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Integrated Marine Electronic Systems – Some User Associated Issues for the Designer

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Marine accidents have many causes but a recurring theme is poor watch-keeping often caused by weak bridge management. Information overload is sometimes blamed for accidents and attempts to reduce information overload may include electronic systems which have been produced for integrating information from various electronic sources so that information is concentrated on fewer screens. This article explores some of the issues facing the designers of such systems. While acknowledgement is given to some of the technical problems, the article concentrates on those issues associated with the user of such systems, in particular, domain knowledge, screen design and user control. Available Marine Accident Investigation Reports for 2004 are used to highlight that, in that year, only one passenger vessel incident was attributed in part to poor data from electronic aids. However, it is accepted that a much wider study of such reports is needed before any firm conclusions can be drawn.

KEY WORDS

1. Integrated systems. 2. Marine electronic aids. 3. Design issues.

1. INTRODUCTION. Safety in the marine industry is of paramount importance and for some time integrated electronic systems have been used so that the officer of the watch is bombarded with less information. The development of IEC 61924 (on integrated navigation systems) has been on-going for over five years and, more recently, it has been suggested (Fisher, 2005) that integrating information may increase safety. However, there have been few studies which evaluate the best methods of realising practically the integration of information from electronic systems in the shipping industry, although task description methods and work cycles have been suggested as being helpful (Mills, 1998).

This article attempts to give an overview of the practical advantages and disadvantages of using integrated marine electronic navigation and communication aids with examples from both commercial shipping and the fishing industry in the UK as a first step in the direction of improving our knowledge about integrated marine systems. Fishing is the most dangerous peacetime occupation in the UK (Campbell, 2005) in terms of loss of life and if safety within this industry can be increased by using integrated electronic systems then such systems should be implemented. The paper attempts to identify areas of special concern when integrating marine information from the designer's viewpoint, and then, as a brief postscript, by considering the findings of some recent UK *Marine Accident Investigation Branch* (MAIB) reports to see whether integrated information may have helped to prevent the accidents. However, because integrated systems are relatively new and many vessels do not yet use them, such scanty evidence which exists at present cannot be conclusive. A longer time-frame focussing on vessels with integrated electronic systems is needed before drawing any worthwhile conclusions. First, though, we turn to a brief historical background after which the characteristics of integrated information systems are considered.

2. BACKGROUND. During the 1980s in particular, a concept known as the *Bridge '90* developed which worked towards a one-man [*sic*] bridge primarily for military naval use but also for general merchant shipping. This ideal suggested that it was possible to have only one person on watch while navigating ships provided the information necessary to proceed was integrated by the electronic computer systems. Much work was done on developing prototypes of suitable systems, basically driven from two different directions: first, the Royal Navy had agreed by 1988 that it was no longer affordable to fit each new warship as an individual design but some common consensus was needed leading to a standardising of the equipment needs of each vessel for communication and navigation (Hadley, 1988). The second direction came from the seminal work of Abramowski (1976) which Witty (1984) used to further the integration of navigation and fishing aids within the fishing industry (Mills, 1999). However, little work has been done since the 1980s to investigate thoroughly the use of integrated information systems in the fishing industry apart from a project in Denmark (Beech and Anderson, 1995).

Within the military based navies, Osga (1989) and Stoop (1990) worked towards guidelines for integrating information for ships' bridges using their experiences within the USA and Dutch navies respectively but much of this work was not implemented partly due to cost and partly due to the need to change maritime law so that single chip integration is legally acceptable (Mills, 1999). In addition, network topologies need to become reliable enough for personnel to have confidence in them in safety critical situations. However, it is worth noting that a recent draft international standard (ISO/DIS 8468, 2005) assumes traditional multiple workstations (Sections 5.1.2 to 5.2.3) and shows little evidence of taking an integrated approach to displaying information on the bridge.

Thus, integration of information in the marine world has developed to be a combining of the outputs of the various sources of data so that the officer of the watch can obtain readily and speedily the information needed to make decisions. In essence, it is a moving away from the control room scenario of traditional bridges through a reduction in the number and usage of screens to a situation where there may be only a navigation screen usually based on the chart and, for fishing vessels, a 'fishing' screen showing such information as the position and attitude of the net. These systems usually involve the radar output as part of the navigation information as well as data from the global positioning system (GPS) and the echo-sounders etc. Data from a weather system, for example, can also be superimposed on the navigation screen. Of course, at present, maritime law demands the carrying of backup systems so there would still be other screens functioning as output devices in operation on any bridge or in any fishing vessel's wheelhouse.

Before proceeding further, it will be useful to discriminate between automated and integrated systems since these are sometimes confused.

3. AUTOMATED OR INTEGRATED SYSTEMS?

Automated systems have been used for many years for navigation in the form of autopilots which use human input of waypoints but then execute these instructions automatically. Indeed, a traditional 29 feet sailing vessel has successfully automatically navigated from Fair Isle in the Shetland Islands (off north-east Scotland) via the Orkney Islands to Gateshead in north-east England, albeit linked to a remote (human) controlled system (Labbe, 2005). *Integrated* systems, on the other hand, operate automatically but use information which has been selected by the system from a choice of sources with some information being discarded in the process. Thus, an integrated system has control, at least to some extent, of the information it can use and consequently, the system must make decisions as to what information it displays to the user and what information it uses to activate other parts of the system. A very simple integrated system is an alarm attached to, but not embedded in, an echo-sounder which sounds when the vessel enters water below a stipulated depth; here the automated system reads the depth data selected from one of say two depth-sounders and processes this for reading on the screen by the user. The echo-sounder is programmed so that should the depth reading fall below a certain programmed level, the system activates the alarm; in so doing, the system has taken a decision (always pre-programmed, of course) on the information it has received.

In reality, integrated systems are far more complicated than this simple example since they use data from a number of different electronic sources and display these data on a single screen. An example of an integrated system being used within the fishing industry is that of an electronic chart which also displays fish-finding data. Here, the data from the sonar and netsonde (a sonar system giving readings about the position, attitude and free capacity of the net) are fed on to the chart so that the fishing skipper can see immediately the position of the net in relation to the vessel itself as well as where the most prolific shoals of fish are. While the netsonde and sonar may only be automated with respect to each other and the chart, the chart itself will choose which information it can best exhibit and thus there is a loss of data determined by the system itself. For example, if there is a shoal of fish over a large obtrusion, such as a rock or wreck on the seabed, the system decides (through pre-programming) which item to display; here, safety would dictate that the obtrusion should take precedence over the fish since snagging the net could easily capsize the fishing vessel (particularly if the vessel is a 'beamer').

Thus for our purposes in this article, an automated system is one which automates some procedures without loss of any data while an integrated system has the ability to make a choice of which data/information is to be displayed to the user.

4. ADVANTAGES OF USING INTEGRATED INFORMATION SYSTEMS.

From the academic literature, Mills (1998) derived six design principles for integrating information based on task scenarios associated with trawling. These principles focussed on task domain knowledge informing the grouping of information, task sequences utilising the user's previous domain knowledge with such sequences being completed on one display, task assignments being based on the optimisation of human and system characteristics, and confusion being avoided between similar but different information. Of importance here, functional integration should be used for automated data transfer (Mills, 1998). These principles can be related to both integrating individual electronic aids on the bridge and integrating separate bits of information necessary for safe navigation and fishing. Further, Mills (1998) showed that it should be possible to apply these principles so that an integrated fishing and navigation system for a fishing vessel is reduced to two screens, one each for fishing and navigation. Within this system, the user makes all important decisions but routine tasks are automated as is information transfer between systems. We shall return to this point later as it depends on network topologies and also possible loss of data. However, such a system does drastically reduce the number of screens in a fishing vessel's wheelhouse, thus preventing unnecessary duplication. It is possible that an integrated system, therefore, will reduce the user's cognitive load since the user will no longer have more than a couple of screens to monitor; however, given that decisions such as those of navigation and of which fish to attempt to capture must remain with the skipper (Mills, 1998), there is a possibility that a poorly designed integrated system could increase cognitive load if vital information was too scanty or missing. Thus, the designer of such systems carries an increased burden of ascertaining that the design is adequate from both a work cycle viewpoint and a safety aspect.

Although maritime law has yet to allow full integration of consoles, much of the information integrated can be displayed on a personal computer (PC) which allows easy transferring of data for training purposes. In addition, this hardware configuration will be familiar to many mariners and so will ease the transition from training situations to practical usage at sea (Mills, 1999).

The advantages, then, of using integrated systems include the reduction of screens for monitoring and interaction, the user's involvement still in making crucial decisions and the automation of routine tasks which do not involve any significant decision making (Mills, 1998). In addition, the use of PCs for training should facilitate the use of integrated systems at sea (Mills, 1999).

5. DISADVANTAGES OF INTEGRATED INFORMATION SYSTEMS.

Even though a relatively small number of integrated marine electronic systems are in use in both the commercial shipping industry and the fishing industry, there are still some issues associated with using these systems. There are a number of possible disadvantages which may be divided into two types: those to do with the system architecture itself and those associated with its implementation, including those aspects which may affect the user. We shall deal briefly with the technical disadvantages first.

5.1. *Technical disadvantages*. Given the success of the recent *Ghost Ship* project (Labbe, 2005), it is apparent that ships, like aeroplanes in the air, are now capable of being remotely controlled as they travel on the sea. However, the use of integrated systems requires not only sub-systems which communicate directly with each other but also a network topology which is reliable even under safety critical situations. At the moment, the law prevents a single chip system being used (Mills, 1999) since the

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maritime world does not accept that such a system has a sufficient safety record to allow it to be used at sea where possible safety critical situations may arise. Thus, certain network topologies are not able to be used at present but no doubt if time proves their reliability, then they will become acceptable.

Further, security of the system needs to be tight especially in the light of recent terrorist activities; a ship is very vulnerable when at sea especially if it is large enough to require long distances for manoeuvring. The wider implications of terrorist threats on ships at sea are beyond the scope of this article but it should be noted that any interference with integrated or automated data could be a potential threat to the vessel's safety. While incorrect data at any stage in its lifecycle is dangerous for the vessel and its personnel (Levine and Loizou, 1999), it is especially so if the integrating system is open to sabotage either from members of the ship's crew or remotely. Here, automated systems are also at risk since if it is known, for example, that the system reads a particular data input at a certain point, and this input may be altered either remotely or directly, then the resulting change could cause sufficient havoc to be a safety threat. If the scenario were such that the system then used this faulty data for making a decision (say about navigation) then the resulting manoeuvre could entail loss of life.

Another technical issue is reliability of the integrated systems to behave consistently while always choosing the most accurate data. Often integrated systems use data from a choice of sub-systems such as from one of two global positioning systems. The experienced officer of the watch will know that one may be more reliable in terms of accuracy than the other, the weaker system only practically being used for backup (Mills, 1999). The integrated system may not know this and may read either system as directed by its internal programming with the consequence that some data may not be as helpful as it could through data interference (Levene and Loizou, 1999). Thus, reliability of an integrated system must be tested well before being used at sea as the main device.

Reliability leads naturally to the problem of priority of data (Mills, 1999). The integrated system will of necessity have to prioritise the data it receives and then discard the data it considers to be redundant. The previous paragraph above indicated that there could be a risk of the system discarding the more accurate data particularly if the source of that data varies according to geographical area, for example. It is not unknown for an echo-sounder, for example, to give spurious readings sometimes causing an accident unless the officer of the watch notices and takes action (MAIB, 2005b). This lack of reliability can occur in any electronic system but the problems can be compounded in an integrated system simply because the more accurate data may have been discarded. Indeed, the need for cross-checking readings from navigational instruments in order to ascertain position emphasises the difficulties of discarding multiple readings as redundant information (MAIB, 2005b). Again, thoughtful design of the system in the first place is of paramount importance in order to ensure that the level of accuracy of data is set above that which may influence any decisions taken by the users (Wetherbe and Vitalari, 1994).

5.2. *Non-technical problems associated with integrated systems.* One of the main reasons, it seems, why integrated systems have not been implemented as often as they might is simply that of cost. Both commercial shipping and the fishing industry are in recession in the UK due to a number of factors further discussion of which is beyond the scope of this article. However, to expect an industry such as fishing, which in the

UK still often pays its workforce on a commission scale (the more fish caught implies more wages which are divided amongst the crew on a percentage weighting), to spend large sums of money on unproven systems is seen by the conservative fishing vessel owners as unnecessary expense. However, there is some undocumented evidence (expressed verbally to the writer) that such systems do increase productivity.

Where information is represented in an integrated form on a single screen, there is likely to a problem of interpretation of the data simply because often symbolism is used in order to compress the detail and maximise the relatively restricted screen space. This means that users have to remember the meaning of the symbols after learning them much as users of land maps do. However, because of the richness of data which it is possible for the integrated system to produce, such symbols can be numerous and also lacking in intuition in terms of design. Similarity of symbols may also lead to confusion or mis-interpretation by the user.

Another similar but different problem to that of not interpreting correctly a symbol on the chart for example, is that of visualisation. This wider problem can lead to reading incorrectly three-dimensional data from what is still a two-dimensional image on the screen. Here, symbols using colour can be affective since they can emphasise shading effects (Jackson, MacDonald and Freeman, 1994). More generally, visualisation of coded data can be improved with training; for example, a typical radar image is indecipherable to an untrained eye, yet it can be easily interpreted by an experienced and trained navigation officer. Visualisation errors in chart reading are not dissimilar to a person misreading a land map and may result in misinterpreting the position of the vessel. Clarity of detail helps to prevent this.

In human terms, perhaps the most important problem visualising integrated information is the lack of control the user may feel (Howard, 1999). If the system is reading the various inputs into the integrated system, the user has no control over the data's accuracy and will have lost the ability to check different sub-systems against each other. For example, an officer of the watch who knows that a certain GPS is more reliable and accurate than its backup will use this difference in the two readings to check that the reliable system is still working efficiently and accurately; further, cross-checking is essential for safe navigation (MAIB, 2005b). In an integrated system, the officer can only trust the system to read the more accurate sub-system. However, while the law still requires vessels to carry a backup system this problem is not insurmountable since the sole use of an integrated system is not legal (at least within the UK).

While the system is functioning correctly and the ship is being navigated stably, an integrated electronic system can be helpful to the mariner. Few fishing skippers, for example, would go to sea today without an auto-pilot. However, should the system become faulty in any way whatsoever, then the officer of the watch must be able to detect this and in some way over-ride the consequences of the fault so that the vessel is navigated safely. Thus the designer must allow for system faults to be communicated to the officer of the watch immediately, perhaps by an alarm; in no cases, should the system default to a typical but incorrect output (Levine and Loizou, 1999).

So far, this article has attempted to give an overview of some of the advantages and problems which may arise from the use of integrated electronic marine systems. These points have implications for the designer in terms of safety and the user's satisfaction. Table 1 summarises the main characteristics of integrated electronic marine systems and also identifies the associated issues for the designer.

Table 1. Some issues for the designer.

Characteristic of the integrated system	Possible design issue
Sufficient information for correct decision	Domain knowledge needed
Reduction in screens	Problems of incorporating sufficient information into limited screen space
Automated routine tasks	Reduces boredom and hence related tiredness
Sub-systems' communication necessary	Certain sub-systems may not be usable through inability to communicate data
Network reliability	Reliability needs time to prove quality
Possible data corruption	Data must not corrupt; system must not default to incorrect data
System must prioritise data	Domain knowledge needed
System must select most accurate data where choices are available	Domain knowledge helps in design but system may still not choose 'correctly'
Cost inhibits general usage in smaller vessels	Cheap components; design optimisation; major constraint
Small screen space (relatively)	Symbolism used; size of text/symbols; legibility of information on screen; colour coding etc.
Visualisation of information	Training may be necessary; how will this be implemented particularly on small fishing vessels?
User's lack of control	In non-safety critical situations, this may be resented by user, leading to a decrease in efficiency of work
Default in case of system error	No default should be used but a meaningful error alarm sounded

6. DISCUSSION OF DESIGN ISSUES. From Table 1, there appear to be at least three areas specifically associated with the user where the designer needs extra caution when involved in producing an integrated marine information system. In addition, there are the issues already discussed concerning the functionality design and including the prevention of data corruption, reliability of the total system, no false readings through defaults, data priority and automating of routine tasks. These functionality aspects of the system are important but are beyond the scope of this article since they are essentially hardware/software design problems rather than user specific issues. The three areas of direct concern for the user can be summarised as domain knowledge, screen design issues and user control and these will each be discussed briefly in turn.

6.1. *Application domain knowledge*. The point has been made elsewhere (Mills, 2005) that the designer is likely to produce a more usable design of a system if knowledge of the application area (domain knowledge) is part of the designer's work experience. This is recognised by some marine electronics companies which try to employ people who have spent some of their working life at sea, preferably in the sector of manufacture. For example, a company manufacturing electronic systems primarily for use on yachts may either train their designers by insisting they spend some time on ocean-going yachts or the company may give priority at selection to potential employees who have already gained this experience. In such a specialised area as marine electronics, this is a wise precaution as the type of systems used on marine vessels and the environment in which they must operate efficiently and reliably is far removed from the life experience of those people who have not experienced some life at sea.

When attempting to design integrated marine systems, it is essential that domain knowledge is exploited to the full as only an experienced mariner can know what information is required for achieving a specified goal. When choices of data are available, then the domain knowledge may be crucial in designing the system so that it chooses the best solution for a particular situation. For example, the experienced mariner who knows which GPS will give the most accurate result, as mentioned above, only knows this through the experience of working with both systems in a variety of environments (particularly weather changes) and in different task sequences. Indeed, there may be situations where certain equipment is better suited to different goals or environments. For a familiar example, a domestic radio land-line telephone is excellent if the user wants to move around the house while talking to a friend but this equipment is useless when the electricity supply is cut. Only those who have experienced this situation can appreciate the practical advantages, in this situation, of a non-mobile, but electrically independent, 'old' telephone. Indeed, such an analogy can be continued in that people are now being advised to keep such a telephone for emergencies during domestic power cuts and to keep such a telephone in a suitably accessible place for using in the dark or with a torch. Knowledge of similar (but obviously different) situations at sea which may become safety critical under certain circumstances, can only enhance the designer's skills and knowledge (Mills, 2005).

6.2. *Screen design issues*. When integrating information, there is always the problem of compressing the information from more than one screen on to one screen. Even if larger screens are employed for the 'master' screen, it is usually difficult for the designer to find sufficient space to clearly display all the information possible. This problem is not new; for centuries, map makers have had to contend with what information to leave out as maps are produced to smaller scales. However, on a screen outputting information integrated from a number of other screens, the problem is changed to one of prioritising the various data in order to allow the user to achieve the required goals. With a map it is fairly obvious that clearly visible landmarks such as large public houses, castles and other large identifiable characteristics should still be shown, whereas with an integrated marine system the choice may be much more subtle. With duplicated data, it may not always be a simple choice of one of the data sets since these may serve their purpose best in different circumstances. For example, in thick fog, the radar may be more usefully displayed in greater detail than the chart features which are only visible in clear weather. This leads naturally to user control which will be considered shortly.

Before leaving this brief discussion about the design of the screen, it should be noted that the designer must be conscious of using symbols with only one meaning but which are easily understood and which are sufficiently prominently displayed so as to be visible to the user in all environmental conditions. Ivergard (1989) for example, recommended only using symbols which subtend 1 degree of arc with coloured characters/symbols not being placed more than 15 minutes of arc from the line of sight. In addition, room lighting should not be changed when colour screens are used since this will change the luminance contrast (Ivergard, 1989). This means that some compromise will be necessary in terms of colour and symbols since most vessels are at sea both during daylight and at night. Technically, it is possible to change the colours on the screen in accordance with the ambience of the environment but this may require the user to learn another set of colour coding which may not be acceptable.

If 3-dimensional visualisation is contemplated as in some object-oriented representations (Mills, 1998), then the designer will need to ascertain that the objects are realistically recognisable or at least easily learnt. More generally, given that much of the display will be dynamic rather than static, there is a need to design for data availability rather than information extraction alone (Howard, 1999). Often, training can help with visualisation but given the lack of fishermen, for example, who undertake even compulsory training (MAIB, 2005a) it is unlikely that such training would be taken. In these situations, it is better for the designer to try to avoid the *necessity* of system training by designing for clarity of representation of the information and using the previous knowledge and experience (Howard, 1999) of the user.

In such a short overview, it is impossible to be specific about the many aspects of designing for the contraction of data from multiple screens to a single or duple set. Indeed, there is a need for tests to be carried out to ascertain readability scores and interpretation levels of integrated marine systems; these tests should be accomplished both under ordinary sea conditions and within safety critical situations.

6.3. *User control.* Users need to feel in control of the computer system (Dix, Finlay, Abowd and Beale, 1993) and so generally they feel uneasy if they are controlled by the system or feel that neither the system nor themselves is controlling the system's activities. It is possible that in an integrated system the system may cause a sensation for the user of feeling that they are being controlled by the system or that they have no control over the system which can also lead to a feeling of frustration especially if the system does not act as expected or wanted. The designer should always try to leave the user at least feeling they have control over the system, even though this is not always easy using software intelligent agents (Dix, Finlay, Abowd and Beale, 1993); the one exception to this is in a safety critical situation, such a vessel sinking, where the user may not be able to control logically and where the user's actions may become irrational. In these situations, the system should be given as much of the work in the task sequence as possible (Redmill and Rajan, 1997). Here then, is a tension for the designer since it is difficult to design a system which both controls and also gives the user control. However, compromise here can produce a workable system if the design is such that all data needed is automatically fed into the system and the user is left with single decisions which require toggle type input. An example of this type of design is the later global maritime distress and safety systems which are automated with the information which the rescue centre requires but which allows the user to press the 'red button' while leaving a five second lapse before the distress signal is sent so that it may be retrieved should an error have been made (Mills, 1995). User control thus needs to be considered carefully by the designer and again possession of domain knowledge, together with knowledge of safety critical systems design, is advantageous.

7. MAIB REPORTS.

This article has attempted to identify some of the issues of particular relevance to the designer of integrated marine electronic systems but it is worth asking if these systems could have prevented some of the accidents which have befallen vessels recently. Since the fishing industry has used integrated

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electronic systems and more are being introduced into new vessels as they are commissioned, the completed full MAIB reports for accidents during 2004 (as available at November 2005) together with those listed in the 2005 *Fishing Digest* (2005) have been surveyed for evidence of problems associated with marine electronic systems. In addition, the completed preliminary reports (MAIB, 2004) for accidents to all types of vessels which occurred in 2004 have been examined. A brief analysis of these reports follows.

In 2004, 10 UK fishermen died which is about average over the last four years with 2000 being exceptional with 32 deaths (*Fishing Digest*, 2005). Of the 24 accidents associated with fishing vessels in the UK in 2004 (*Fishing Digest*, 2005), 22 of these are listed within the *Digest*. The main findings of these short reports indicate that lack of stability of the vessel, flooding of the engine-room and/or bilges, poor watch-keeping and poor maintenance of vessels were amongst the main reasons for the accidents. Apart from the usefulness of EPIRBs (emergency position indicating radio beacons), the only mention of electronic aids is for look-out assistance such as radar guard zones and automatic target acquisition. Clearly, if the navigation screen integrates the radar with the chart, then an alarm should be incorporated into the system so that the presence of vessels within the guard zone are identified to the user by the alarm so that the user can take action to prevent collision.

Of the 30 preliminary examination reports for 2004 completed by November 2005, the MAIB recommendations only mention one incident, a near miss between a fishing vessel and a coastal cargo vessel, where radar and GPS should have been used together instead of the GPS alone (contrary to regulations (MAIB, 2004)). Here integration of the systems could have prevented a near miss and indeed would have assisted with prevention had a guard zoned radar been integrated with the chart and GPS. An alarm would have alerted the officer of the watch in order to take preventive measures.

Another full report (MAIB, 2005a) of three small fishing vessels in each of which loss of life occurred, pointed out that poor maintenance and lack of seaworthiness of the vessels were the main causes. In these and similar cases little help would have been given by an integrated electronic system for navigation and/or fishing.

8. CONCLUSION.

This article has endeavoured to make a first attempt at identifying the main characteristics of integrated marine electronic systems and has identified areas of particular concern for the designer. While there are advantages in using integrated marine systems, the safety related aspects have yet to be fully explored as has also the real value of such systems to users. Tests are needed to evaluate the usability of such systems as well as psychological tests to measure the cognitive load which integrated systems may cause for the user. A longer time-span must pass before integrated marine systems can be deemed reliable but first impressions suggest that they can only be helpful to a tired mariner on watch since it is possible for such systems to integrate alarms for radar guard zones and other safety features. Cost may be a preventative cause of widespread purchase, particularly within depressed industries such as the fishing industry especially is. The legal side of integrated systems such as the use of network topologies and the associated technical reliability will also need to be addressed. However, further work is needed to explore all these issues in more depth.

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