Automatic Identification System (AIS): A Human Factors Approach

Abbas Harati-Mokhtari
(Liverpool John Moores University, UK & Chabahar Maritime University, Iran)
(Email: A.Harati-Mokhtari@2003.ljmu.ac.uk)

Alan Wall, Philip Brooks and Jin Wang
(Liverpool John Moores University, UK)

Introduction

Majority (80 to 85%) of all recorded maritime accidents are generally attributed to human error or associated with human error. Contribution of human error to maritime accidents has increased over a ten-year period 1991 to 2001 (Baker and Seah, 2004). Most of the accidents are the result of senseless and avoidable human errors. The concern about human factors is growing as human error is significantly implicated in so many marine accidents. Pomeroy and Tomlinson (2000) stated that many of the failures are actually the result of errors (i.e. latent failures) that have been designed and constructed into highly complex systems especially system integration and interfacing. The scale of damage suffered, taken together with the implication of human error as a major cause for the accidents, has made human factors study an important area of concern globally.

Many individuals and organisations are involved in marine navigation risk management framework. The main focus is to enhance safety of mariner's performance through motivation, education and training, system design, and procedures and rules. Figure 1 is a systematic risk management framework adapted from Rasmussen (1997, 2000).

The behaviours associated with the navigation process are at the lowest level and the international organisations responsible for setting laws, at the highest level. The way in which decisions of top levels influence activities of lower levels, and the feedback from lower levels to top levels, will be very important determinants of safety in marine navigation. In addition, some external dynamic forces will put pressures on the system and change the structure of the system over time (Rasmussen, 1997, 2000).

HUMAN ERROR

The impact of marine work environment on mariners and ships are likely to increase the possibility of error on board ship. Factors such as changes in working practice, information overload, information and equipment over-reliance, inadequate training, and fatigue have influenced some accidents at sea such as the collision between *Norwegian Dream* and *Ever Decent* (Pomeroy and Tomlinson, 2000), and the grounding of passenger ship *Royal Majesty* (National Transportation Safety Board, 1997). Human errors depend up on the internal factors related to the operators' characteristics and differences such as skill, experience, task familiarity, etc. and the external factors to the operators such as equipment design and installation, task complexity, work environment, organisational factors, operating procedures. A proper balance between the capability of the human operator and the difficulty of the task would decrease the likelihood of human error (Whittingham, 2004).

Dekker (2002) distinguishes between the Old View of human error, which views human error as a cause of failure and New View of human error, which views human error as a symptom, rather than a cause, of failure. In the New View, human errors are regarded as warning signs of problems deep in the system (latent factors).

Some basic types of human error widely referred to in human research are (Reason, 1990):

Slip is an error due to failure in *execution* of an action sequence.
Lapse is an error due to failure in cognitive *storage* of task information.
Mistake is an error due to failure in cognitive planning of an action sequence. Mistakes are further subdivided in to two types, rule-based, and knowledge-based. Rule-based mistakes occur

in the selection stage of a plan to achieve a desired outcome. Knowledge-based mistakes occur in the generation stage of a new experiential plan in unique situations for which no predefined control plan exists.

Violation is an inappropriate action carried out intentionally and in contravention of safe working practices.

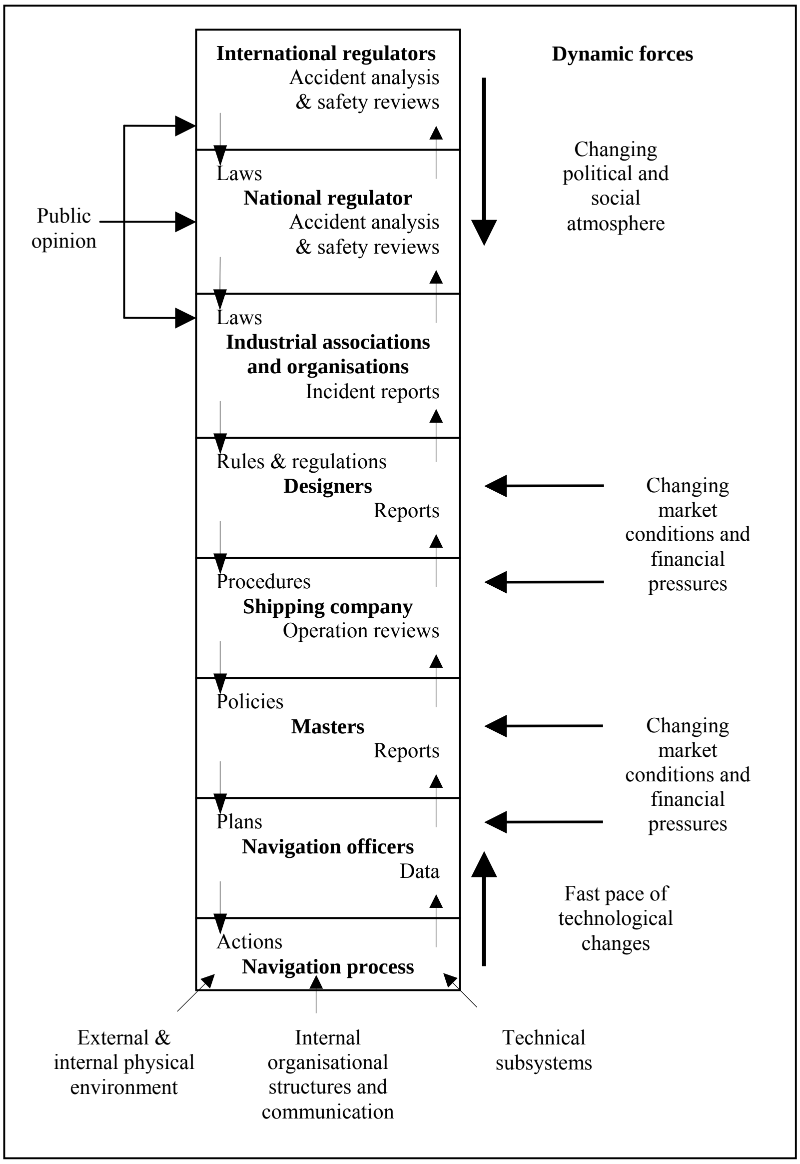

Figure 1. The socio-technical system involved in safety and risk management in marine navigation system (adapted from generic model of Rasmussen, 1997, 2000)

AUTOMATIC IDENTIFICATION SYSTEM (AIS) AND HUMAN ERROR

The International Maritime Organisation (IMO) (2001) objectives for implementation of AIS are to enhance safety and efficiency of navigation, safety of life at sea, and maritime environmental protection. The motivation for adoption of AIS was its autonomous ability to identify other AIS fitted vessels and to provide extra precise information about target ships that can be used in collision avoidance. It has the ability to detect other equipped targets in situations where the radar detection is limited such as around bends, behind hills, and in conditions of restricted visibility by fog, rain, etc.

Poor performance and transmission of erroneous information by AIS are vital issues on the use of AIS equipment for anti-collision operations. These issues have also been raised in the 16th session of IALA AIS Committee. Research at Liverpool John Moores University has been carried out to investigate the issue of human error on the accuracy of the AIS data transmitted and its impact on the ships bridge. This study discusses the results of 3 separate AIS data studies for some of the individual AIS fields. The 3 studies consist of:

1- ***VTS-based AIS study*** carried for about one month during September – October 2005 at Liverpool Vessel Traffic (VTS) station on vessels leaving and approaching port, at anchor and alongside for a total number of 94 different vessels.

2- ***Data-mining AIS study*** conducted for data recorded by AISLive Company of Lloyds Register-Fairplay Ltd. The data consisted of 400,059 AIS reports from 1st March to 17th March 2005, in a worldwide geographical area. 30946 of the AIS entries were selected for a more detailed analysis.

3- ***Proactive AIS study*** conducted through the services of AISweb of Dolphin Maritime Software Ltd, UK, in a wide geographical area from 23rd November 2005 to 2nd May 2006. The data were recorded at ad-hoc times and dates.

Findings

The findings of the research are summarised below, organised by individual AIS field.

MMSI number

The MMSI number problem was particularly noted with many vessels transmitting the incorrect default MMSI of 1193046 (The Nautical Institute, 2005a). This may be the default MMSI for a specific model of AIS transponder that due to wrong equipment setup at installation time or a specific equipment fault it defaults back to this number. Whatever the cause, more than one ship concurrently has been using this MMSI number.

In our Proactive AIS study observations there were up to 26 vessels transmitting the incorrect MMSI number of 1193046, with different particulars, using the AISweb database. Three more MMSI numbers (0, 1, 999999999) appearing on multiple stations were also detected in the Proactive AIS study. This phenomenon is a serious issue. The navigating officers on the bridge should check their AIS transmission data regularly to make sure that their AIS equipment is free of such faults and transmitting correct information. There are other similar reports (The Nautical Institute, 2005b, 2005c) of target swap with sudden and unexpected change of data between vessels.

In the “Data-mining AIS study”, 2% of the erroneous static information identified was in the field containing MMSI numbers, which only include those incorrect MMSI entries with figures incorporating less than 9 digits. It is possible that, even with the correct number of digits, some of the digits showing are wrong when compared with an accurate MMSI database. This could be due to installation errors. In a small number of cases it could be test equipment.

Vessel type

In the “VTS-based AIS study” 6% of vessels had no vessel type available and 3% were defined as “vessel”. The problems of this category include vague or misleading vessel types. Commonly, the general ship type “Cargo” or “Vessel”, rather than an informative ship type is entered into the AIS equipment, but other peculiarities exist. Table 1 shows examples from our “VTS-based AIS study” where similar vessels were broadcasting different ship types under AIS. In some cases the problem is unnecessary vagueness, as for example the use of “Cargo” for a vessel, when “tanker” could have been correctly used. In other cases, the most important and appropriate descriptor may be difficult to assess, unless more guidance is provided to navigators and installers. For example, a high-speed ro-ro passenger ferry can legitimately be defined as a “High Speed Craft” or “Passenger” or “Cargo” under AIS. All three types were observed separately on three sister vessels servicing the same port.

Vessel type (according to Lloyds Register database)	AIS ship type observed on similar vessels during "VTS-based AIS study"
Tanker	"Cargo", "Tanker"
Dredger	"Dredger", "Vessel"
High-speed ro-ro passenger	"Cargo", "HSC", "Passenger"
Supply vessel	"Tug", "Vessel"

Table 1. Examples of similar ships showing different AIS "ship type" descriptors from the "VTS-based AIS study"

Part of the problem is that there is currently not enough categories defined to cover all ships types and it is not feasible to have every potential ship-type. However, some very common and distinctive categories of vessels, such as container, car carrier and bulk carrier, are not separately identified in the AIS specification and would be identified as "cargo". Such differentiation would be helpful for visual identification at sea, as well as for VTS operators. Similarly "Tanker" applies to the different categories of chemical tanker, petroleum tankers and gas carriers. However, incorporating more ship types would require time-consuming regulation and system changes that is not feasible in short-term.

Within the current system, it would increase confidence in the system if navigators see more accurate descriptions with fewer variations between similar vessels. This can only be enforced in the first instance, by better guidance to installers and navigators.

Additionally, this so-called static field showing "vessel type" is altered for some vessel types according to their navigational status on voyage. There is also potential ambiguity between a vessel type and vessel status as in the ship type "Vessel-sailing" used in some models. These aspects are discussed in detail later in section on navigational status.

Ship's name and call sign

Although in the limited "VTS-based AIS study" there were not any incorrect name or call signs identified, in the wider "Data-mining AIS study", problems noticed were that fields were left blank. No name or call sign were given in 0.5% of the total AIS messages recorded. Another problem noticed was use of abbreviated ship name that in many cases, but not all, was because an insufficient number of characters were available which limits this field to 20 characters in the AIS equipment. The errors in these two categories are either, due to error of installation or due to the regulatory design, which does not allow ships names in full if they are longer than 20 characters. These limitations mean that there can be confusion about the ship's name, when a prime purpose of AIS was to clarify this problem. It is still a common practise to use a ship's name in voice communications even though the alternatives of using MMSI number (via Digital Selective Calling) or call sign are also available.

Vessel navigational status

In the "VTS-based AIS study", 30% of ships were detected as displaying incorrect status information and there were probably more examples undetected by the research. Four percent displaying an incorrect status for power driven vessels underway using their engines by showing their status as underway sailing, an option that should be used only by sailing vessels under sail. Other examples detected by the research include a ship underway at 10 knots shown as moored and ships alongside or at anchor shown as underway or sailing.

Navigational status is very important information in situational awareness and anti-collision, particularly as it can decide when a ship would be the "stand-on" or "give way" vessel. Rather confusingly, the AIS data programming shows that navigational status for some vessel categories is given in the field of ship type as well the navigational status field.

In table 2 we have shown some examples of ship types, their different status according to IRPCS and the corresponding data, which would be shown by the AIS. The examples have been selected to show how the philosophy of entries of AIS data is different between different vessel types, In some categories the system has kept ship type according to stated philosophy of the static AIS data. So, for example, a fishing vessel remains a fishing vessel throughout its voyage and life. The voyage related field of navigational status would vary on voyage depending on whether it is engaged in fishing or not. Similarly in table 2, a sailing vessel would change only navigational status and not ship type. Conversely, in table 2, a tug would be shown as the static field of vessel type of "tug" when not involved with towing. When the tug picks up a tow, the so called static field of vessel type is changed from "tug" to "towing or "towing and length of tow exceeds 200 m or breadth exceeds 25 m" as applicable (that is the word "tug" actually means a tug not towing). The reason for this decision by AIS regulators is undoubtedly because the navigational status field can then be used by tug to show when it is additionally "restricted in her ability to manoeuvre" or not. Similarly a dredger would alter its ship type throughout its voyage. It is not clear if a pilot vessel should or should not change its vessel type when it is not engaged in pilotage duties.

It is important for the navigators to be aware and prepared for such ambiguities by specific AIS training both from the programming and from the interpretation perspectives, as indeed they are currently made aware for the intricacies of lights and shapes.

Anti-collision information defined by lights and shapes under the International Regulations for Preventing Collisions at Sea			Equivalent settings on an AIS receiver programmed according to the IALA Guidelines for AIS		
Category of vessel	**Navigational status**	**Extra information**	**Vessel type**	**Navigational status**	**Extra information**
Power driven vessel	Underway	$L < 50m$ or $L \geq 50m$	Passenger/cargo/tanker/HSC/other types of ship	Underway using engine	In length field
Pilot vessel - Not engaged in pilotage duty	Underway	$L < 50m$ or $L \geq 50m$	Other vessel or still Pilot vessel?	Underway using engine	In length field
	At anchor	$L < 50m$ or $L \geq 50m$	Other vessel or still Pilot vessel?	At anchor	In length field
Pilot vessel - Engaged in pilotage duty	Underway	$L < 50m$ or $L \geq 50m$	Pilot vessel	Underway using engine	In length field
	At anchor	$L < 50m$ or $L \geq 50m$	Pilot vessel	At anchor	In length field
Tug - Not engaged in towing	Underway or making way	$L < 50m$ or $L \geq 50m$	Tug	Underway using engine	In length & speed fields
Tug - Engaged in towing	Underway or making way	$L < 50m$ or $L \geq 50m$ & L of tow $\leq 200m$	Towing	Underway using engine	In length & speed fields
Tug - Engaged in towing	Underway or making way	$L < 50m$ or $L \geq 50m$ & L of tow $> 200m$	Towing & L of the tow exceeds 200m or breadth exceeds 25m	Underway using engine	In length & speed fields
Tug – Engaged in towing and restricted in her ability to manoeuvre	Underway or making way	$L < 50m$ or $L \geq 50m$ & L of tow $\leq 200m$	Towing	Restricted in her ability to manoeuvre	In length & speed fields
Tug – Engaged in towing and restricted in her ability to manoeuvre	Underway or making way	$L < 50m$ or $L \geq 50m$ & L of tow $> 200m$	Towing & L of the tow exceeds 200m or breadth exceeds 25m	Restricted in her ability to manoeuvre	In length & speed fields
Fishing vessel - Not engaged in fishing	Underway or making way	$L<50m$ or $L \geq 50m$	Fishing	Underway using engine	In length & speed fields
	At anchor	$L<50m$ or $L \geq 50m$	Fishing	At anchor	In length field
Fishing vessel – Engaged in trawling	Underway or making way or at anchor	$L<50m$ or $L \geq 50m$	Fishing	Engaged in fishing	In length & speed fields
Fishing vessel - Other than trawler engaged in fishing	Underway or making way or at anchor	$L<50m$ or $L \geq 50m$	Fishing	Engaged in fishing	In length & speed fields
Fishing vessel - Other than trawler engaged in fishing with outlying gear >150m	Underway or making way or at anchor	$L<50m$ or $L \geq 50m$	Fishing	Engaged in fishing	In length & speed fields. Use of safety message field to communicate obstruction?
Dredger - Not engaged in dredging or underwater operation	Underway or making way	$L<50m$ or $L \geq 50m$	Cargo ship or other type	Underway using engine	In length & speed fields
	At anchor	$L<50m$ or $L \geq 50m$	Cargo ship or other type	At anchor	In length field
Dredger - Engaged in dredging or underwater operation with obstruction	Underway or making way or at anchor	$L<50m$ or $L \geq 50m$	Engaged in dredging or underwater operations	Restricted in her ability to manoeuvre	In length & speed fields. Use of safety message field to communicate obstruction?
Sailing vessel - under sail only	Underway		Sailing	Underway by sail	
Sailing vessel - Propelled by machinery (with or without sail)	Underway		Sailing	Underway using engine	

Table 2. Comparison of selected ship types and navigational statuses defined in IRPCS with AIS options according to IALA (2002) guidelines

Length and beam

In the "VTS-based AIS study", 47% of the ships displayed incorrect length and 18% of them displayed incorrect beam in their AIS information. The vessels reporting incorrect lengths included:

- 6.4% that showed 0 for their length;
- 36.3% with an error of between 1 metre and 5 metres, and
- 4.3% with an error of more than 5 metres.

The vessels reporting beam inaccurately included:

- 6.3% showing 0 for their beam;
- 8.5% indicating an inaccuracy between 1 metre and 5 metres and
- 3.2% indicating an inaccuracy of more than 5 metres.
- Another 67% of observed vessels indicated an error of less than 1 metre in beam, which has not been included in our inaccuracy figures for the beam. Although, no doubt, some discrepancies are due to rounding, the majority of cases had an inaccurate non-zero decimal figure (e.g. 23.7 instead of 23.3). Although not critical, this may indicate a certain attitude to AIS data generally.

Draught

An obvious discrepancy in 17% of AIS draught entries observed in the "Data-mining AIS study" is its non-availability or reporting of 0m draught. It was also observed that in 14% of the AIS entries draught is greater than length of the ship. We were unable to verify if the remaining 69.5% was inaccurate or not.

Destination and estimated time of arrival (ETA)

In the "Data-mining AIS study" the sample of 30946 AIS transmissions, 49% showed obvious errors in the fields of destination and ETA. Some of the vague or incorrect AIS entries for destination found were; a number instead of destination, a country name instead of port name, an abbreviated name difficult to interpret, the words "not available" or "not defined" or "null", mischievous input (e.g. "to hell") or a blank field. It should be appreciated that the study was only able to identify inconsistencies and many erroneous entries would be undetected. Conversely the vague entries for ETA and destination may actually be the vessel's best knowledge in a small number of cases. Accurate knowledge of the correct destination of other vessels on the AIS can be very useful in areas of high traffic congestion and in port approaches or at the entrance to inland waterways. It was observed that ETA is also not updated in a number of AIS transmissions. Although these fields are optional, if it is to be of use, ships should maintain it accurately and regularly.

Heading, course over ground (COG), speed over ground (SOG), and Position

Unfortunately during this research it was not possible to investigate heading, COG, SOG, and position. Further research on accuracy of such fundamental AIS information is very important if AIS is going to be used for anti-collision purposes and allow successful data fusion with radar information. However in the "Data-mining AIS study" it was found that 1% had shown latitude of more than 90° and longitude of more than 180° or the position 0°N/S, 0°E/W. in addition, a heading offset of 90 degrees or more (The Nautical Institute, 2006) and a vessels AIS incorrectly transmitting position 00°N 000°W (The Nautical Institute, 2005c) has already been reported.

Other AIS-related problems

Correct installation of AIS and its integration with other navigational equipments, accuracy of manual data being input to the system, and ability of the mariners to correctly interpret received information are great concerns if AIS is to be used to enhance decision making on the ship's bridge. Bailey (2005) claims that 80% of AIS messages contain some error or inaccuracies. Installation of AIS and mariners training in the use of equipment are important issues that affect AIS operations, which have not been prioritised in the implementation of AIS. It has been argued (The Nautical Institute, 2005c) that AIS has the potential to be a useful navigational aid if correctly used, due to its high updating rates on the changes made by other ships. However, at present, the reality is that in many cases, information, which is being provided, is directly misleading. This is especially dangerous if the AIS information must be relied upon at critical times such as when visibility is restricted and when radar detection ability is limited.

In the case of the accident between *Hyundai Dominion* and *Sky Hope* (Marine Accident Investigation Branch (MAIB), 2005) a safety text message was used to send a collision warning that was not identified by the addressed vessel. It is not clear whether text messages should be used for such purposes by the mariners. If they are to be used, both auditory and visual warning signals, with adjustable individual response parameters, could be incorporated to facilitate better and more appropriate responses (Hellier and Edworthy, 1999). Warning signals in the form of a buzzer associated with a text message that could appear on the screen to inform the mariners about any incompatibility of the navigational status with speed could have an influential effect in reducing risk in dangerous situations (Baldwin and May, 2005).

If the regulatory authorities are insisting that AIS is employed as an anti-collision aid then it is essential for correct information to be transmitted.

Contrary to intention, there is some evidence that AIS technology actually *increases* VHF calls between ships for the purpose of collision avoidance. Bailey (2005) claims that about 90% of 245 cases of VHF calls recorded at Dover Coastguard Channel Navigation Information Service (CNIS) were concerned with collision avoidance. This may cause more violations of the anti-collision regulations and reduce the ability of the OOW to take appropriate actions in ample time as required by anti-collision regulation. Thus, it could be a factor augmenting the risk of collision in some instances. VHF calls could cause confusion between two ships if they do not agree on specific actions required (Swift, 2004). The increased potential for local arrangements between ships over VHF may cause more confusion and breach of rules of the road (ROR) (Farmer, 2004).

ANALYSIS

Two kinds of failure, active and latent, are associated with accident development in a system. Active failures usually involve unsafe acts of frontline operators in direct contact with the system such as ship's officers or pilots. Latent failures, on the other hand, are generally associated with actions and decisions of those who are indirectly connected with the system, such as managers, designers, and rules and procedures makers.

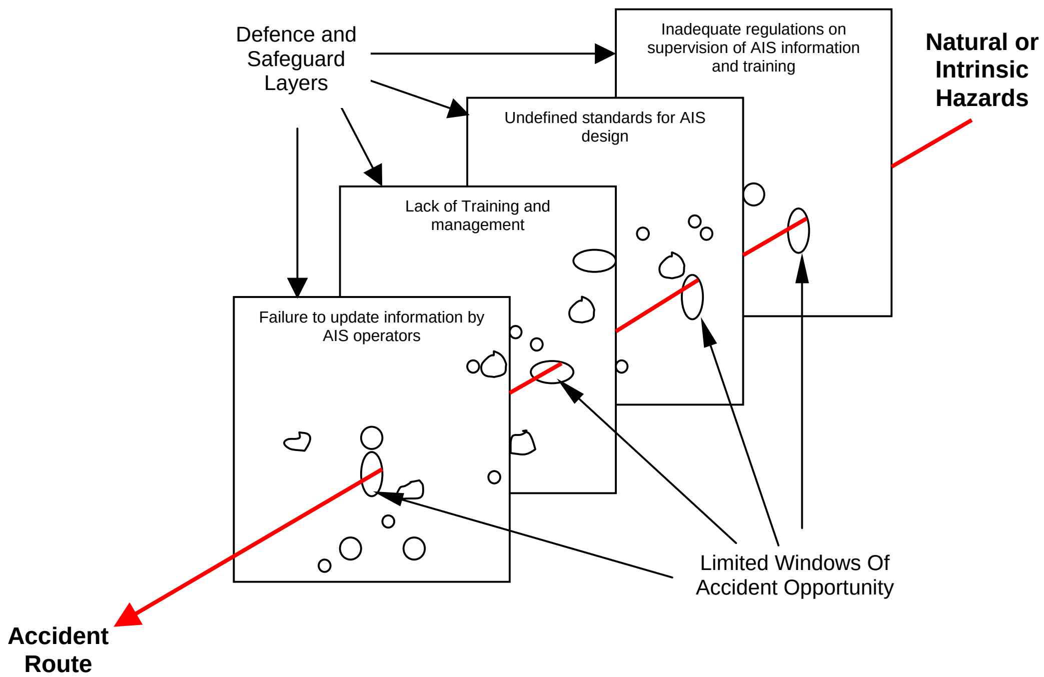

Figure 2. The "Swiss Cheese" model of human error in AIS system, contributing to accident (adapted from the generic model of Reason, 1990, 1997)

Figure 2 is an accident model for the AIS adapted from the "Swiss Cheese" model that shows one possible accident trajectory that may occur in the system.

Using system's approach, based on an application of the "Swiss Cheese" model, failures at different levels of the AIS system are summarised. Table 3 shows the failures observed in the AIS system. Suggestions for remedial action to reduce likelihood of such errors and thus minimise accident opportunities, are also shown. This study indicates that for the AIS to be successful in its proposed aims and objectives, further steps need to be taken by various stakeholders, including the regulatory organisations.

Level of Failures	AIS Problem	Remedial action
Frontline Operator failure. Mainly simple forgetting and inattention or omission of action by ship's navigating officers.	-Failures to update or change information. -Observed in dynamics and/or voyage related information of AIS such as length, beam, draught, destination, ETA, etc. -Incorrect information has been entered.	-A compulsory check list to be filled before, during and at the end of each voyage by navigating officers would be helpful.
Installation failures. Error associated with action of technicians installing the equipment.	-Error in static information set at the time of installation of the AIS.	- Installation of AIS equipments by certified competent technicians. -Proper calibration, and test of the equipment after installation.
Design failures or omissions. They result from the actions or inactions of equipment designers.	-Errors due to over simplification of predefined options available for some data fields, such as default categorisation of ship type or navigational status in the system.	-An interlink mechanism between speed and navigational status. -An interlink between AIS and other navigational equipment. -Use of internationally standardised maritime professional terms and phrases according to IRPCS for menu-based fields of information.
Training and management failures. Lack of knowledge by navigators about the equipment and lack of management by masters to properly supervise the integrity of data.	-Lack of competency of mariners to use the equipment properly.	-Proper theory and practical training for mariners and operators ashore. -Regulations for requirement of the AIS user certificate. -Proper supervision from senior officers on board for integrity of AIS data. -More responsibilities by shipping companies for not sending navigator to sea without proper AIS training.
Regulatory failures. Lack of standardisation for equipment design. Inadequate regulation on training of navigators in AIS operations. Lack of supervision on the proper use and data accuracy of the equipment by local authorities.	-Wrong application of rules to define default list of options.	-Definition of specific unified standards for equipment design. -Following of agreed standards by different AIS designers and manufactures. -Proper regulation for compulsory training should make by international regulatory organisations. -Proper supervision on AIS operation on board ships by Local authorities. -Penalties for knowingly displaying incorrect information should be imposed consistently by regulatory authorities.
Violations. -Lack of supervision by local authorities on the accuracy of information transmitted by AIS.	-Observed in AIS field of destination. Poor design could also lead to inaccurate entries.	-International regulations are needed in this regard to authorise and engage local government agencies such as port state control (PSC) in inspection and examination of the accuracy of AIS data in their territorial waters.

Table 3. Summaries of the human failures associated with AIS equipment

CONCLUSION

- The findings of the present studies, and previous research show that the data provided by AIS are not reliable in many cases and therefore mariners cannot wholly trust the equipment. This could lead to further deterioration in AIS usage and data quality.
- There is an assumption by some navigators and accident investigators that the AIS is an aid to safe navigation by providing additional information for anti-collision purposes. The use of AIS fields to show anti-collision status has some peculiarities for some vessel categories not dissimilar to some of those in the use of lights and shapes. Understanding the use of lights and shapes is a familiar part of navigator training and similar AIS training needs to be introduced. This training would also encourage the use of the narrow definition of the word "sailing" in the context of the AIS message and in the IRPCS.
- IMO needs to clarify the regulations about use of safety text messaging for anti-collision conversations between vessels. Should this method of collision avoidance be approved, the existence of an effective audio-visual warning signal to notify the receipt of safety text messages with suitable training in this regard would also help. Proper training of navigators and other AIS users is an important issue as demonstrated in the *Hyundai Dominion* and *Sky Hope* (Marine Accident Investigation Branch (MAIB), 2005). Lack of familiarity with AIS is likely to reduce the confidence of navigators in using it in their normal anti-collision activities. An international mandatory AIS training course would improve its use at sea.
- It was noticed during this research that many of the input errors in field of ship's navigational status are due to memory slips or omission to execute an action. The AIS equipment could easily have self-checking mechanisms and links to other equipment to detect obvious inconsistencies. Use of warning signals could also be extended to include a link with the ship's navigational light system.
- The automation of AIS is mainly related to the transmission and reception of data and the integrity of the system is dependent on many manual inputs. The current unreliability of AIS data is a critical issue against the AIS trustworthiness as a navigational aid in collision prevention activities. Proper supervision, surveillance of accuracy, and enforcement of quality of AIS data by competent maritime authorities would enhance its efficacy in all navigation operations.
- It is apparent that some optional fields of AIS information, such as destination and ETA, are not considered important by the mariners as in most cases they are not updated. Navigators need more encouragement to maintain the data showing on their equipment. It will also give them more confidence in AIS data broadcasted from other ships.

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