team(s) for a "team adventure" as well as a more structured approach to operating the full mission simulator.

The course eventually leads to "busy engine room" activity. Exercises are evaluated by the non-participating team and conclude with a debriefing. The capstone exercise involves evaluating the quality of team procedures involved in an engine room watch handover.

The course concludes with a relevant case study, course summary and critique.

This simulator-based course is 40 hours/five days in duration and brings to the engineering team the concepts and philosophies of resource management previously only experienced by bridge personnel.

Students are introduced to the basics, followed by exercises on the simulator concluding with actual case studies. The course includes STCW assessment and a final examination.

Course Syllabus:

This course for the engineering team includes the following subject areas in its presentation:

- Simulator Familiarization
- Engineering Organization and Procedures
- Team Building and Development
- Situation Awareness and Error Trapping

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- Effective Communication and Communications Models
- Management of Stress and Distraction
- Fatigue and Circadian Rhythm
- Multicultural Diversity

The course allows the members of the engineering team to learn the keys to effective engine room resource management, including:

- The secret of anticipation and situation awareness;
- How to obtain relevant information early;
- Building a detailed and shared mental model of the situation;
- How to be prepared;
- How to make realistic decisions sensitive to constraints;
- How to share the workload;
- Monitoring progress by cross checking each other.

This course is designed to be customised to individual company procedures reflecting ISM requirements or taught in a generic form on an open enrolment basis.”

4.4.3 Crew Resource Management (Warsash Maritime Centre, 2005)

Course Syllabus:

The purpose of this course is to introduce the main tenets of resource management and how these should be applied to enhance the operational safety and efficiency of company vessels. The main topics covered are:

- The ‘systems’ approach
- Safety of operations
- Environmental issues
- Co-operation and Teamwork
- Situation awareness
- Decision making and Critical Thinking
- Human Factors and Human Error
- Crisis Management and Human Behaviour
- Leadership and Workload Management
- Risk Assessment and Risk Management
- Identification of and breaking error chains
- Efficient use of resources and delegation
- Communications
- Planning and Prioritising
- Identification of cause of problem and timely correct response
- Methodical and logical approach to fault diagnosis and problem solving
- Identification and justification of "assumptions"
- Emergency Preparedness
- Contingency Planning

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- Competencies related to STCW 95
- Assertiveness
- Cultural Awareness

The course is both seminar/group workshop and simulator based.

On completion of the course delegates from both the Engineering and Deck departments will have worked together and will have a clear understanding of all aspects of ship resource management, including the issues relating to its successful introduction within an organisation.

Course Objectives:

By the end of the course delegates will be able to:

- Develop a quality improvement orientated culture with respect to safety of operations, protection of the environment and achieving goals within acceptable limits.
- Develop a pro-active methodical and systematic approach to the management of systems, operations and communications through teamwork and to evaluate any deviation from a specific operational objective plan and analyse the reasons for this deviation.
- Identify and analyse risk factors, to include consideration of human behavioural factors, which contribute to human error and situation awareness.
- Identify the priorities to which a manager must attend with respect to the safety of operations:
 - within hours of joining the vessel;
 - during the commissioning of the vessel;
 - before the vessel gets under way;
- Develop the skills and confidence of the more junior members of the team through appropriate briefing, guidance and de-briefing techniques.
- Assess own performance and formulate objectives for 'Continuing Professional Development' purposes.
- Develop fault diagnosis strategies and methodologies.
- Identify and terminate the development of error chains.
- Identify essential on-board training needs of both individuals and the team with regard to both operational, emergency and crisis situations.
- Work together in the simulators to achieve a successful outcome from an emergency or crisis situation.

Junior officers will gain some insight into the decision making activities of senior officers and to the development of teamwork.

Bridge Simulator Scenario

Participants will refresh and develop their radar ARPA and electronic navigation techniques in series of exercises in close quarters navigational scenarios, in varying traffic densities and weather conditions.

Engine Room Simulator Scenario

For the purposes of the course, participants travel to Southampton in order to take over a vessel, recently purchased by the company, which has been laid up for some three months. The vessel is at 'dead ship' conditions although a shore power supply is connected. A pre-purchase survey has been conducted and pre-purchase maintenance work has been carried out. Details of survey and maintenance work will be made available on joining. The participants are tasked with reactivating and commissioning the vessel; bringing the vessel to pre-voyage 'stand by' conditions and undertaking a short voyage from Southampton to Rotterdam via the Straits of Dover.

Vessel Particulars:	Deadweight -	30,000 tonnes
	Power (MCR) -	26,500 kW
	Rev/min (MCR) -	122
Main Propulsion Unit:	Sulzer 6RND90M Slow Speed, Reversible, Direct Coupled to Fixed Pitch Propeller.	

Total Ship Simulation Scenario

The purpose of this scenario is to promote co-operation between the two departments in order that an emergency situation does not become a crisis and the ship can be managed safely and effectively.

The Engineering officers will be in the Engine Room simulator and the Deck officers in the Multi Purpose simulator. The ship will be on passage from Southampton to Rotterdam and at the time of the incident will be making a transit of the Dover Straits. The emergency will start with an incident in the engine room, which over a period of one hour will cause increasing problems for the Engineers and make them unsure of their ability to keep the engine running. The Master and bridge team will need engine reliability in order to accomplish a safe transit of the Dover Straits. Both the deck and engine departments will have to consider alternative courses of action and utilise their resource management skills to ensure the safety of life and the vessel.

Debriefing

Debriefing session involve the course participants analysing the outcomes of the combined briefing/planning session and the operational exercise itself. Participants decide and record on a flipchart positive elements with respect to their performance and those elements that could be improved upon. The participants will be particularly concerned with:

- Management issues based on problem definition; formulating alternative solutions and selecting the best option; drawing up the desired outcomes specification; planning; organisation; delegation; monitoring; control of activities and correcting as necessary; evaluating outcomes relative to the 'specification' and determining if the outcomes are acceptable. In particular they will consider how well their planning dealt with situations met which should have been considered during the planning stages (i.e. 'What if....' considerations).
- Recognising 'windows of opportunity' and, based on imposed constraints, prioritising according to operational needs.

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- Human factors issues and identifying the individual links of any error chains, which resulted from their activities and responses to ‘instructor generated’ and/or ‘self generated’ fault scenarios during the exercise. In the case of relevant exercises they answer the question: "would I/we have been prepared to cope with the emergency or crisis situation when serving on a company vessel?"

Human Factors Lecture/Group Work Sessions

The human factors lecture are divided into two sessions. In the first session the participants are given an overview of human factors issues to include: communication and active listening, influence styles, cultural diversity, management styles, situation management and team working. In the second session, they are taught how to ‘think critically’.

Within this first session, the participants are asked to explore the strengths and weaknesses of different styles of communication before being given the opportunity to examine their own communication styles. Similarly, the participants are asked to discuss different management styles, the benefits and disadvantages of each style and the problems that might arise in teams where a particular style predominates. Participants are then given an opportunity to evaluate their own management style.

The objective of the first session is to enable the participants to reflect upon the ways in which their own thinking, communication and behaviour can influence operational safety and efficiency of company vessels. The participants are given opportunities, in short exercises, to practise new ways of communicating and behaving.

In the second human factors session, the focus is on problem solving. The participants are given training in critical thinking; a process of evaluating and diagnosing that prevents trainees from seeing situations as a series of isolated events. They are taught how to integrate information, how to identify (in)consistency and uncertainty and how to adjust or refine their conclusions by deliberate testing and evaluation. They are also taught a procedure for handling time constraints. The participants are divided into teams of navigating and engineer officers and given a desk top scenario in which they are asked to apply their new training to ‘think their way out’ of a difficult problem.

The objective of the second human factors session is to provide the participants with a new skill that will help them when they encounter unexpected, unplanned, or unexplainable incidents on-board. It will also prepare the participants for the subsequent combined simulations.

Course Delegates:

The course is suitable for all ranks of serving deck and engineering officers; however, the ideal group of ten delegates would comprise:

- Master
- First officer x 2
- Second Officer
- Third Officer
- Chief Engineer
- Second Engineer x 2
- Third Engineer
- Fourth Engineer

Company shore based staff are also encouraged to attend the course.

4.5 Comparison of Syllabi

When comparing the example syllabi detailed in the previous section, it can be seen that the emphasis of all three courses is on the development of the non-technical skills related to the use of automation, rather than the knowledge requirements of automation. Only one syllabus specifically addresses “automation awareness” as a separate module (MRM Course, The Swedish Club, 2005). However, the other two example courses make specific mention of the human factors issues that are generally accepted as being directly related to errors arising from the interaction of people with systems, such as situation awareness, monitoring, cross-checking and error trapping. In addition, such issues are embedded in these courses through the use of full mission simulators, which present automated systems for the course delegates to interact with.

It should be noted that all three of the courses described above have been developed to satisfy different customer needs. This explains the difference in the choice of modules in these courses and their mode of delivery. The following quoted text is the module descriptor of the Automation Awareness module of the Swedish Club’s MRM course. However, it should be noted that even within this module, the unit entitled “AUTOMATION AS A TEAM MEMBER” reveals that the course actually embodies all the concepts involved in resource management skills i.e. communication, assertiveness, judgment and decision-making.

“The Automation Awareness module was introduced to create proper attitudes towards automation - to consider automation as useful "team members" but also to increase awareness of possible dangers and avoid overconfidence in automation. The module is divided into five chapters:

INTRODUCTION

In the introduction there is a comparison between automation performance and human performance - the typical characteristics.

AUTOMATION CHARACTERISTICS

This chapter deals with the characteristics related to automation.

AUTOMATION DANGERS

There may be several dangers related to automation. The chapter describes how automation affects workload in different modes, that there may be new types of errors, the risk of misunderstandings and the importance of proper attitudes to automation.

AUTOMATION AS A TEAM MEMBER

Automation is really a "team member" - it carries out delegated instructions, it communicates and challenges you. The chapter describes how we should look upon automation in relation to other course modules:

- Authority and Assertiveness
- Workload
- State of the Ship
- Communication and Briefings
- Judgment and Decision Making
- Challenge and Response

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LEARNING AUTOMATED SYSTEMS

The importance of learning automated systems is discussed. The chapter provides guidelines for learning automated systems:

Learning guidelines:

- normal common modes first
- mental model
- practice
- add normal uncommon modes
- "free play" practice
- learn abnormal modes
- Failure Mode Analysis
- mentally rehearse" (The Swedish Club)

Table 4-1. below highlights the differences in syllabi content for the example courses.

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Syllabus Topic	BRM	ERRM	CRM / MRM
Attitudes and Management Skills	✓	✓	✓
Cultural Awareness	✓	✓	✓
Communications	✓	✓	✓
Authority and Assertiveness	✓	✓	✓
Positive Feedback	✓	✓	✓
Short Term Strategy	✓	✗	✗
Management Styles	✓	✓	✓
Workload Management	✓	✓	✓
Shared Mental Models	✓	✓	✓
Error Chains	✓	✓	✓
Error Handling	✓	✓	✓
Decision making	✓	✓	✓
Leadership	✓	✓	✓
Crisis and Crowd Management	✓	✗	✗
Automation Awareness	✓	✗	✗
Engineering Systems Management	✗	✓	✓
Teamwork and Co-operation	✗	✓	✓
Management of Stress	✗	✓	✗
Fatigue and Circadian Rhythms	✗	✓	✗
Monitoring and Cross-checking	✗	✓	✓
Emergency Preparedness	✓	✓	✓
Environmental Issues	✗	✗	✓
Risk Management	✗	✗	✓
Planning and Prioritising	✗	✗	✓
Critical Thinking	✗	✗	✓

Table 4-1 Comparison between the syllabi of example Maritime Resource Management Training Course.

Appendix F lists those IMO model courses whose syllabi have some relevance to the mitigation of human error in automated ship-borne maritime systems. When developing future resource management courses, the content of these IMO model courses should be taken into consideration.

4.6 Improving MRM Training

One of the findings of this study is that human errors in the use of automated ship borne maritime systems are a subset of all human errors that play a part in accident causation.

Consequently, the conclusion from this comparison of MRM and specific automation awareness training is that currently there is little distinction between specific training to mitigate human error in automated ship borne maritime systems and more general resource management training aimed at reducing human error. Consequently, the following recommendations to improve mitigation of human error in the use of ship borne automated systems through training are of a general MRM nature.

- a. Consideration should be given to making Resource Management training mandatory by placing it in Part A of the STCW 95 Code.
- b. To support the above, qualified trainers are required that need both pedagogical and human behaviour training as well as being subject matter experts. (See IMO Model course 6.09 – Training Course for Instructors);
- c. Output driven courses lead to rigid structures that are not easily adapted to meet student learning needs;
- d. Courses should be developed with the customers’ needs in mind following training needs analysis and should be delivered using a student-centred focus/method. When developing such courses the following points of guidance should be followed:
 - Course participants are unlikely to learn much more than a few unrelated facts if the course is dominated by lectures, or, if a simulator is used as no more than a demonstration tool;
 - Resource management training has to be matched to level of development of the course participants;
 - Students need to be weaned off reliance on the instructor through the gradual introduction of the more complex aspects of the course, as it progresses;
 - The opportunity for interaction between junior and senior officers needs to be encouraged as much learning occurs through dialogue with one’s contemporaries;
 - As adult learners, ships’ officers need to be encouraged to reflect on their actions in order to process this information to develop new theories;
 - Resource management courses should include a specific course objective that will lead to an understanding of human errors related to the use of automated ship-borne maritime systems and how these errors may be mitigated.
- e. Resource Management training should be considered for inclusion in all cadet officer training programmes.

4.7 Suggested MRM Training curriculum

The research undertaken for this study confirms that automation components of any existing curriculum are really subsets of resource management. The concept of an ‘ideal’ curriculum, comprising solely automation components, may be misguided at present because the relevant issues are currently and perhaps more suitably, dealt with under the wider umbrella of CRM. A curriculum that only deals with automation issues would be out of context.

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Based on the results of a Training Needs Analysis, training course designers will provide a syllabus, in accordance with customer needs, which will be based upon a set of criteria that include the following:

- Target group of trainees (i.e. experience, qualifications, role);
- Duration of training period and budget;
- Degree of sophistication of automation on company's vessels;
- Training facilities available (i.e. availability of simulation devices);
- Experience and quality of instructors;
- Assessment of competence requirements.

Consequently the form of any training course, which forms part of a curriculum, will vary according to the application of these criteria.

The research conducted for this study compared the syllabi of three exemplar MRM type courses, which between them provide the majority of the current provision. The evidence from this research suggests that, based on an analysis of the frequency of modules within the syllabi in Section 4.5, the following list of core modules would always be part of any training course dedicated to the mitigation of human error in automated ship-borne maritime systems. Other modules may be included as a result of the Training Needs Analysis.

- Attitudes and management skills
- Cultural awareness
- Communications
- Authority and assertiveness
- Positive feedback
- Management styles
- Workload management
- Shared mental models
- Error chains
- Error handling
- Decision making
- Leadership
- Emergency preparedness

Training developers should be considering how, within the current MRM courses, they incorporate exercises and scenarios covering relevant automation issues, which are embedded within a MRM context. Development of individual training developers who have the knowledge and pedagogical creativity to do this is paramount.

5 Guidance for automated maritime systems

5.1 Guidance for shore-based company management

Shore-based company management should avoid assuming that automation will lead to a reduction in manpower/manning levels without further analysis. Any proposed reductions in manning requirements through the adoption of automation should be investigated through formal methods of evaluating the manning requirements (e.g. through the methods suggested by ABS guidance [46]). Consideration should be given to the number of crew necessary to safely operate the vessel in the event of a complete automation failure, e.g. in the event of the failure of a distributed control system.

Shore-based company management should obtain feedback from representatives of the final users and maintainers of the automation during the procurement of automated systems. As a minimum, users and maintainers should have input in determining the requirements and in evaluating the options available (e.g. commercial-off-the-shelf (COTS) equipment). Ideally, the company should devise and implement a Human Factors Integration (HFI) plan alongside any new and upgrade equipment procurement programmes to support good Human Factors (e.g. ABS guidance [45]). The HFI plan should include provision for early identification of any HF issues potentially raised through use of COTS equipment (see Section 3.1.3 for further details).

Shore-based management should ensure that automated ship-borne systems can be used to easily obtain an overview of those systems that are being monitored and controlled by the automation, so that on-board duties can be carried out safely and effectively.

Shore-based management should question potential suppliers of COTS automation equipment on the level of Human Factors and Ergonomics design features incorporated into the equipment. Shore-based management's enquiries should seek to establish the existence and extent of the following:

- Input from automation users, or representatives of the users (e.g. in defining requirements, evaluation of design concepts, etc.);
- Use of operational experience on predecessor systems (e.g. frequently reported issues in use);
- A Human Factors Integration plan to support the design process;
- Human Factors activities during the design (e.g. task analysis, human error analysis, etc.);
- Use of Human Factors standards and guidelines in the design process;
- Level of Human Factors knowledge and experience within the design team;
- Guidance on training requirements.

Further guidance and additional details can be found within STGP 11 [45] and Section 3.1.3.

Shore-based management should actively canvas automation users for their experience with existing maritime automation, especially for incidences of misunderstanding and confusion in using the equipment. This operator experience should be disseminated to all potential users of the operators, to make them aware of any potential misunderstanding and confusion issues. The operator experience should also be exploited in determining the requirements for any upgrade and replacement equipment.

In procuring automated systems, shore-based management should ensure that the proposed system does not interfere with operators accessing the information cues used on older non-automated systems. Users should be able to revert to manual control should the automation fail. Users should be able to over-ride automation in the event of a conflict (although the facility to issue a warning may be retained). Manual control of the new system (when necessary) should not make workload demands on ship crews above those on older non-automated systems.

Shore-based management should encourage ship crews to maintain the necessary skills to operate the vessel manually. Automation should not get in the way of crew manually operating or monitoring the system and environment.

Shore-based management should ensure that automation users receive sufficient training, including refresher courses. They should also monitor the effectiveness of training and amend the form of the training if necessary. (e.g. through Training Needs Analysis) to optimise the effectiveness of the training. Ship crews should be provided with training in reverting from automated to manual operation, especially under simulated abnormal and emergency operating conditions.

COTS equipment that is heavily reliant on different modes to display information and provide control should be avoided.

Shore-based management should ensure that the crew handover period in port is sufficiently long to allow the old crew to pass their knowledge onto the new watchkeepers. Shore-based management should also investigate training methods that bypass the inadequacies of 'cascaded training' (e.g. computer-based training).

5.2 Guidance for shipboard management

Shipboard management should encourage the crew to practise the skill sets involved in manual operation and monitoring of systems needed in the event of failure of the automated system. The crew should be encouraged to use other cues in the environment to cross-check the output of automation and to develop and maintain their situation awareness on sources independent of automation.

Shipboard management should encourage crew communication to support shared awareness and understanding of current operations, especially when different teams are remotely located (e.g. maintain good communication between the bridge and engine room). Shipboard management should practise good Crew Resource Management (Bridge Resource Management and Engine Room Resource Management) methods to maximise crew resilience and general awareness in the face of automation failure and/or confusion.

Shipboard management should encourage the crew to report any concerns and issues they may have with the functioning and operation of the automation. Crew should be encouraged to share any instances of misunderstanding and confusion they experience in using the automation. Any issue that could potentially result in an incident should be conveyed to shore-based management.

Shipboard management should ensure the crew conduct regular cross-checking of automation functioning.

During periods of low workload and benign operating conditions, shipboard management should consider reverting automated functions (some or all) to manual control and monitoring, to provide the crew with the opportunity to practise their skills and familiarise them with the procedures for reverting from automatic to manual control.

Shipboard management should ensure that all automated system-users on-board are aware of how, why and when to use any emergency functions that are available through the system (e.g. emergency run, emergency over-rides, shutdowns and resets).

5.3 Guidance for automation users (e.g. Seafarers)

Users should try to avoid making assumptions about automation. Many automated systems function in an entirely different way from an expert human operator. In addition, automation function can vary enormously from ship to ship.

Users should be encouraged to use periods of low workload to practise manual skills. Automation read-outs can be manually cross-checked. Use can be made of other cues in the physical environment that allow the user to inform their situation awareness independent of the automation display. For decision aids, the users could attempt to arrive at a decision independently of the aide, before comparing their solution against the recommendations of the automated decision-aid.

Users should be encouraged to voice concerns they have over the functioning of an automated system. Automated systems are notoriously difficult to understand. Users should avoid assuming that other members of the team will be more familiar with the automation and therefore that others would be the first to spot any potential problems.

Users should be encouraged to report any misunderstanding and confusion they experience with the automation, especially if the misunderstanding could have potentially resulted in an incident if left undetected. Users should report these experiences through any channels they feel comfortable doing so; if necessary, through any confidential reporting systems in place (e.g. CHIRP and MARS).

Users should take the opportunity to familiarise themselves with the procedure for reverting from automatic to manual control.

Users should contribute to crew communications that support shared situation awareness. Users should contribute to crew communications that support shared understanding of automation functions and activities.

Users should be aware that automation has vulnerabilities and can fail, sometimes in inexplicable ways. Users should be on guard that automation is particularly prone to being a cause of human operator misunderstanding and confusion.

Users should prepare themselves to ensure they get the best from any training provisions. Users should provide feedback where they perceive improvements could be made in the training provisions.

Users should be aware of the issues that can arise from confusing the current mode of any control and/or display device (especially for computer GUIs). Users should guard against mistaking the currently selected automation mode, especially under high workload conditions and when feeling the effects of fatigue.

Much of the guidance in the above sections is implied in the provisions of the ISM Code. However, the code is a goal setting document and although it has sections on resources and personnel, emergency preparedness and maintenance of the ship and equipment, none of these specifically mentions automated ship borne maritime systems.

5.4 Guidance for automated marine systems

The guidance can be graphically mapped using the Vee Model of Vessel Lifecycle [83]. The model is presented in Figure 5-1.

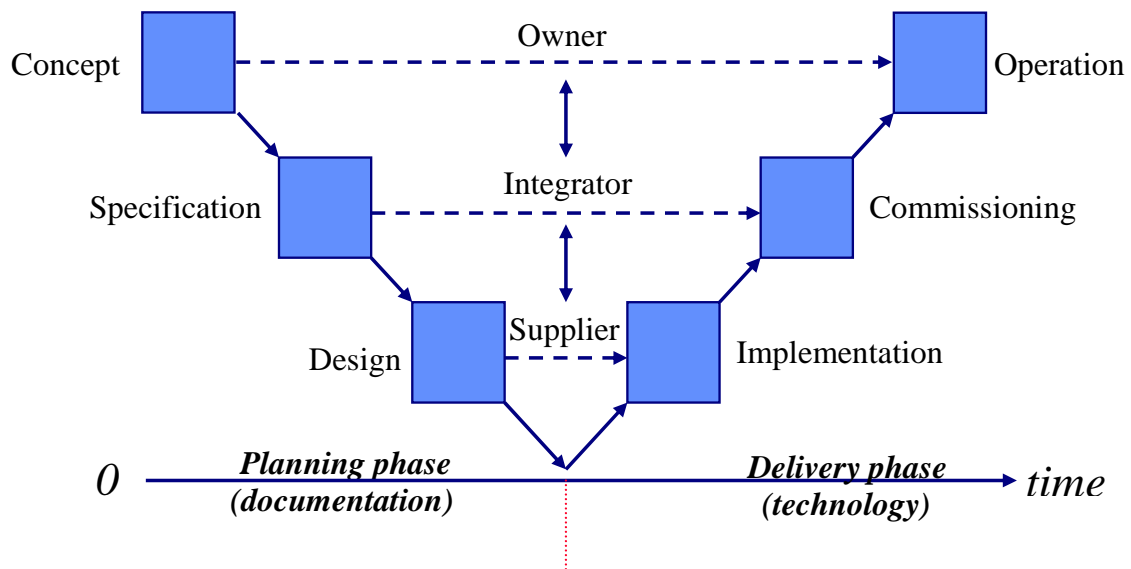


Figure 5-1 The Vee Model of Vessel Lifecycle [81]

The guidance developed for automated marine systems can be mapped onto the vessel lifecycle as per below.

Concept phase:

- Verify any assumed savings in manning levels anticipated with the introduction of automation.

Specification phase:

- Ensure automated systems do not interfere with manual control and monitoring of the vessel.
- Ensure automated systems provide an overview of systems being monitored and controlled by the automation.
- Avoid COTS equipment that is heavily reliant on modes for operation.

Design phase:

- Involve users in the procurement of new equipment.
- Question commercial-off-the-shelf (COTS) suppliers on the level of Human Factors involved in their products.

Implementation phase:

- Increase operator awareness of mode errors.
- Provide training in automation.

Commissioning phase:

- Provide training in automation.
- Encourage crew to report any concerns with the function and operation of automation.

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- Provide opportunities to practise the procedures involved with reverting from automatic to manual control.
- Ensure crew are aware of how, why and when to use any emergency functions.
- Increase operator awareness of mode errors.

Operation phase:

- Encourage operators of automation to share experiences involving misunderstanding and confusion during operation. This experience should be collected and disseminated to other users.
- Support ship crews in maintaining their skill sets.
- Provide training in automation.
- Ensure crew handover periods are sufficient to allow the old crew to pass on their knowledge to the new watchkeepers.
- Encourage crew communication to support shared awareness and understanding.
- Ensure crew conduct regular cross-checking of automation.
- Consider reverting to manual control and monitoring during low workload and benign operating conditions.
- Provide opportunities to practise the procedures involved with reverting from automatic to manual control.
- Consider using periods of low workload and benign operating conditions to practise the procedures involved with reverting from automatic to manual control.
- Increase operator awareness of mode errors.

Please note that some guidance can span multiple phases and this is reflected in duplication of the guidance under all appropriate phases.

6 Conclusions

6.1 Maritime automation issues

The following human element issues were identified from the maritime case studies:

- There is sometimes an over-reliance in the automation by the ship's crew leading to a false sense of security that the automation will always handle the situation safely;
- Ship's crews are often over confident in the data presented to them by automated control systems and this leads to a lack of crosschecking of data;
- There is often a lack of understanding by the ship's crew of automated control systems and any inherent weaknesses they may possess;
- Automated ship-borne maritime systems do not always have the best ergonomic design considerations.
- On some screen-based automatic control systems, the human-computer interface can be very confusing to the user.
- Due to the inherent latency in some control systems, it may not always be possible to recover an error, even if it is very quickly realised.
- Serious consequences can arise if ship's crew are unaware of the failsafe actions that a control system can take automatically following an operator error.
- Maintenance and calibration errors when setting up automatic control systems can lead to catastrophic consequences.
- Some current automated systems do not adequately augment the situation awareness of the system operators.
- A typical modern bridge arrangement can present the crew with information overload issues.
- Poor bridge design and ergonomics can have detrimental effects on human performance and increase the incidence of human error.
- Inconsistencies exist in the display formats of Navigational Information between manufacturers. Greater standardisation is required.
- Human operators rarely understand all the characteristics of automated systems; system weaknesses and limitations can remain hidden from the operator.
- Designers do not design automated systems with the range of competence of the automation operator community in mind.

The current taxonomies and philosophies used by maritime incident investigating authorities to categorise incidents have inconsistencies, which mean there can be a failure to establish the complete causal chain of incidents.

6.2 Standards and guidelines for addressing the effects of automation issues

The International Maritime Organization has a number of regulations and guidelines in place that are relevant to the mitigation of human error in automated ship-borne maritime systems (Resolution A.947(23); MSC Circulars 982, 1061 and 1091; SOLAS Regulation

V/15). Making the maritime industry more aware of these regulations and guidelines was seen as necessary to try and ensure that appropriate human error mitigation strategies are implemented within industry.

In the main, Human Factors design standards and guidelines are not specifically targeted at automation issues, although there is indirect coverage, for example, in designing to minimise human error. One notable exception is provided by the Federal Aviation Administration [50] that prescribes the design requirements for automation. This appears to encompass the width and breadth of automation issues, drawing upon experience from all industries, in addition to theoretical research. However the document focuses upon defining what is required and there is little guidance on achieving compliance. In addition, Endsley et al [33] have developed a set of guidelines for designing automation to support development and maintenance of the operator's situation awareness.

Human Factors Integration plans, whilst not specifically restricting themselves to automation issues, do provide guidance; with the added bonus of managing Human Element issues in general.

Adoption of a User Centred Design (UCD) philosophy is a further strategy that should be pursued during the procurement phase of automated systems. Common UCD strategies include involving users in the determination of requirements and the evaluation of equipment options.

6.2.1 Guidance from other industries

The Aviation Industry is at the forefront of regulations aimed at certification of operators (i.e. demonstrate a required level of competency). However the focus appears to be more on demonstrating declarative knowledge ('know that') at the expense of procedural ('know how').

The Chemical Industry is driven by a framework of requirements. To a large extent, guidance for achieving these requirements is not provided. One notable exception is the Energy Institute methodology for assessing the manning requirements for automated plant [57].

The Nuclear Industry regulatory bodies require licensed sites to undertake a Human Factors Engineering programme (broadly equivalent to a Human Factors Integration plan).

Common mitigation strategies for addressing automation issues centre on manning, training and design.

Confidential report systems have proved effective in disseminating operator problems to the community at large. However, it is retrospective in nature and therefore can form only part of any mitigation strategy.

6.3 Training requirements to address automation issues

6.3.1 Review of CRM training

Currently the only mandatory requirements for the non-technical skills of crisis management are the IMO Seafarer's Training, Certification and Watchkeeping Code. No mention is made of human error in relation to automation.

CRM courses need to pay as much attention to the delivery of training as to the content itself.

Current training courses that address resource management issues tend to be delivered in three forms:

- Bridge Resource Management
- Engine Room Resource Management
- Maritime or Crew Resource Management

Only one syllabus specifically addresses 'automation awareness', whilst two others encompass Human Factors issues including human error. All of the courses have been developed to satisfy different customer needs and therefore direct comparisons are inappropriate. In addition, there is no standardised presentation of syllabi content between them.

6.3.2 Improving MRM training

One of the findings of this study is that human errors in the use of automated ship borne maritime systems are a subset of all human errors that play a part in accident causation. Consequently, the conclusion from this comparison of MRM and specific automation awareness training is that currently there is little distinction between specific training to mitigate human error in automated ship borne maritime systems and more general resource management training aimed at reducing human error. Consequently, the following recommendations to improve mitigation of human error in the use of ship borne automated systems through training are of a general MRM nature.

- a. Consideration should be given to making Resource Management training mandatory by placing it in Part A of the STCW Code.
- b. To support the above, qualified trainers are required that need both pedagogical and human behaviour training as well as being subject matter experts. (See IMO Model course 6.09 – Training Course for Instructors);
- c. Output driven courses lead to rigid structures that are not easily adapted to meet student learning needs;
- d. Courses should be developed with the customers' needs in mind following training needs analysis and should be delivered using a student-centred focus/method. When developing such courses the following points of guidance should be followed:
 - Course participants are unlikely to learn much more than a few unrelated facts if the course is dominated by lectures, or, if a simulator is used as no more than a demonstration tool;
 - Resource management training has to be matched to level of development of the course participants;
 - Students need to be weaned off reliance on the instructor through the gradual introduction of the more complex aspects of the course, as it progresses;
 - The opportunity for interaction between junior and senior officers needs to be encouraged as much learning occurs through dialogue with one's contemporaries;
 - As adult learners, ships' officers need to be encouraged to reflect on their actions in order to process this information to develop new theories;
 - Resource management courses should include a specific course objective that will lead to an understanding of human errors related to the use of

automated ship-borne maritime systems and how these errors may be mitigated.

- e. Resource Management training should be considered for inclusion in all cadet officer training programmes.

6.4 Guidance for automated maritime systems

These are directed at three stakeholder groups: shore-based company management; shipboard management (e.g. Ship's Master); and automation users (e.g. seafarers).

- Verify any assumed savings in manning levels anticipated with the introduction of automation.
- Involve users in the procurement of new equipment.
- Question commercial-off-the-shelf (COTS) suppliers on the level of Human Factors involved in their products.
- Encourage operators of automation to share experiences involving misunderstanding and confusion during operation. This experience should be collected and disseminated to other users.
- Ensure automated systems do not interfere with manual control and monitoring of the vessel
- Support ship crews in maintaining their skill sets
- Provide training in automation
- Avoid COTS equipment that is heavily reliant on modes for operation
- Ensure crew handover periods are sufficient to allow the old crew to pass on their knowledge to the new watchkeepers.
- Encourage crew communication to support shared awareness and understanding.
- Encourage crew to report any concerns with the function and operation of automation.
- Ensure crew conduct regular cross-checking of automation
- Consider using periods of low workload and benign operating conditions to practise the procedures involved with reverting from automatic to manual control.
- Increase operator awareness of mode errors.

7 Recommendations

7.1 Recommendations for further research

It is suggested that a larger study of maritime incidents and accidents using primary data sources be conducted to develop the human element issues raised during the limited review detailed in Section 2.5 into a detailed taxonomy to assist in the categorisation of maritime incidents and accidents. The taxonomy would also serve to raise the awareness of automation issues within the maritime incident and accident investigation community.

A review of methods to encourage manufacturers of automation to adopt better Human Factors and Ergonomics guidance should be conducted. The customer has already identified that some progress could be made through raising general levels of awareness through peer-reviewed publications and conference papers. A further novel approach may be to develop a Human Element evaluation scheme to assess the degree to which automation equipment incorporates Human Factors and Ergonomics features to reduce the occurrence and mitigate the effects of human error. By designing the evaluation scheme to be administered by an inspector for the purposes of assessing the risk for calculating maritime insurance premiums (e.g. via Protection and Indemnity clubs), automation incorporating good Human Factors and Ergonomics would be encouraged through reduced premiums (reflecting the reduced risk of human error contributing to incidents and accidents), whilst automation with poor Human Factors and Ergonomics design would be discouraged through increased premiums and/or adverse terms.

Initial feasibility research could be conducted into whether simulation of automation failure and abnormal operation states could improve operator recognition of automation malfunction. In the aviation industry, security screener performance for detecting threats (a relatively infrequent event) is improved by exposing screeners to artificial but realistic x-ray images of threat objects during the routine baggage handling. By incorporating similar mechanisms in maritime automation systems to simulate failure states and abnormal operation at appropriate times (e.g. during periods of low workload), operators may be provided with the necessary experience to recognise these relatively infrequent occurrences when they happen in the real world. If such a system could be implemented, it would appear to offer a solution to preventing the failures seen in the 'Royal Majesty' incident. The research would also need to consider the safety implications, for example, what mechanisms would need to be in place to ensure the simulated failure state did not initiate during critical operations.

The maritime industry should review the design guidance for automation available in the aviation industry (e.g. FAA guidelines [50], see Section 3.2.2) to exploit the increased awareness and experience of automation issues within the aviation industry. Where considered appropriate, existing maritime design guidance could be supplemented by adopting and adapting aviation guidance.

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A Appendix A – Review of existing MAIB accident and incident reports that cite automation as a causal factor

REF.	NARRATIVE	REMARKS
0154/2005	Failure of auto synchronization system for generators caused over speed of generator and blackout. Power reconnected after one hour and vessel continued on passage.	Electrical control system failure.
0212/2002	Master started engine and applied combinator control in the wrong direction, causing vessel to leave quay and nearly causing lorry to fall from loading ramp. Company instructions since issued recommending masters to avoid starting engine before ramp is raised and to review ISM Code procedures in this regard.	Poor ergonomics of system design?
0315/2004	ME cooling water alarm shut down operated while under pilotage in confined waters, causing loss of propulsion and black out. Vessel dropped anchor but grounded aft end, which swung in the river current. Shut down was the result of a cooling water sensor failure on an MAK engine. This shut down has now been equipped with a 45 second delay.	ME cooling water sensor failure
0377/2002	While on passage, the main engine shut down due to loss of pressure in main engine cooling water system. This was caused by a sticking automatic temperature control valve preventing the opening of the valve. This led to boiling of the cooling water and gassing up of the pump. This in turn led to a loss of pressure with the auto control system shutting down the engine.	Sticking ME automatic temperature control valve.
0534/2001	Cargo vessel ran aground at the entrance to the Sound of Mull on passage from Sweden to Belfast. The exact circumstances of the accidents could not be determined due to the lack of recorded data and several anomalies in the account of the chief officer. The grounding occurred as a result course not being altered in accordance with the passage plan, of which the following might have contributed: the chief officer was alone on the bridge at the time and might not have been aware of all navigational dangers; the course alteration might have been delayed to allow a fishing vessel to pass at a safe distance; the chief officer might have had difficulty when changing from automatic to manual steering; the sea room in which to take avoiding action in the Sound of Mull was limited	Difficulty in changing over from automatic to manual steering?
0813/2004	As vessel transiting Kiel canal, main engine fresh water pressure sensor failed causing main engine to shut down. Vessel drifted into both embankments before stopping. Engine restarted and continued through canal with tug assistance.	Failure of ME pressure sensor.

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REF	NARRATIVE	REMARKS
0846/2005	The owner reports that whilst on passage the vessel ran out of fuel hence the call to the coastguard. The fuel gauge showed that the tank had fuel, the skipper since recognised that the gauge was faulty. The skipper responded in the IRF by indicating that on future occasions the tank will be manually dipped.	Faulty fuel gauge.
0863/2004	Raw cooling water inlet restricted, possibly by plastic bag or other external restriction. Engine high temperature alarm did not operate due to undetected wiring fault. No.4 piston seized and vessel was towed back to port by lifeboat.	ME high temperature alarm failure.
1122/2003	A 10 metre fishing vessel, with four people on board, lost engine power when the fuel pump's shut-off solenoid failed. Skipper was unable to override the shut-off and he called for assistance.	Fuel shut-off solenoid failure. Failsafe was to shut fuel off.
1141/2002	Vessel ran aground while leaving port. Contact breakers in the steering relay system welded together resulting in a system failure. The master left the bridge to replace the contact breakers, leaving the chief engineer alone on the bridge.	Steering relay failure.
1651/2002	Vessel swinging to Port close to berth. Master changes engine control from bridge to Starboard wing. Vessel increases speed without input from Master. Attempts full astern and then changing control back to bridge without success. Anchors dropped and engine emergency stop operated. Vessel collides with berth causing damage to both.	ME bridge control system failure.

Table A-1 MAIB accidents and incidents citing automation as a causal factor

B Appendix B – IMO Safety of Life at Sea (SOLAS) Chapter V Regulation 15

Regulation 15	Principles relating to bridge design, design and arrangement of navigational systems and equipment and bridge procedures
Summary	<ul style="list-style-type: none"> • Requires owners, naval architects, manufacturers and administrations to ensure compliance with specified ergonomic principles. • Requires owners and masters to ensure that bridge procedures are adopted which take ergonomic criteria into consideration
Text	<p>1. All decisions which are made for the purpose of applying the requirements of regulations 19, 22, 24, 25, 27 and 28 and which affect bridge design, the design and arrangement of navigational systems and equipment on the bridge and bridge procedures* shall be taken with the aim of:</p> <p>1.1 facilitating the tasks to be performed by the bridge team and the pilot in making full appraisal of the situation and in navigating the ship safely under all operational conditions;</p> <p>1.2 promoting effective and safe bridge resource management;</p> <p>1.3 enabling the bridge team and the pilot to have convenient and continuous access to essential information which is presented in a clear and unambiguous manner, using standardized symbols and coding systems for controls and displays;</p> <p>1.4 indicating the operational status of automated functions and integrated components, systems and/or sub-systems;</p> <p>1.5 allowing for expeditious, continuous and effective information processing and decision-making by the bridge team and the pilot;</p> <p>1.6 preventing or minimizing excessive or unnecessary work and any conditions or distractions on the bridge which may cause fatigue or interfere with the vigilance of the bridge team and the pilot; and</p> <p>1.7 minimising the risk of human error and detecting such error if it occurs, through monitoring and alarm systems, in time for the bridge team and the pilot to take appropriate action.</p> <p>Refer to Guidelines on ergonomic criteria for bridge equipment and layout (MSC/Circ.982) and the Performance standards for IBS (resolution MSC.64(67); annex 1); and for INS (resolution MSC.86(70); annex 3).</p>
Guidance Notes	<ol style="list-style-type: none"> 1. Regulation 15 applies primarily to companies, ship builders and naval architects. Masters and watchkeepers of all vessels are responsible for ensuring the efficient deployment and use of bridge resources in particular noting the requirements of 15.6. 2. The Regulation addresses the principles to be followed in the design and layout of ships' bridges and the establishment of bridge procedures using ergonomic criteria. These criteria are detailed in IMO MSC/Circ.982. Where ships are fitted with Integrated Bridge Systems

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	<ol style="list-style-type: none">3. The Regulation specifically covers decisions which are made for the purpose of applying the requirements of Regulations 19 (Navigational Equipment), 22 (Bridge Visibility), 24 (Heading/Track control systems), 25 (Operation of main source of Electrical Power and Steering Gear), 27 (Nautical Charts and Publications) and 28 (Records of Navigational Activities.)4. The Regulation addresses designers, manufacturers and shipowners with respect to the bridge design and layout. However, the responsibility for ensuring correct bridge procedures are adopted lies with the Master.5. Masters should therefore be familiar with the principles involved to ensure that personnel are fully familiar with the equipment and its layout and that procedures are adopted which optimise the design and layout of the ship's bridge.6. Of particular importance to Masters is paragraph .6 relating to the prevention or minimisation of unnecessary work or distractions in order to minimise fatigue and maximise the bridge team's vigilance.7. See also ISO 8468 (Ships' Bridge Layout and Associated Equipment - Requirements and Guidelines,) and ISO 14642 (Ships and Marine Technology - Ships' Bridge Layout and associated Equipment - additional requirements.)8. For Electromagnetic Compatibility (EMC) refer to Regulation 17 and IEC 60945 <p>MSC/Circ.982- Guidelines on Ergonomic Criteria for Bridge Equipment and Layout</p>
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Table B-1 IMO SOLAS Chapter V Regulation 15

C Appendix C - IMO Specification of minimum standard of competency in crises management and human behaviour

From: IMO Seafarer's Training, Certification and Watchkeeping (STCW) Code Table A-V/2

COMPETENCE	KNOWLEDGE, UNDERSTANDING AND PROFICIENCY	METHODS FOR DEMONSTRATING COMPETENCE	CRITERIA FOR EVALUATING COMPETENCE
Organize shipboard emergency procedures	<p>Knowledge of:</p> <ol style="list-style-type: none"> 1. the general design and layout of the ship; 2. safety regulations; 3. emergency plans and procedures. <p>The importance of the principles for the development of ship specific emergency procedures including:</p> <ol style="list-style-type: none"> 1. the need for pre-planning and drills of shipboard emergency procedures; 2. the need for all personnel to be aware of and adhere to pre-planned emergency procedures as carefully as possible in the event of an emergency situation. 	Assessment of evidence obtained from approved training, exercises with one or more prepared emergency plans and practical demonstration.	The shipboard emergency procedures ensure a state of readiness to respond to emergency situations.
Optimise the use of resources	<p>Ability to optimize the use of resources, taking into account:</p> <ol style="list-style-type: none"> 1. the possibility that resources available in an emergency may be limited; 2. the need to make full use of personnel and equipment immediately available and, if necessary, to improvise. <p>Ability to organize realistic</p>	Assessment of evidence obtained from approved training, practical demonstration and shipboard training and drills of emergency procedures.	Contingency plans optimize the use of available resources. Allocation of tasks and responsibilities reflects the known competence of individuals. Roles and responsibilities of teams and individuals are

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COMPETENCE	KNOWLEDGE, UNDERSTANDING AND PROFICIENCY	METHODS FOR DEMONSTRATING COMPETENCE	CRITERIA FOR EVALUATING COMPETENCE
	drills to maintain a state of readiness, taking into account lessons learnt from previous accidents involving passenger ships; debriefing after drills.		clearly defined.
Control response to emergencies	<p>Ability to make an initial assessment and provide an effective response to emergency situations in accordance with established emergency procedures.</p> <p>Leadership skills.</p> <p>Ability to lead and direct others in emergency situations including the need:</p> <ol style="list-style-type: none"> 1. to set an example during emergency situations 2. to focus decision making given the need to act quickly in an emergency 3. to motivate, encourage, an reassure passengers and other personnel. <p>Stress handling.</p> <p>Ability to identify the development of symptoms of excessive personal stress and those of other members of the ship's emergency team.</p> <p>Understanding that stress generated by emergency situations can affect the performance of individuals and their ability to act on instructions and follow procedures.</p>	Assessment of evidence obtained from approved training, practical demonstration and shipboard training and drills of emergency procedures.	<p>Procedures and actions are in accordance with established principles and plans for crisis management on board.</p> <p>Objectives and strategy are appropriate to the nature of the emergency, take account of contingencies and make optimum use of available resources.</p> <p>Actions of crew members contribute to maintaining order and control.</p>
Control passengers and other personnel during	<p>Human behaviour and responses.</p> <p>Ability to control passenger</p>		

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COMPETENCE	KNOWLEDGE, UNDERSTANDING AND PROFICIENCY	METHODS FOR DEMONSTRATING COMPETENCE	CRITERIA FOR EVALUATING COMPETENCE
<p>emergency situations</p>	<p>and other personnel in emergency situations including:</p> <ol style="list-style-type: none"> 1. awareness of the general reaction patterns of passengers and other personnel in emergency situations , including the possibility that: <ol style="list-style-type: none"> 1.1. generally it takes some time before people accept the fact that there is an emergency situation. 1.2. some people may panic and not behave with a normal level of rationality, that their ability to comprehend may be impaired and they may not be as responsive to instructions as in non-emergency situations. 2. awareness that passengers and other personnel may, <i>inter alia</i>: <ol style="list-style-type: none"> 2.1. start looking for relatives, friends and their belongings as a first reaction when something goes wrong. 2.2. seek safety in their cabins or in other places on-board where they think that they can escape danger 2.3. tend to move to the upper side 		

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COMPETENCE	KNOWLEDGE, UNDERSTANDING AND PROFICIENCY	METHODS FOR DEMONSTRATING COMPETENCE	CRITERIA FOR EVALUATING COMPETENCE
	<p align="center">when the ship is listing.</p> <p>3. appreciation of the problem of possible panic resulting from separating families</p>		
<p>Establish and maintain effective communications</p>	<p>Ability to establish and maintain effective communications, including:</p> <ol style="list-style-type: none"> 1. the importance of clear and concise instructions and reports 2. the need to encourage an exchange of information with and feedback from, passengers and other personnel. <p>Ability to provide relevant information to passengers and other personnel during an emergency situation, to keep them appraised of the overall situation and to communicate any action required of them, taking into account:</p> <ol style="list-style-type: none"> 1. the language or languages appropriate to the principal nationalities of passengers and other personnel carried on the particular route. 2. the possible need to communicate during an emergency by some other means such as demonstration, or by hand signals, or by calling attention to the location of instructions, muster stations, life-saving devices or evacuation routes, when oral communication is impractical. 3. the language in which emergency 		

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COMPETENCE	KNOWLEDGE, UNDERSTANDING AND PROFICIENCY	METHODS FOR DEMONSTRATING COMPETENCE	CRITERIA FOR EVALUATING COMPETENCE
	announcements may be broadcast during an emergency or drill to convey critical guidance to passengers and to facilitate crew members in assisting passengers.		

Figure C-1 Minimum standards of competence in crisis management and human behaviour

D Appendix D - STCW Guidance on keeping a navigational watch

From: IMO Seafarer's Training, Certification and Watchkeeping (STCW) Code Section B-VIII/2 part 3-1

Bridge Resource Management

4 Companies should issue guidance on proper bridge procedures and promote the use of checklists appropriate to each ship, taking into account national and international guidance*

* ICS *Bridge Procedures Guide* (Witherby Marine Publishing, 32/36 Aylesbury Street, London EC1R OET, UK) may be of assistance in the preparation of programmes.

5 Companies should also issue guidance to masters and officers in charge of the navigational watch on each ship concerning the need for continuously reassessing how bridge-watch resources are being allocated and used, based on bridge resource management principles such as the following:

1. a sufficient number of qualified individuals should be on watch to ensure all duties can be performed effectively;
2. all members of the navigational watch should be appropriately qualified and fit to perform their duties efficiently and effectively or the officer in charge of the navigational watch should take into account any limitation in qualifications or fitness of the individuals available when making navigational and operational decisions;
3. duties should be clearly and unambiguously assigned to specific individuals, who should confirm that they understand their responsibilities;
4. tasks should be performed according to a clear order of priority;
5. no member of the navigational watch should be assigned more duties or more difficult tasks than can be performed effectively;
6. individuals should be assigned at all times to locations at which they can most efficiently and effectively perform their duties and individuals should be reassigned to other locations as circumstances may require;
7. members of the navigational watch should not be assigned to different duties, tasks or locations until the officer in charge of the navigational watch is certain that the adjustment can be accomplished efficiently and effectively;
8. instruments and equipment considered necessary for effective performance of duties should be readily available to appropriate members of the navigational watch;
9. communications among members of the navigational watch should be clear, immediate, reliable and relevant to the business at hand;
10. non-essential activity and distractions should be avoided, suppressed or removed;
11. all bridge equipment should be operating properly and if not, the officer in charge of the navigational watch should take into account any malfunction which may exist in making operational decisions;
12. all essential information should be collected, processed and interpreted and made conveniently available to those who require it for the performance of their duties;

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13. non-essential materials should not be placed on the bridge or any work surface;
14. members of the navigational watch should at all times be prepared to respond efficiently and effectively to changes in circumstances.

E Appendix E - STCW Guidance on keeping an engineering watch [proposed]

STCW Code, Section B-VIII/2, part 3-2 paragraphs 8-1 and 8-2 [proposed]

STW 36/WP.3

ANNEX 1

Page 2

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ANNEX

AMENDMENTS TO THE SEAFARERS. TRAINING, CERTIFICATION AND WATCHKEEPING (STCW) CODE

PART B

RECOMMENDED GUIDANCE REGARDING PROVISIONS OF THE STCW CONVENTION AND ITS ANNEX

Section B-VIII/2 - Guidance regarding watchkeeping arrangements and principles to be observed

Part 3-2. Guidance on keeping an engineering watch

Engine-room resource management

8-1 Companies should issue guidance on proper engine-room procedures and promote the use of checklists appropriate to each ship, taking into account national and international guidance.

8-2 Companies should also issue guidance to chief engineers and officers in charge of the engineering watch, manned or unmanned, on each ship concerning the need for continuously reassessing how engineering watch resources are being allocated and used based on engine-room resource management principles such as the following:

- 1 a sufficient number of qualified individuals should be on watch to ensure all duties can be performed effectively;
- 2 all members of the engineering watch should be appropriately qualified and fit to perform their duties efficiently and effectively or the officer in charge of the engineering watch should take into account any limitation in qualifications or fitness of the individuals available when making engineering and operational decisions;
- 3 duties should be clearly and unambiguously assigned to specific individuals, who should confirm that they understand their responsibilities;
- 4 tasks should be performed in a clear order of priority;
- 5 no member of the engineering watch should be assigned more duties or more difficult tasks than can be performed effectively;
- 6 individuals should be assigned at all times to locations at which they can most efficiently and effectively perform their duties and individuals should be reassigned to other locations as circumstances may require;

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- 7 members of the engineering watch should not be assigned to different tasks or locations until the officer in charge of the engineering watch is certain that adjustments can be accomplished efficiently and effectively;
- 8 instruments and equipment considered necessary for effective performance of duties should be readily available to appropriate members of the engineering watch;
- 9 communications among members of the engineering watch and between members of the engineering and navigational watches should be clear, immediate, reliable and relevant to the business at hand;
- 10 non-essential activity and distractions should be avoided, suppressed or removed;
- 11 all engine-room equipment should be operating properly and, if not, the officer in charge of the engineering watch should take into account any malfunction or inoperable equipment due to maintenance, which may exist when making operational decisions;
- 12 all essential information should be collected, processed and interpreted and made conveniently available to all for the performance of their duties;
- 13 non-essential materials should not be placed so as to hinder engine-room operations;
- 14 members of the engineering watch should at all times be prepared to respond efficiently and effectively to changes in circumstances;
- 15 clear and effective data monitoring to identify possible areas of concern in equipment or systems should be ensured so as to prevent breakdowns/accidents/incidents; and
- 16 effective methods of cross-checking information, data and indications should be developed to obviate the need for total reliance on any specific type of equipment, system or component.

F Appendix F - IMO Model courses relevant to the mitigation of human error in automated ship-borne maritime systems.

SHIP SIMULATOR AND BRIDGE TEAMWORK, 2002 Edition

This Model Course is practical and theoretical and consists of a series of exercises performed on a ship handling simulator. Classroom lectures, to provide the necessary theoretical background for the exercises, are included. Particular items dealt with in these lectures are illustrated either by including them as part of an exercise or by a separate simulator demonstration. Bridge teamwork is dealt with either as interactive Computer Based Training (CBT) or lecture.

TA122E ISBN: 9280141627

PROFICIENCY IN CRISIS MANAGEMENT AND HUMAN BEHAVIOUR TRAINING INCLUDING PASSENGER SAFETY, CARGO SAFETY AND HULL INTEGRITY TRAINING, 2000 Edition

This course covers the mandatory training requirements for masters, chief mates, chief engineer officers, second engineer officers and every person assigned immediate responsibility for embarking and disembarking passengers, loading, discharging or securing cargo or closing hull openings on board passenger and ro-ro ships. It is based on the provisions of section A-V/2 and table A-V/2 of the STCW Code.

T129E ISBN: 9280150855

OPERATIONAL USE OF INTEGRATED BRIDGE SYSTEMS INCLUDING INTEGRATED NAVIGATION SYSTEMS, 2005 Edition

The safe and efficient use at sea of integrated bridge systems (IBS) and integrated navigation systems (INS) requires a level of knowledge beyond that normally given in the training of an officer in charge of a navigational watch. It is not just a matter of learning to use new controls, display techniques or how to switch on and off automatic functions. More importantly, it is learning the decision making processes that must be applied in order to gain the full benefits of the integration in a safe manner and avoid the new problems that automatic controls and integrated systems can sometimes provoke.

This model course has been designed recognizing that integrated bridge systems and integrated navigation systems are a voluntary installation on vessels and they differ significantly in their configuration and operation from vessel to vessel. They can also interconnect to other bridge equipment and systems, which may be compulsorily fitted to vessels, as part of SOLAS or other requirements.

T132E ISBN: 9280142038

OPERATIONAL USE OF ELECTRONIC CHART DISPLAY AND INFORMATION SYSTEMS (ECDIS), 2000 Edition

This course is intended for officers in charge of a navigational watch on ships equipped with ECDIS.

T127E ISBN: 9280161121

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<p>Abstract</p> <p>This report is in response to the Maritime Coastguard Agency's requirement to develop guidance for the mitigation of human error in automated ship-borne systems. A review of maritime incidents and accidents identified ten informative case-studies that, together with other issues located in the maritime literature, provided a core of human element issues associated with automation. Standards and guidelines for automated systems were identified from other safety-critical industries and from the Human Factors community in general. A review of current Crew Resource Management (CRM) training courses found only one addressed 'automation awareness' issues whilst a further two encompassed 'human error' issues. Recommendations for improving the delivery of CRM training are made. Provision of an environment to enable ship crew's to practice critical thinking skills is also recommended. Guidance on the use of automated systems was developed for three stakeholder groups: shore-based management, shipboard management (e.g. ship's master) and automation users (e.g. seafarers).</p>			
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