*Journal of Maritime Research, Vol. V. No. 2, pp. 59-74, 2008*



*ISSN: 1697-4840*

# INTEGRATION WORK ON THE SHIP'S BRIDGE

M. Lützhöft[1] and J. M Nyce[2]

Received 3 February 2008; received in revised form 15 February 2008; accepted 1 July 2008


## ABSTRACT

**As technology on board gets more automated and integrated there is the hope that seafarers will do less work. But as seen in other domains, as ships become more automated it seems that operators perform more and different work, for which many of them are ill prepared. We describe here the results of a field study on Swedish ships. With today's technologies, seafarers on ships with (and without) integrated bridge and navigation systems have to perform less manual work but more *integration work*. Integration work, as we define the term, is a process, initiated and driven by the seafarer. In particular, it is working proactively to construct a workplace that 'works' for them, given their tasks and duties. The paper discusses whether workload has really been reduced or only shifted to another mode or form.**


**Key words:** Human Factors, integrated systems, human-machine interaction.

## INTRODUCTION

As technology on board gets more automated and integrated there is the hope that seafarers will do less work. But, paradoxically as ships become more automated it seems that they do 'more' work, or different work, for which many of them are ill prepared. Seafarers on ships with today's technologies have to perform more *integration work*.

---

[1] Asst. Professor, Chalmers University of Technology (margareta.lutzhoft@chalmers.se), Tel. +46317721464, no street SE-41296, Göteborg Sweden. [2] Department of Anthropology Ball State University (jnyce@bsu.edu), Tel. 7657898793, 2000 W University Ave, 47306 Muncie Indiana, USA.

Integration work, as we define the term, is a process, initiated and driven by the seafarer. In particular, it is working proactively to construct a workplace that 'works' for them, given the tasks and duties they have to carry out. Integration work is a traditional part of the kind of labour seafarers have performed for centuries. In fact, this work is often taken for granted by those who perform it, and seldom talked about by seafarers in any explicit way. Because this work is seldom referred to directly, it is hardly surprising that the researchers have paid little attention to it. However, with new technology like integrated bridge systems, integration work becomes more important than ever before. What is clear is that there is a fundamental difference between the situated tasks that call for integration work and the way tasks are often specified in engineering/ergonomics literature. A review of the literature on cognitive ergonomics and human factors found that there were few field studies, and even fewer that describe work in "complex, confusing, noisy, and dynamic" environments (2003) This paper adds to this literature.

**BACKGROUND**

A number of field studies have been performed in complex work domains, focusing on the effects of new technology and automated systems on the operator. This has been studied in nuclear power plants (Mumaw et al., 2000), healthcare (Gauthereau, 2003), aviation (Sarter and Woods, 1997) and shipping (Grabowski and Dhami, 2005). The effects have been described in terms of workload shifts (Bainbridge, 1983), new kinds of work (Dekker and Woods, 1999), automation surprises (Woods and Sarter, 2000), and loss of mode awareness (Sarter and Woods, 1995). These are all studies of effects on operators, but not much on how people cope. In the present study, during qualitative fieldwork on the impact of automated bridge systems, we began to focus on what was a neglected feature of work in this literature, integration work on the bridge.

The effects of new technolgy have not been well addressed by marine manufacturers or engineers either. Nevertheless, manufacturers are aware of this problem. At the Nautical Institute IBS conference in 2003, a representative of a large manufacturer said: **"it is becoming increasingly difficult to get people to sit down and find the problem. Complaints are often too generic. We need more input".** As part of this study several representatives of the maritime electronics industry were interviewed. They agreed with these comments. Today, they are sending out surveys, interacting with clients at trade shows, establishing training programs for dealers and customers, analysing feedback forms from customers, and their letters. In addition to this, equipment is tested on the company or customer test ships. While manufacturers and vendors tend rely on traditional Human Factors research, still they want to know more.

In the maritime literature, the usual solution to improve work on the bridge is to add more technology and/or increase automation. It is an open question however whether this will solve issues of work on the bridge. Many navigators are not convinced. One equipment manufacturer said at the NI 2003 IBS conference: **"Officers perceive IBSs [Integrated Bridge Systems] as scary but the individual components are the same as before"** If some officers perceive IBSs as scary, it could be valuable to the manufacturer to try to find out why. Rather than to simply add automation, the human factors research community have for a long time argued that what needs improvement is not the technology per se but the man-machine dialogue (Hatfield and Smith, 1975, Millar and Clarke, 1978, Wilkinson, 1974). To achieve this, naturalistic studies of work and technology use need to be performed. A number of such studies have been carried out in the maritime field by Hutchins (1995), Norros and Huuki (1998), Grabowski and Dhami (2005), Belcher (2002) van Westrenen (1999) and several Danish researchers (Andersen, 2001, Koester, 2005, May, 1999).

Studies in other domains reveal some of the adaptations human perform in response to new technology. Clumsy automation – when a system creates new cognitive and physical demands, that tend to come together at times of high demand – is overcome by two related adaptations; system tailoring where the system is adapted, and task tailoring where the user's behaviour is adapted (Cook and Woods, 1996). System tailoring is about changing the technical system and task tailoring is about adapting the work strategy. Both of these adaptations have been observed in the present study. However, while they describe how humans adapt, some believe that it is the system that should adapt more to the operator.

Hollnagel (1995) outlines three ways that machines can be adapted to humans. The first is through design. For this, the designer needs a model of the user, which can be a static model for simple domains, but a dynamic model is probably more adequate for complex tasks. This is a difficult undertaking, because it forces the designer to be explicit about what he is designing for. The second is adaptation during performance, where the system should adapt and change its performance to match operator needs. This is complementary to adaptation through design, and may be necessary since our knowledge of seafarers is necessarily incomplete at any given point in time. Adaptation during performance poses increased demands on the modelling of the operator.

The third way is adaptation through management. To help overcome deficiencies in the design of a system, management can adapt the working environment by providing support and modifying work goals. For this kind of adaptation to work, a continuous monitoring of effects is needed, and this basically constitutes adaptation by continuous redesign. Courteney (1996) warns that if standards in one area is changed (design, training or operations) then the others must follow. For example a change in design must be followed by a change in training.

One intent of automation and standardisation is to reduce the workload of seafarers. But even with the best of intentions, automation can add to rather than subtract from the workload. The result is that seafarers have had to develop strategies to integrate information from different technologies into something that allows them to get the work done. On a ship, which was built as a container ship in the 60's, rebuilt to a cruise liner in 1990 and visited by us in 2001, we found 15 different manufacturers' names on the navigation, control and communication equipment. We have also found that bridges evolve; equipment is added, but seldom taken out (Lützhöft et al., 2007). This is one reason seafarers have to perform integration work; technological resources are never constant. And while we see humans adapting, what is technology doing?

**METHOD**

To study this issue, the first author has over a period of almost four years (2000-2004) spent close to 300 hours distributed over 25 days, on ship's bridges (15 ships). Prior to this research she was a maritime officer, with 13 years of sea experience. Three major ship types were studied: small archipelago vessels that travel the Stockholm archipelago, larger Baltic ferries/passenger ships journeying the waters between Finland and Sweden, and cargo ships trafficking the Baltic, the North Sea and the Atlantic.

The methods used to gather data were observation and interviewing, and at times a second observer was present. Techniques to record data were field notes, sound recording, video and still pictures. When possible, copies of documents or charts were made. The interviews were both formal and informal, and were conducted with seafarers on and off ships. Recordings were transcribed, notes and interpretations were often compared and discussed with the second observer. All transcriptions and other data were analysed in an iterative manner. Early interpretations and patterns were checked against the literature and field data, and this guided the next round of data collection. Subsequent ideas and interpretations were formed and likewise tested and refined against theory and field data. Although single quotes are used to make points here, they are all backed up by observations and similar statements at other times.

Technology manufacturers and policy makers were interviewed. To some extent regulation and standardisation processes have been studied. In sum, an effort has been made to get close to the practitioners while following the requirements of science – accurate data collection, comparison and contrast of field data, matching data against the literature and locking data to theory – all this helps us 'make sense' of what is going on on the bridge.

**RESULTS**

While on board, not many incidents and no accidents were seen, but gradually it became clear what seafarers did to avoid accidents. From the seafarers' point of view however, they were not avoiding accidents, they were just doing their job and doing it well. This contradicts the common sense view that seafarers spend a lot of their time avoiding accidents. What we did see on board, was how seafarers cope with their work and errors, how they learn and how they perform work-arounds given new technology. We saw examples of integration on several levels: integration of human work and machine work, integration of information representations and integration of learning and practice. Integration work is always about co-ordination, co-operation and compromise. When human and technology have to work together, the human has to co-ordinate resources, co-operate with devices and compromise between means and ends.

Here we will discuss two of these levels of integration; human and machine work, and data and information. We will discuss why these kinds of integration are performed, why it is deemed necessary by the seafarer and give examples. We will link this discussion to the literature, which documents that technology has surprising effects and can impede users, but there is little there on integration work, as defined here. Handling computers, for instance, is not always straightforward. Wiener summarised it in this way:

"The machine will still be literal-minded on its highest level, and will do what we have told it to do rather than what we want it to do and what we imagine we have told it to do." (Wiener, 1985). Humans are not "literal-minded", at least not in this sense. The following is a cargo ship officer who talks about the integrated bridge system, which shows how differently humans and computers go about 'thinking'.

**"When you're learning the system…at first you don't understand how it's meant to work, but then you start thinking backwards, like a computer".** Many have shown that new technology often demands a new way of working. However, it also can demand a new way of thinking, with interconnected, seamless or integrated systems. Cook and Woods (1996) point out some putative benefits of technical integration: it may reduce the physical size of the device, it may reduce maintenance and it may even increase functionality. However, they argue that the value of such changes may be small, and unintended side effects can pose significant new work (and risks) for those involved. Here, integration is a process, which is initiated and driven by the seafarer who works actively to be 'part of the loop', and this can lead to significant amounts of new work. The reason seafarers perform integration work is to do work technology was intended to help them perform. However, technology at times may be solving non-existent problems, and in the process even creating new problems. As many of the interviewed seafarers said: **"When we need it the most, the technology cannot help us".**

The Merriam-Webster on-line dictionary[1] defines **integration** this way: to unite with something else, to form, co-ordinate, or blend into a functioning or unified

[1] http://www.m-w.com

whole. Also, to harmonise and synthesise. In this study, the integration of various components means that trade-offs, tailoring and adaptations have to be made. A functioning whole is to a great extent due to seafarers' work, and a unified (perfect) whole may not even be possible. There are several ways in which humans construct a functioning whole out of parts. When the seafarer's view and the machine's view do not match, the human most often has to do the changing, the harmonising and the synthesising. If machine and human together are to constitute a working navigational system, the one who has to adapt the most is the human. The seafarer is the elastic, adaptive component, and performs the integration work. It is also a part of the seafarer culture to be able to 'handle anything', and thus when a burden is added, seafarers frequently adapt and handle it.

**Integration of representations of data and information**

The integration of representations is performed by the seafarers as they work, mentally or by using artefacts such as displays, or pen and paper. This is similar to one of the core principles in distributed cognition 'People establish and co-ordinate different types of structure in their environment' (Hollan et al., 2000). Representations here also include what seafarers can perceive of the real world as seen out of the bridge windows. An example of such integration is the position fixing cycle Hutchins describes; how navy personnel integrated the outside view with a paper chart, via several devices and techniques (1995).

By information we mean data that has meaning for the seafarer and the task at hand. There are several reasons seafarers perform integration of data, information and reality. The most important is that it is seen as necessary, because the seafarers need to integrate or compare data to construct a plan-for-action. This construction is vital to work onboard but is not always supported by the technology – machines cannot communicate in ways seafarers see as useful or intelligible given the circumstances. Integration work is subject to external constraints as well, of which a clear example is the requirement to use and compare different means of position fixing, and not to trust one source alone. Therefore, maritime regulations can also lead to the demand for data integration.

For seafarers to construct their own integrated system takes effort, especially since what developers and manufacturers choose to integrate on screens or in systems is not always what the seafarers find useful. The comparison of two waypoint lists from two navigation devices provides an example of this. To ascertain whether the two lists were the same, the officers checked the courses between the waypoints. However, in one list the course was represented with three digits (000) and in the second with four (000.0; one decimal point). This was not seen by the officers themselves as requiring a lot of effort, but it clearly did demand cognitive work and the transformation of one kind of representation into another had to be done many times over (a waypoint list may contain up to a hundred points, sometimes more).

Double checking of this kind is performed for two reasons: at times the seafarer prefers, given the task at hand, a manual check and at times the technology cannot do it. Even when a machine can do it, this may, as one officer says, **"take too long to perform… and then the result is long lists that still have to be checked manually"** (Lützhöft, 2003). This suggests a certain amount of scepticism exists on the part of the seafarers regarding representations of information.

When using bridge technologies in combination, the units used to represent data may be incompatible. For instance, an echo sounder, tide tables and a chart may all use different measurements; feet, fathoms or meters. This adds to the workload and demands close attention on the part of the navigator and requires that a navigator perform conversions into a common, single unit. Further, on different displays, different symbols may denote the same thing, and even on (or within) a single display there may not be a consistent symbology. Nautical charts are constructed using one of several chart datums, which is a reference system to which depth soundings refer. A GPS navigation system, a paper chart and an electronic chart might all be using different chart datums when referring to the 'same' thing, and even within one ECS this can occur. This could lead to potentially hazardous errors in position, in fact has already caused one known grounding of a ship in the Norwegian archipelago. However, this is a hard problem to solve because aids come from different manufacturers or publishers. A related problem is the mental integration work performed by seafarers when using charts, radars and views out of the window, all displayed in different ways: north up, head up, course up (Porathe and Sivertun, 2002). There is no common vocabulary, 'designer' or co-ordinator for such important representational issues.

Many maritime displays typically display a single datum in digital form, from which it can be difficult to perceive, infer or track change. For example, for the display of cross-track error on board we have seen a display with a choice of two presentations, either a number "1,4 R" or "0,9 L" (right and left) or another with an analogue image showing a ship symbol and a line. Many ships have both types on different screens, and both displays are used but by different officers. One pilot comments: **'Of course, I use the image…the numbers [digital], no, [because] then you need another piece of information [that indicates which side the drift is]'**. To represent offset distance, the analogue representation collapses the two data points 'there is offset' and 'to which side it is' into one image, whereas the digital requires further work to arrive at the same point. Also, while the rate of change is not directly visible with either, the analogue allows for easier perceptual estimates than the digital.

When exact numbers are needed, digital representations are regarded as better. For instance, analogue representations of engine revolutions are accepted. To represent speed, seafarers prefer digital, as exact speed can be needed to compute arrival times. In contrast, most officers prefer the analogue ROT dial (rate-of-turn, how fast a ship is turning) over the digital, as the digital is said to lag in an unacceptable way.

It is important not to digitise just because it can be done or because it saves display space. Rather it is important to first find out how data are used and which representation makes more sense to seafarers given the task at hand. In regards to forward speed do they want exact numbers? Or can they accept a lag and lower accuracy? Then this may not be acceptable regarding sideways drift which they quickly need to perceive and react to. If it makes the job at hand easier, and lowers the mental workload – why not use analogue representations?

Seafarers want to compare and co-ordinate data and information, but in many cases the representations cannot be immediately correlated. When sensor data are combined or fused into a single representation, issues of trust, quality, age and traceability of origin can surface and this needs to be addressed.

**Integration of human and machine work**

Integration work between humans and machines can be described as the act of achieving co-ordination with an artefact through expert performance by a person (Hutchins 1990). Many aspects of new technology make this kind of expert performance difficult to achieve. Seafarers attempt to build working human-machine systems, to 'integrate themselves' into a co-operational system for several reasons. Firstly, they do it when they see it as necessary. When there is a misfit between humans and machines, seafarers have no choice but to rebuild the integrated systems in ways they themselves understand. Secondly, seafarers want to do this – most of them want to use new technology. They want to have control and they want to be able to use the tools they believe can provide them with this control. They also believe or at least hope that human-machine systems can relieve them of certain kinds of work and uncertainty, without the technology being an additional burden to them.

A poignant example is one electronic chart system, which allows for registering a position at which a person has fallen overboard, to simplify finding that position when having turned the ship. This is called a MOB situation (man over board), and is a critical situation with much time pressure. However, the chart system demands that the operator go through 5 steps to register the position (submenus, button pushes). At the same time, he has to start turning the ship, call the captain and crew, sound alarms and launch a special MOB lifebuoy. To ensure these steps were remembered, the crew on the ship had printed these 5 steps out on strips of Dymo tape and taped them to the frame of the screen. Because technical systems are becoming increasingly interconnected, the way to perform the 'same' tasks can become perhaps even harder to do. However, many manufacturers may claim that nothing has changed, and argue that after all these technical systems have the same components as before. Nevertheless, a 'system' is not a stable entity but a constantly changing ensemble of actors and artefacts. There are seemingly endless combinations, and the interconnections can often be hard for seafarers to see and the underlying principles of these systems may be even more difficult for them to discover and understand.

Another example: on one occasion a radar which was part of an integrated navigation system on a cargo ship did not work. When the officers had tried everything they could think of and had at hand (manuals, discussions, self-test performed on radar) the radar was switched off. Before switching off, both officers were clearly worried about what effect this would have on the rest of the system and were uncertain which of the other parts would continue to operate. This is because when devices are technically integrated their co-ordination is more hidden to users than before. This means that seafarers often have to perform more work to reconstruct and understand the system. It also requires more effort on the part of manufacturers to construct an integrated system that makes sense to those who use it.

A related problem occurs when a device does not work as expected. Several officers have said something to the effect of: **"Is there a malfunction in this device or have I made a mistake?"** The more integrated and automated systems become, the harder it is to figure out what has happened, how to carry out repairs and to make the system 'work' correctly again. Feedback from automated and integrated systems can be weak (Woods and Sarter, 2000), and what feedback there is may not be what the seafarers need or want to know at a particular time. Since tasks and situations are not stable, what is needed and wanted when it comes to technological aids also keeps changing over time. This is something else manufacturers perhaps have not taken into consideration as much as they should have.

Even when technology works as intended still integration work is needed. In archipelago piloting, large amounts of data, information and strategies have to be co-ordinated - a learning process that continues throughout a pilot's career (Lützhöft and Nyce, 2006). For this reason, officers say they would not want to leave all the work to the technology, because as one officer says: **'You can't just sit here and relax…you have to look the whole time'.** These officers prefer actively working to simply monitoring. This active work may represent the same or even more effort than just monitoring, but they believe it affords better control and integration than just monitoring. It also allows for a more effective taking over when necessary.

Therefore, the officers feel that they 'get more' out of the 'same effort'. For example, on a cargo ship with a very modern integrated bridge system, officers did not use all the available functionalities their automated devices possessed. They would rather be actively working than simply monitoring the actions of machines. This meant that they did not hand over to the bridge system all the work they knew (or suspected) it could perform. Instead, they used the techniques and devices they were familiar with to navigate; GPS, radar and paper chart, see Lützhöft (2002). In short, off-loading or sharing work between humans and systems then seems to rely on and be determined by familiarity, experience and trust, and even when something works as intended, the seafarers may continue to work in their own ways.

Earlier we discussed how humans adapt to new systems, for instance by system tailoring (Cook and Woods, 1996). This entails changing the system, and performing work to make the system compatible with the seafarers' cognitive strategies. Inherent in this is a risk that the system change may become ritualised (for instance how a system is set up before each use) and the basis of the ritual lost to the practitioners, especially if they are novices. Rituals like these may also lead to a lower understanding of the system. A second strategy is task tailoring, where seafarers instead adapt their strategies to carry out tasks, so as to accommodate constraints embedded in the new technology. Neither of these adaptation strategies is effective in the long run.

A central problem here is that understanding machine actions is not easy. The crew of the Royal Majesty knew that when the chart on the radar screen was 'chopping' (jumping) that meant it was unstable and not to be trusted, and by extension they believed that when there was no chopping, the radar chart must be safe and stable. This belief was unfortunately erroneous (Lützhöft and Dekker, 2002). Further, machines are not social. A machine is not a new crewmember, but is often intended to take the place of one. Machines are not directable in the way humans are (Lützhöft and Dekker, 2002, Woods, 2002), meaning that it is harder to for instance delegate work to them. But machines still perform 'work' as well as look and feel trustworthy. Seafarers try to integrate these new devices into the working human-machine system but what makes this difficult is that machines are not situated. They are not situated or embedded in 'reality' because models in computers and technology often reflect an impoverished, incomplete or faulty view of the world.

The view of the world that they *do* have is pre-programmed and relatively static and hardly ever matches the dynamic picture of the world that the practitioner uses and constantly reconstructs. The machine's image is unsituated because it is hard-wired, programmed into it by someone who has perhaps not 'been there' and into a machine that can never 'be there'. Someone else has chosen what the seafarer needs and wants to see and know about the world and the system. Someone has decided what the seafarer needs to do his job. Seafarers are in a sense sailing with "black boxes", whose rules are difficult to deduce or change. A machine does not 'know' where it is and what the consequences of its actions may be. The most important problem here may be that it is never 'ahead', can never really anticipate, whereas anticipation and thinking ahead is fundamental to maritime safety.

A number of suggestions have been made about how to solve this problem. First, machines may need to be more 'situated' which might not be possible in the foreseeable future. Expert systems are still very dumb when compared to the local rationality of individuals. Second, machines need to be able to give an account of or at least indicate what is going on, what Dourish (2001) calls accountability. Abstraction and system integration makes this hard. Third, some means of sharing or trading of control between humans and machines must probably be negotiated (Inagaki, 2003, Hedenskog, 2003), and some negotiation of knowledge, authority and responsibility

(Suparamaniam and Dekker, 2003, Östberg, 1988) also needs to be taken into account. It has been shown that team performance is better if a computer is used as a 'critic' instead of giving 'expert' advice. This raises questions about knowledge allocation and the roles humans and machine should play (Cook et al., 1998). It is becoming increasingly clear that allocation strategies, static divisions into 'physical' tasks, do not work well because of the dynamics of work situations.

An abstraction which it is increasingly important to represent well is how automated systems are doing. Due to the nature of automation, often human seafarers do not know how well it is doing, what it is doing and how it is doing it. The literature suggests that such representations should include three things. Firstly, they should be event-based, highlighting changes and events. Secondly, they should be future-oriented, to support the seafarers in knowing what to do and when, and thirdly, they should be pattern-based, to allow seafarers to quickly pick up abnormalities without additional cognitive work (Woods et al., 1994, Christoffersen and Woods, 2000). But all these conditions may differ or require different interpretations, given the task at hand.

Technology is often used to replace parts of or all of human work and theoretically to make work safer, more efficient or less costly. Replacement is not always straightforward, which is known as the 'substitution myth' (Dekker and Hollnagel, 1999). Research shows that often a lot of effort has to be expended to get the new system to work and that new technology, when it is not well designed or integrated, may even introduce new types of accidents (Lützhöft, 2003, Lützhöft and Dekker, 2002). However, new technology can also help seafarers shape new strategies, as for example an electronic chart system which not only helps to 'fix a position', but also helps seafarers plan trips in different ways than before. But technology can also become a barrier to work, and become something that has to be 'worked through' for example to navigate, which adds more work to the 'real work' (Lützhöft, 2003). This research confirms the axiom that when tools become visible (when they malfunction) they are ineffective because an operator has to focus on the tool instead of the task itself. Bødker calls this effect focus shift (Bødker, 1996). This must be researched further so that we do not to add to the seafarers' workload when they are performing their tasks, using new tools and aids.

## DISCUSSION

A main force driving the installation and use of shipboard technology today is economics, and to a lesser extent safety (National_Research_Council, 1994). Other drivers are competition, technology development and innovation. Constraining forces are partly the same: economy, technology development, regulations, standards, and safety concerns. Courteney (1996) presents a disheartening list (from aviation) which indicates that "the trends and practices in the modern aerospace business are pulling in directly the opposite direction to that required for improvement in the 'human factors' area". Among the issues mentioned are regulations, staff turnover, success measures, commercial pressures and responsibilities – the aviation industry and the maritime industry seem to share many of the same problems. How to solve this is unclear, but a promising way forward is to study how designers and engineers construct 'user models' (Busby and Chung, 2003, Dagwell and Weber, 1983) and how to improve this process. For now, it is the integration work that seafarers perform which evens out the bumps caused by clumsy automation.

For new navigation technologies to realise their full potential, they must be accepted by the seafarer community. Evaluation at all stages, and if necessary, redesign, is particularly important because once a technology is generally adopted, it is rarely formally or scientifically assessed for effectiveness (National Research Council, 1994). One reason that evaluation schemes must be put into place is that as new technologies start to solve problems, new ones may be introduced. In other words, operational procedures and training have to be changed to be flexible enough to accommodate technological innovations and 'improvements', unintended or not. Only adding technology, no matter how advanced, can not resolve all maritime safety issues.

Designers often assume that adding additional features to a device is acceptable, because users can ignore what they do not need. A related assumption here is that users always know what they need. Unfortunately, neither of these assumptions is entirely accurate. This is particularly true on today's ships where the borders between human and machine work and consequently between innovation and failure are difficult to trace out. We need to be more involved in the design of new tools, to ensure that we provide for an efficient, effective and satisfying workplace. Integration work shows how humans are good at making things fit together and how to make use of the tools and instruments at hand. If tools and aids are not already tuned to their intended use, humans will expend effort to make them such. It is this which we here call integration work. We need to make the design of tools and aids more centred on their prospective use – for which we need to consult future users. They should be involved as experts on the use, the tasks and the work, but not as designers.

Flach *et al.* (2003) point out (using an aviation example) that, the engineer and the operator think about technical systems in different ways. The engineer uses a causal model, thinking for instance: "What happens to the craft if we apply X to it?" Our operator, the seafarer uses an intentional model: "How do I make the craft do this, or how do I apply X?" Therefore, we must find out more about the nature of practice, especially about how seafarers construct, maintain and repair a technical system of which they themselves are a part. We need to ask the question that many seafarers will recognise: "What are your intentions?", before we resort to design, redesign or simply assume that human fallibility causes systems to fail.

## ACKNOWLEDGEMENTS

We thank the seafarers and companies for their interest and their participation. We gratefully acknowledge the financial support of VINNOVA, the Swedish Mercantile Maritime Foundation, the Swedish Maritime administration and Region Västra Götaland.

## REFERENCES

Andersen, P. B. (2001), Maritime Work and Communication. *Australian Journal of Information Systems, May 2001,* 8 (2), 83-102.

Bainbridge, L. (1983), Ironies of Automation. *Automatica,* 19, 775-779.

Belcher, P. (2002), A sociological interpretation of the COLREGS. *Journal of Navigation,* 55, 213-224.

Busby, J. S. & Chung, P. W. H. (2003), In what ways are designers' and operators' reasonable-world assumptions not reasonable assumptions? *Trans. IChemE,* 81, 114-120.

Bødker, S. (1996), Applying activity theory to video analysis: How to make sense of video data in HCI. IN NARDI, B. A. (Ed.) *Context and consciousness: Activity theory and human-computer interaction.* Cambridge, MA, MIT Press.

Christoffersen, K. & Woods, D. D. (2000), How to make automated systems team players. Columbus, OH, Institute for Ergonomics, The Ohio State University.

Cook, R. I. & Woods, D. D. (1996), Adapting to New Technology in the Operating Room. *Human Factors,* 38, 593-613.

Cook, R. I., Woods, D. D. & Miller, C. (1998), A Tale of Two Stories: Contrasting Views of Patient Safety. *Workshop report: Assembling the Scientific Basis for Progress on Patient Safety. National Patient Safety Foundation at the AMA.* Available: http://www.npsf.org/exec/report.html [2004, October].

Courteney, H. Y. (1996), Practising What We Preach. *Proceedings of the 1st International Conference on Engineering Psychology and Cognitive Ergonomics.* Stratford-upon-Avon, UK.

Dagwell, R. & Weber, R. (1983), System Designers' User Models: A Comparative Study and Methodological Critique. *Communications of the ACM,* 26, 987-997.

Dekker, S. & Hollnagel, E. (Eds.) (1999), *Coping with Computers in the Cockpit,* Aldershot, Ashgate.

Dekker, S. & Woods, D. D. (1999), Automation and its Impact on Human Cognition. IN DEKKER, S. & HOLLNAGEL, E. (Eds.) *Coping with Computers in the Cockpit.* Aldershot, Ashgate.

Dourish, P. (2001), *Where the Action Is: The Foundations of Embodied Interaction,* Cambridge, MA, MIT Press.

Flach, J. M., Jacques, P. F., Patrick, D. L., Amelink, M., Van Paassen, M. M. & Mulder, M. (2003), A Search for Meaning: A Case Study of the Approach-to-Landing. IN HOLLNAGEL, E. (Ed.) *Handbook of Cognitive Task Design.* London, Lawrence Erlbaum Associates.

Gauthereau, V. (2003), Work Practice, Safety and Heedfulness: Studies of Organizational Reliability in Hospitals and Nuclear Power Plants ThD Thesis 2003:942. Linköping, Quality and Human-Systems Engineering, Linköping University.

Grabowski, M. & Dhami, H. (2005), Early Adoption Technology Impact: AIS on the St. Lawrence Seaway. *Journal of Navigation,* 58, 17-30.

Hatfield, M. R. & Smith, M. H. (1975), Implications of Advanced Automation for Ship's Personnel. *Proceedings of the Symposium on the Use of Computers in Shipboard Automation.* London, 11-12 March, 1975.

Hedenskog, Å. (2003), Increasing the Automation of Radio Network Control. LiU-Tek-Lic-2003:51 Department of Computer and Information Science, Linköping University, Linköping.

Hollan, J., Hutchins, E. & Kirsh, D. (2000), Distributed cognition: toward a new foundation for human-computer interaction research. *ACM Transactions on Computer-Human Interaction,* 7, 174-196.

Hollnagel, E. (1995), The Art of Efficient Man-Machine Interaction: Improving the Coupling between Man and Machine. IN HOC, J.-M., CACCIABUE, P. C. & HOLLNAGEL, E. (Eds.) *Expertise and Technology.* Hillsdale, NJ, Lawrence Erlbaum Associates.

Hutchins, E. (1995), *Cognition in the Wild,* Cambridge, MA, MIT Press.

Inagaki, T. (2003), Adaptive Automation: Sharing and Trading of Control. IN HOLLNAGEL, E. (Ed.) *Handbook of Cognitive Task Design.* Mahwah, NJ, Lawrence Erlbaum Associates.

Koester, T. (2005), Human Factors in the Design Process - A New approach to the Design of Maritime Communications Equipment. *Proceedings of Human Factors in Ship Design, Safety and Operation. 23-24 February 2005.* London, Royal Institution of Naval Architects.

Lützhöft, M. (2002), Studying the Effects of Technological Change: Bridge Automation and Human Factors. *Ortung und Navigation,* 2, 107-113.

Lützhöft, M. (2003), How Navigation Systems are Used - Data from Field Studies and Implications for Design. *The Nautical Institute Conference: Integrated Bridge Systems and the Human Element.* 16-17 September, London.

Lützhöft, M. & Dekker, S. W. A. (2002), On Your Watch: Automation on the Bridge. *Journal of Navigation,* 55, 83-96.

Lützhöft, M. & Nyce, J. M. (2006), Piloting by heart and by chart. *Journal of Navigation,* 59.

Lützhöft, M., Sherwood Jones, B., Earthy, J. V. & Bergquist, C. (2007), MTO-Sea: Competent Cadets Make Safer Systems. *RINA Human Factors in Ship Design, Safety & Operation IV.* 21-22 March 2007, London.

May, M. (1999), Cognitive Aspects of Interface Design and Human-Centered Automation on the Ship Bridge: The Example of ARPA/ECDIS Integration. *People in Control: An International Conference on Human Interfaces in Control Rooms, Cockpits and Command Centres.* 21-23 June, Bath, England.

Millar, I. C. & Clarke, A. A. (1978), Recent Developments in the Design of Ships' Bridges. *Proceedings of the Symposium on the Design of Ships' Bridges.* 30th November, London.

Mumaw, R. J., Roth, E. M., Vicente, K. J. & Burns, C. M. (2000), There Is More to Monitoring a Nuclear Power Plant than Meets the Eye. *Human Factors,* 42, 36-55.

National_Research_Council (1994), *Minding the Helm: Marine Navigation and Piloting,* Washington, DC, National Academy Press.

Norros, L. & Hukki, K. (1998), Utilization of information technology in navigational decision-making. IN WAERN, Y. (Ed.) *Co-operative Process Management: Cognition and Information Technology.* London, Taylor & Francis.

Porathe, T. & Sivertun, Å. (2002), Information Design for a 3D Nautical Navigational Visualization System. *Proceedings of The Eighth International Conference on Distributed Multimedia Systems, September 26-28.* San Francisco, Ca.

Sarter, N. B. & Woods, D. D. (1995), How in the World Did We Ever Get into That Mode? Mode Error and Awareness in Supervisory Control. *Human Factors,* 37, 5-19.

Sarter, N. B. & Woods, D. D. (1997), Team Play with a Powerful and Independent Agent: Operational Experiences and Automation Surprises on the Airbus A-320. *Human Factors,* 39, 553-569.

Suparamaniam, N. & Dekker, S. (2003), Paradoxes of power: the separation of knowledge and authority in international disaster relief work. *Disaster Prevention and Management,* 12, 312-318.

Van Westrenen, F. (1999), The Maritime Pilot at Work. PhD Thesis, TU-Delft, The Netherlands.

Wiener, N. (1985), The Brain and the Machine. IN MASANI, P. (Ed.) *Norbert Wiener Collected Works with Commentaries. Vol. IV, Cybernetics, Science, and Society; Ethics, Aesthetics, and Literacy Criticism; Book Reviews and Obituaries.* Cambridge, MA, MIT Press.

Wilkinson, G. R. (1974), Ergonomics in Ship Design. *Journal of Navigation,* 27, 471-478.

Wilson, J. R., Jackson, S. & Nichols, S. (2003), Cognitive Work Investigation and Design in Practice: The Influence of Social Context and Social Work Artefacts. IN HOLLNAGEL, E. (Ed.) *Handbook of Cognitive Task Design.* Mahwah, NJ, Lawrence Erlbaum Associates.

Woods, D. D. (2002), Laws that Govern Cognitive Work. http://csel.eng.ohio-state.edu/productions/laws [Retrieved 2008-08-28].

Woods, D. D., Johannesen, L. J., Cook, R. I. & Sarter, N. B. (1994), *Behind Human Error: Cognitive Systems, Computers, and Hindsight,* CSERIAC SOAR 94-01. Ohio, USA, Wright-Patterson Air Force Base.

Woods, D. D. & Sarter, N. B. (2000), Learning From Automation Surprises and "Going Sour" Accidents. IN SARTER, N. B. & AMALBERTI, R. (Eds.) *Cognitive Engineering in the Aviation Domain.* Mahwah, NJ, Lawrence Erlbaum Associates.

Östberg, O. (1988), Applying Expert Systems Technology: Division of Labour and Division of Knowledge. IN GÖRANZON, B. & JOSEFSON, I. (Eds.) *Knowledge, Skill and Artificial Intelligence.* London, Springer.