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# "The technology is great when it works"

## Maritime Technology and Human Integration on the Ship's Bridge

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## Abstract

Several recent maritime accidents suggest that modern technology sometimes can make it difficult for mariners to navigate safely. A review of the literature also indicates that the technological remedies designed to prevent maritime accidents at times can be ineffective or counterproductive. To understand why, problem-oriented ethnography was used to collect and analyse data on how mariners understand their work and their tools. Over 4 years, 15 ships were visited; the ship types studied were small and large archipelago passenger ships and cargo ships. Mariners and others who work in the maritime industry were interviewed. What I found onboard were numerous examples of what I now call integration work. Integration is about co-ordination, co-operation and compromise. When humans and technology have to work together, the human (mostly) has to co-ordinate resources, co-operate with devices and compromise between means and ends. What mariners have to integrate to get work done include representations of data and information; rules, regulations and practice; human and machine work; and learning and practice.

Mariners largely have to perform integration work themselves because machines cannot communicate in ways mariners see as useful. What developers and manufacturers choose to integrate into screens or systems is not always what the mariners would choose. There are other kinds of ‘mistakes’ mariners have to adapt to. Basically, they arise from conflicts between global rationality (rules, regulations and legislation) and local rationality (what gets defined as good seamanship at a particular time and place). When technology is used to replace human work this is not necessarily a straightforward or successful process. What it often means is that mariners have to work, sometimes very hard, to ‘construct’ a co-operational human-machine system. Even when technology works ‘as intended’ work of this kind is still required.

Even in most ostensibly integrated systems, human operators still must perform integration work. In short, technology alone cannot solve the problems that technology created. Further, trying to fix ‘human error’ by incremental ‘improvements’ in technology or procedure tends to be largely ineffective due to the adaptive compensation by users. A systems view is necessary to make changes to a workplace. Finally, this research illustrates the value problem-oriented ethnography can have when it comes to collecting information on what users ‘mean’ and ‘really do’ and what designers ‘need’ to make technology easier and safer to use.

# Acknowledgements

In the early morning of the 28th of September 1994 the telephone woke me. The caller was a friend who told me that there had been a ferry accident during the night. I went to turn on the TV and, unbelieving and stunned, followed the reports about the sinking of the M/S Estonia that whole day. A couple of days later I happened to see an interview, one of many in the aftermath of this tragedy. A cognitive scientist was interviewed about how people react and think in situations such as these, and generally as well. I was working at sea as a deck officer at that time, but had become interested in a new university study program called Cognitive Science. However, I wanted my maritime experience to come to use, and I had not been able to connect cognitive science to maritime experience. Not until that day, that is. It took me a couple of more years to get everything together, but then I started studying in this program. A quirk of fate is that some years later, when I was ready to start my Ph.D. studies a maritime safety research program was funded by the money originally meant to be used for the protective covering of the M/S Estonia with concrete. This program funded several maritime safety research projects, and was administrated by the Swedish Agency for Innovation Systems, VINNOVA. My project was one of those funded, which enabled me to carry out the research underlying this thesis partly funded by that program. Two other parties are gratefully acknowledged for their financial support to this project: The Swedish Maritime Authority (Sjöfartsverket) and the Swedish Mercantile Maritime Foundation (Stiftelsen Sveriges Sjömanshus).

Special appreciation is extended to the Linda Hall Library in Kansas City. The fellowship provided by The Friends of the Linda Hall Library helped me get there, live there, and write much of the background to this thesis.

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I also want to thank all those who made my stay in the U.S. interesting and pleasant. The supportive staff of the Linda Hall Library helped me find a lot of interesting and useful material. Bruce, Kathy and Cindy in particular made me feel welcome.

In Emporia, SLIM (School of Library and Information Management) provided me with a workplace and were kind and helpful to the 'mariner on the prairie'. Thank you Dean Bailiff and all SLIM's staff and students.

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Finally, and foremost, I am thankful to Bengt, for being there.

## How to read this thesis

The quote in the title was uttered by a mariner. Many others would agree.

In this thesis I will frequently use the 'I' of the beholder, since it largely deals with the situatedness of the mariners and of me as an observer. The concepts mariner and officer are used interchangeably, and 'pilot' is used for an officer with pilot's competence (allowing the pilot to navigate restricted waters and harbours). All informants are referred to as 'he', but this does not mean there are no female mariners. The difference between Human Factors and human factors is that the former is a research area (sometimes called cognitive ergonomics) and the latter a commonly used concept to describe all 'human-related' issues. Ergonomics is an approach that then subsumes Human Factors. Both the words maritime and marine are used, but 'maritime' is allegedly the British term.

If you are not very interested in academic pirouettes read chapter 1 for an introduction, chapter 4 for results and a discussion, section 5.1 for conclusions and section 5.2 for the contributions.

For technology manufacturers and others in the maritime community who want to know more about the method, read chapter 1, the introductory section of chapter 2, section 2.5, chapter 4, section 5.1 and 5.2.

For an executive summary turn to page xi.

This thesis has the following outline: chapter 1 contains an introduction to the study and the research issues from which it emerged, following the principle of "is that so what next". This principle I have borrowed from Professor Erik Hollnagel who learned from one of his mentors to use it to judge the quality of a paper or report. According to this principle there are three main themes that should be present in a paper: the attention-getting one (is that so?), the one identifying the central issues (so what?), and one explaining what is to be done about it (what next?). The three sections 1.1, 1.2 and 1.3 take up these three issues in turn. The problem domain is described in section 1.1 and in several places thereafter. Chapter 2 contains a methodological background, a discussion of ethnography and epistemology, the research strategy and a discussion of being an insider as well as a section discussing the usefulness of ethnography for the maritime domain. Chapter 3 reviews earlier maritime research, and chapter 4 presents a summary and discussion of the research project results and the appended papers. The conclusions, take-home points and ideas for future work are found in chapter 5.

## Contents

## Executive summary


### Introduction
Several maritime accidents seem to indicate that something about modern technology is making it difficult for some mariners to perform safe navigation (Accident Investigation Board, Finland, 1995, 2000; National Transportation Safety Board, 1997). Accidents and groundings partly due to technology problems are not a new occurrence – however, the introduction of modern technology appears to add a new and problematic dimension to these accidents. It seems that not only are some accidents being technology-assisted, but also the technological remedies prescribed to avoid accidents are at times ineffective or counterproductive.

### Method
The bulk of earlier maritime studies is performed in simulators or using questionnaires. Here, a problem-oriented ethnography was used in which selected parts of a context are studied. In this case this meant probing and understanding the way that the operators under study see, describe and understand their work and their tools, rather than measuring in a traditional sense. Interviews and observations are used rather than experiments, and the data are interpreted and analysed rather than statistically treated and presented. The study was longitudinal; data were collected several times over a period of several years. Over 4 years, 15 ships were visited. The ship types studied were small archipelago passenger ships, large archipelago passenger ships and cargo ships. Furthermore, the range of informants is wide; mariners have been interviewed, as well as individuals working with maritime administration and technology, accident analyses, teaching and piloting.

### Results
While on board I gradually began to see how mariners ‘got the job done’. I saw what was happening on board, how mariners cope with their work and errors, how they learn and how they perform work-arounds on new technology. I saw examples of integration on several levels: integration of human work and machine work, integration of different kinds of information representations and integration of learning and practice. I also came to see that the regulations governing the work on the bridge as well as the design of it often seemed to contradict the mariners’ view of the way things ‘work’. Integration is about co-ordination, co-operation and compromise. When human and technology have to work together, the human (mostly) has to co-ordinate resources, co-operate with devices and compromise between means and ends. In integration of this kind there is

not any intrinsic idea of ‘good fits’. Instead, mariners have to work to make the adaptations, to get various types of technology aligned in appropriate ways that makes it possible to get their work done. Whether this means adapting themselves or their surroundings, the job of Human Factors and ergonomics researchers is to make this adapting easier. Examples of what is integrated, fused into a working whole by the mariners include:

- Representations of data and information.
- Rules, regulations and practice.
- Human and machine work.
- Learning and practice.

*Integration of representations of data and information*
There are several reasons mariners perform integration of data and information, but mainly it is because the machines cannot communicate in ways mariners find useful or intelligible given the circumstances. For example, the same data may be presented in incompatible formats. Mariners also want 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. For mariners to construct their ‘own’ integrated system takes a lot of effort, in evaluating and choosing among types of representation and comparing data which were not designed to be compared. This study found that what developers and manufacturers choose to integrate, into screens or systems, is not always what the mariners choose.

*Integration of rules, regulations and practice*
In the maritime domain there are many rules, regulations, procedures and guides imposed by legislation from the ‘outside’. As shipping has been around for millennia, practice (seamanship) has evolved and is as important to the community as legislation. Some of the reasons mariners have to integrate (force a fit) between rules and practice are:

- Rules can be contradictory.
- Rules can be underspecified or vague.
- Rules can be hard to implement in the light of contradictory goals (e.g., time, safety, economy, manning).
- Rules tend to be rigid and therefore hard to fit to a dynamic world.
- Rules can be interpreted differently by mariners and ‘outsiders’.

*Integration of human and machine work*
Mariners perform work to build functioning human-machine systems, to 'integrate themselves' into a co-operational system. When there is a misfit between humans and machines, mariners have no choice but to 'reconstruct' the integrated systems in terms and ways they themselves understand. Mariners 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. Mariners also believe or hope that human-machine systems can relieve them of certain kinds of work and uncertainty, without the technology being a burden to them. Technology is often used to replace parts or all of human work and to make work safer, more efficient or less costly. This 'replacement' is not always straightforward, and effort has to be expended to get the 'new' system to work. When devices are technically integrated the co-ordination is more 'hidden' and 'invisible' to users than before, and mariners often have to employ more work and effort to reconstruct and understand the system. Even when technology works 'as intended' integration work is needed.

*Integration of learning and practice*
There is much integration of learning and practice, both formal and informal that goes on. In fact, for many officers their career as well as their identity as officers rests on a never-ending learning process. There is little training provided by anyone for new technical systems, and many maritime academies cannot keep up with the rate of change. Most manufacturers do provide training for their systems, but this is not inexpensive. At present, it is common to get no or only on-the job training for new technologies.

**Conclusions**

- Ethnographic method and analysis is valuable because it provides a useful way of collecting information on what users 'mean' and what designers 'need' to make machines easier and safer to use.
- Many ostensibly technically integrated maritime systems are neither well integrated from a human co-operative point of view, nor from a technical point of view. Mariners have to bridge these gaps of integration by performing integration work, by adaptation, tailoring and shedding (or co-operation, co-ordination and compromise).
- Work cannot be broken into pieces and then put back together again. New ways of designing for and thinking about the workplace are already in use in other domains. We suggest that cognitive tasks and social tasks should be the focus, not engineering and devices.

**For more conclusions, please turn to page 88.**

## Acronyms and domain terms explained

| | |
|---|---|
| AIS | Automatic Identification System |
| BRM | Bridge Resource Management |
| Colregs | The international regulations for preventing collisions at sea |
| CSCW | Computer Supported Co-operative Work |
| ECDIS | Electronic Chart Display and Information System |
| GPS | Global Positioning System |
| HCI | Human-Computer Interaction |
| HF | Human Factors |
| HMI | Human-Machine Interaction |
| IBS | Integrated Bridge System |
| IMO | International Maritime Organization |
| INS | Integrated Navigation System |
| IP | Information Processing |
| SOLAS | Safety Of Life At Sea, regulations |

| | |
|---|---|
| Chart datum | Reference system for depths on charts |
| Decca | System for hyperbolic navigation |
| Echo sounder | Device to measure depth under ship |
| Electronic chart | Sea chart on electronic display |
| Fathom | Depth measure: 1.83 meters |
| Hyperbolic navigation | Navigation using radio waves |
| Log | Device to measure ship's speed |
| Loran | System for hyperbolic navigation |
| Nautical mile | Distance measure: 1852 meters |
| Radar | Instrument which detects and presents targets |
| Radio direction finder | Device for finding direction to a radio source |
| Pilot book | Book with information on piloting waters |
| Port | Left side of ship, facing forward, also harbour |
| Sextant | Instrument for celestial navigation |
| Starboard | Right side of ship, facing forward |
| Tide tables | For calculating tidal heights and times |
| Trade | Type of journeys for ships (e.g. coastal, oil) |
| VHF | Very High Frequency, radio band |
| Waypoint | Point on journey where course is changed |

## Papers included in this thesis

1. Lützhöft, M. H. and Nyce, J. M. (In press) Integration work on the ship's bridge. *Cognition, Technology and Work*.

2. Lützhöft, M. H. and Nyce, J. M. (2004) Piloting by heart and by chart. Manuscript submitted for publication.

3. 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, London.

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

5. Lützhöft, M. H. and Dekker, S. W. A. (2002). On Your Watch: Automation on the Bridge. *Journal of Navigation, 55*(1).

6. Lützhöft, M. H. and Dahlman, J. (2002). The human factor in accident analysis - the Kronprins Harald case. *Nordic Navigation, 1/2.*

## Papers not included

Lützhöft, M. H. Human Integration of bridge technology. Submitted: 2005 RINA conference Human Factors in Ship Design, Safety and Operation.

Dekker, S. and Lützhöft, M. (2004). Correspondence, Cognition and Sensemaking: A Radical Empiricist View of Situation Awareness. In S. Banbury and S. Tremblay (Eds.), *A Cognitive Approach to Situation Awareness: Theory and Application*. Aldershot: Ashgate.

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Lützhöft, M. and Dekker, S. W. A. (2003). On Your Watch: Automation on the Bridge. *Seaways, November.*

Lützhöft, M. (2002). Den mänskliga faktorn - eller teknikassisterade olyckor? *Passagerarredaren, 3*.

”This road differs from those on land in three ways. The one on land is firm, this unstable. The one on land is quiet, this moving. The one on land is marked, the one on the sea, unknown.”

Martín Cortés, Breve compendio de la esfera.
Cited in Arturo Pérez-Reverte: The Nautical chart.

# 1 Introduction

Several recent maritime accidents seem to indicate that something about modern technology is making it difficult for some mariners to perform safe navigation (Accident Investigation Board, Finland, 1995, 2000; National Transportation Safety Board, 1997). Other examples can be found in reports from national accident investigation boards[1] and MARS[2], the Marine Accident Reporting Scheme, a confidential reporting system run by The Nautical Institute in which reports can be browsed by anyone. Accidents and groundings partly due to technology problems are not a new occurrence, examples are the Stockholm – Andrea Doria 1956 radar-assisted collision[3] and the Honda point disaster in 1923 involving eight American Navy ships[4]. However, the introduction of modern technology, for example integrated bridge systems, appears to add a new and problematic dimension to maritime accidents. Seeing these accidents through Human Factors eyes, more specifically the new view of human error (see e.g., Dekker, 2001) it seems that not only are some accidents being technology-assisted, but also the technological remedies prescribed to avoid accidents in particular are at times ineffective or counterproductive.

One central problem, for instance, is that mariners are assisted by technology more often in calm circumstances than high-stress ones (Grabowski and Sanborn, 2001, 2003), and mariners interviewed in the present study make the same point. High-stress situations are probably when mariners really could use technology support (of the right kind). To briefly introduce a few key concepts used in this thesis: modern technology here includes integrated navigation and bridge systems, which in some cases include automation. The concept of integration is used here in two ways – to talk about technical integration (performed more or less well) and to talk about integration work, performed by mariners.

In other maritime studies the importance of integration work, as the term is used here, is at times implicit but seldom explicitly studied. Dilloway (1967) does present an early systems point of view, and is concerned with man as an element in an assemblage of elements or machines. Wilkinson (1974) talks about men and machines operating as a unit and an aggregate, whereas Istance and Ivergård (1978) say that integration is when man and machine 'parts' are joined back together after having been

[1] For example, Finland: http://www.onnettomuustutkinta.fi/2601.htm [2004, October]
[2] http://www.nautinst.org/marineac.htm [2004, October]
[3] http://andreadoria.org/ [2004, October]
[4] http://www.history.navy.mil/photos/events/ev-1920s/ev-1923/hondapt.htm [2004, October]

separated in the design chain. Integration according to them basically consists of ‘the design of the man-machine interface.’ Courteney (1996) discusses these issues from an aviation perspective and calls the pilot ‘the interface’ and finally Pomeroy and Jones (2002), in the maritime context, briefly mention the ‘user as integrator’ but do not discuss it at any length.

The bulk of earlier studies made of ship’s officers and new technology is performed in simulators or using questionnaires. These relatively blunt instruments mostly lead to blaming and/or training the operator. Hutchins’ approach (1990, 1995, 1996) was one of the first alternatives I found, and several aspects of this research were appealing: the domain, the methods used and naturally the analysis and conclusions possible from something that looked common-sensical. This was something I wanted to learn: how to observe the real world and be able to analyse and describe what was going on in a way that would give new insights to others and myself. Ethnography is about “describing the world as perceived by those within that world” and to understand under what circumstances activities are given meaning (Harper, 2000, p 245). Bruner suggests we ask ourselves “what would it be like to believe that” when we want to understand other people’s world views (1990, p 26).

Exploratory field studies were made and during these first field visits, in the back of my mind I hoped for something to happen. Something like in Hutchins’ study, where he observed a crew handling their navigation task on a ship that was not under command. Something did happen. However, the data that turned out to be the focal point were not that dramatic. Rather, it was comments made by officers that became the core of this, comments like: “When we really need the technology, it is no help” and “I try to understand how the guy who built it was thinking” and “How will my switching off this part affect the rest of the system?” The problem became even clearer when I looked at regulations for bridge technology, where apparently few of these issues were taken into account.

This is not a claim that this is necessarily the most urgent problem that the maritime community faces, but it is a problem that will increase with the introduction of more technology and more automated systems. Furthermore, it is a problem which I was in a unique position to study, having spent 13 years at sea and holding a master’s ticket. Today humans are often being treated as ‘collectors-actuators’ for machines – collecting and inputting data, waiting, and then performing an action prompted by the machine. This view seems limited and in reality seldom works well. The question then becomes: why does this not work well and how are mariners working around this? This field study shows many aspects of how mariners pull together various resources (mental and material) and make sense of them in different ways.

Rasmussen (1999) alerts us to the fact that system users should no longer be treated as add-ons to a system but as integrated parts of a functional design. Many researchers are now looking further than technology design using what is called Cognitive Task Design (CTD, Hollnagel, 2003). The main argument of CTD is that we must study how the use of artefacts change how we see them and work with them rather than simply focus on the use of the artefacts as such. This clearly shows that humans are to be seen as an integral part of system design and not just an end-user of a stand-alone product. What are the implications of such views for integrated bridge systems, a concept which probably makes most people think of technology only?

This raises a number of issues; finding out why technology sometimes makes work harder, why the traditional solutions are not working well, what is an appropriate method of data collection, interpretation and analysis and finally, how to write up the results in a useful way, and for which audience? In sum the argument presented here is twofold: finding out more about new technology in use on ship's bridges, and evaluating whether ethnography can help in this endeavour.

The format of the following three sections is also explained in the reading instructions. In short, they follow the "is that so what next" principle. This principle is used to get three main themes across in a paper – establishing the background, explaining the central issues and outlining what can be done about it.

## *1.1 Examples from ships (is that so)*

The study was conducted in phases, where the first phase of the field studies served to focus the area of study. This first phase led to the insight that under some circumstances, when using technology, the officers have to infer the intent of the designer. Based on this finding the study was focused on the following questions: which are these circumstances, when and why do they occur, and how are these situations handled? This in turn led to an understanding of how much harder it could be for officers to figure out what was going on in integrated systems than in conventional systems. A second issue was how they worked to integrate themselves into systems that did not explicitly and gracefully allow for the inclusion of human operators. Similarly interesting became the question of what mariners themselves chose to integrate into their work practice including the memorisation of information for tasks like piloting. To set the scene for these issues, first a short history of the bridge and navigational technology and then brief summaries of the three ship types studied in this project.

What is a bridge? There used to be a difference between the bridge and the wheelhouse: at the end of the 19th century the bridge was a deck space, with no roof and no walls, except for the bulwark (a barrier around the bridge). It contained a compass, a steering wheel and telegraphs for communication with the engine room and look-out stations. The wheelhouse was a sheltered structure on the bridge containing a steering wheel, hence the name (Wilkinson, 1971). Since then the bridge has become more and more covered, and today the wheelhouse and bridge are one and the same and include the chart room, which previously might be placed on another deck entirely. In some ships the whole bridge is roofed, with no open bridge wings. Thus, the working environment has changed, by all accounts to the better, as mariners have been increasingly sheltered from the weather.

As the bridge has changed, so have the tools and instruments on the bridge, following the evolution of technology. Today, the most advanced bridges resemble aircraft cockpits or process plant control rooms. We will go back in time for a short while, to see how bridge technology has evolved, and different aspects of use have been emphasised. A review of Bowditch (a navigator's handbook, 1929, 1939, 1958, 1962, 1977, 1984) over the years illustrates how technology, and thus work, on the bridge has changed over time. As chapters are added through the editions, we can see how navigational technology evolved and was put to use on the bridge. The 1929 edition shows that the tools available to a navigator were the charts, the compass, the sextant, and depth soundings. By 1939, the bridge was supplemented by radio direction finding and radio beacons. The 1958 edition features radar and hyperbolic navigation systems such as Decca and Loran, and in 1962 gyrocompasses, echo sounders and modern logs were available. In 1977 and 1984 the addition was satellite navigation.

Reviewing Bowditch shows us the available instruments and tools but tells us little about how they were and are used together – the topic which will be taken up here. There are four basic methods of navigation at sea (these methods will be found in any textbook on navigation, but see also the excellent web site www.navis.gr [October, 2004]). The methods are in practice used in various combinations:

- **Dead reckoning**: The navigator uses a point of departure and from there keeps track of speed and direction sailed.
- **Piloting**: The navigator directs a ship by observing landmarks and navigation aids, such as lighthouses, buoys, depth soundings and the look of the surroundings.
- **Celestial navigation**: The navigator determines the ship's position by observing the sun, moon, and other stars and planets.
- **Electronic navigation**: The navigator uses radar and instruments such as GPS, most often using radio waves or signals.

Dead reckoning is perhaps the earliest method and the one mariners used every day. The word dead is said to have been spelt *ded* and be an abbreviation of *deduced*, so that the original name of the method was deduced reckoning. With the advent of ever more sophisticated electronic navigation instruments the method has fallen into disuse. However, this is not entirely true, as the instruments still make use of it. Between the times that they acquire data and calculate a position – by whatever means and with whatever time intervals – many of them use dead reckoning. One question is whether mariners are made aware of this by the instruments, or otherwise.

Piloting is performed using navigational aids (buoys, lighthouses), which are mostly standardised across the world which means that any mariner may use them to navigate in almost any place. Using landmarks and knowledge of your surroundings independently of navigational aids is less common today unless you actually are a pilot as we now know them, a local expert who comes on board to guide ships the last part of their journey to port. This thesis will show some examples where boundaries again blur between pilots and navigators.

Celestial navigation is often called a craft or an art, even more so than the other methods. It entails using beautiful instruments such as the sextant, and books and tables to aid the calculation. It is not used much today, and the space for teaching it in maritime colleges is decreasing as this method is being displaced by electronic navigation. Although every so often celestial 'bodies' (satellites) are still used for navigation, much of this craft and calculation has been delegated to a device.

Electronic navigation used to mean that the navigator used electronic devices to ascertain his position. The instruments were tools among others, to be monitored and used by the navigator at his discretion. Today the roles are in many cases practically reversed. More and more instruments are *integrated* (technologically), i.e., connected to other instruments in various ways for the exchange of data. For instance, the electronic chart may send data to the radar, and the GPS (Global Positioning System, satellite navigation) sends data to them both. An integrated technological system which is becoming common on ship's bridges is the integrated *navigation* system (INS). When an INS is expanded to include ship management features such as communication, engine and ballast controls and fire alarms it is called an integrated *bridge* system (IBS). The International Maritime Organization (IMO) definition reads: An **integrated bridge system (IBS)** is defined as a combination of systems which are interconnected in order to allow centralized access to sensor information or command/control from workstations, with the aim of increasing safe and efficient ship's management by suitably qualified personnel.

As the amount of tools and the complexity of them increases over time, it becomes more necessary for mariners to cope and this often means to perform 'manual' integration work (Courteney, 1996; Lützhöft and Nyce, In press; McDonald, 2002). Here, integration work is defined as what mariners do to construct a combination of systems and technologies that allow them to perform their work. Integration is about co-ordination between people and artefacts or technologies; be they rules and regulations, training and education, or technical devices.

The three ship types studied in this project are large passenger ferries (e.g., 2000 passengers) in regular traffic between Sweden and Finland, small archipelago passenger vessels in the Stockholm and Gothenburg archipelagos (e.g., 100 passengers) and merchant ships in Baltic, North Sea and transatlantic traffic (dry cargo vessels). The bridges on these three ship types are quite different (both regarding equipment and use), which mariners know and adapt to, but technology manufacturers have a hard time handling. The following summaries were made about half-way through this project and therefore contain examples of issues thought to be central at that time.

**Large passenger ferries in archipelago traffic**

Many of these large passenger ferries have integrated navigation or bridge systems. It is also very common to use a navigation team of two officers (much like in aviation). In archipelago navigation here, parts of the chart information is overlaid as lines on the radar picture to get lanes (a corridor of 'safe water' in regard to depth). These 'lanes' and other information such as an ideal track is pre-programmed into the system by the officers. Radar and electronic charts are still two separate displays in most ships. These officers start out by learning to 'drive' (*driving* a ship is a colloquial term) using much of the available technology. They are expected to know the charts and waters of the area sailed by heart in 1-2 years (if they want to qualify for a pilot's exemption, see also Lützhöft and Nyce, 2004).

Examples of available aids on these bridges are: radar, autopilot with several modes for different degrees of automation, paper and electronic charts and course books (a personal compilation of important information laid out on chart sections). Later, they often steer more or less manually and have learned (memorised) enough to seldom need to use charts. Thus, they start using modern technology and end up knowing how to use both technology and 'basics'. Problems with technology here (when they appear) are often due to automation; not knowing what is going on, when and how to take over. These ships, as most large ships, have a lag (it takes some time for the ship to react to a given control order), which means the crew has to plan well before actions. These mariners are a group that have a large impact on the manufacturers of their bridge technology and they have strong spokespersons lobbying for them and their needs. The domain (Swedish-Finnish archipelago) is unique, nowhere else in the world do they navigate in this way, at such speeds in such a constrained environment for such long periods of time.

**Small passenger vessels in archipelago traffic**

Archipelago navigation in these small vessels is about using very little technology when the visibility is good, the captains drive mostly "by their eyes" (there is ordinarily only one navigator on the bridge, the captain). Radar is described as the most important instrument, but when asked to choose between radar and seeing out of the window, it is hard for them to choose which is more important or accurate. Electronic charts are in use on a number of ships, and in some companies in innovative ways – photographs of the jetties visited on the route are inserted into the chart. The captains trust 'reality' (what they see out of the window) much more than the charts, paper or electronic. They tend to check 'old knowledge' of navigational hazards, inherited from others by word of mouth, against charts. Their knowledge is so thorough that they have been known to find faults in the charts.

They learn (most of them) to "wear the boat like a backpack" when manoeuvring to and from jetties, which can take place 40-50 times in a day. They often use hand-steering and travel at relatively high speeds. Many of the problems with technology here are pragmatic and low-level, for instance a chart display that is too bright to use at night, or a lever which is at an awkward angle. Many of the cognitive ergonomics issues unique to this vessel type are not analysed in depth here but are discussed in a spin-off master's thesis (Nilsson, 2004). The physical ergonomics nature of these problems has been treated in Clausén (2001). However, some of the problems found in these vessels apply to larger ships as well. When this was found to be the case, those data were analysed here, together with the data from the larger ships.

**Merchant ships in 'world-wide' traffic**

Open water navigation is just that, more navigation and less manoeuvring. There is one officer on watch in open waters, supplemented by the captain in restricted waters or when close to shore or port. When officers join a ship with a modern bridge system for the first time, they tend to use 'basic navigation' (radar, charts, GPS) in the beginning and the more modern technology as they have time to learn it. A problem here is that many mariners do not get much training (on for instance new technology) after the merchant maritime academy, and have little time and/or motivation to learn while on board. Navigation can mostly be performed to satisfaction by using 'basics'. However, there are other tasks to perform on the bridge, which the archipelago mariners do not (and could not) perform. Therefore technology can be used as a relieving partner, to take care of parts of the navigation while the officer performs other tasks (for example weather reports, cargo planning and safety-related work). Very seldom is manual steering used, only when approaching port or if the autopilot is malfunctioning.

Technology manufacturers do not know much about the normal daily work of these mariners, as it is hard to get feedback from them. The technology problems here often are due to mariners not understanding the systems, and the difficulty of adapting them to various situations. Especially problematic is the way these ships travel through 'extremes' in that they cross the Atlantic where not much information is needed, waters with heavy traffic such as the English channel where they need to know more and then into shallow and restricted waters to get to port where navigation can be the most problematic. For many the most common situation is open water, and the proliferation of data and information can become frustrating.

As one officer said "they're all showing their muscles on all the screens, why can't they get the system to work better together instead?" Some argue that mariners resist change, and want to keep methods they know work, (see e.g., National Research Council, 1994). In this research however, I have not seen mariners explicitly resist change just for the sake of resistance but I have often heard them say that they want to keep methods they know work. In part this research attempts to describe how mariners work to incorporate their 'basic' methods with the new technology. This is what technological systems should allow, rather than demand that officers create a new method of working every time a new device turns up.

## *1.2 Explanation (so what)*

As part of this project, four representatives of major maritime technology manufacturers were interviewed. They all have different ways of gathering input and feedback about the design and use of their instruments, but most of them agreed they still need more knowledge. Although some use is made of field testing (in special testing vessels or on customers' ships) a lot of the data collected relates to technical issues such as tolerance to vibrations and temperature. This is necessary to comply with standards and certification regulations. Technical standards are often based on numbers and measurements and as such it is easy to decide whether a device fulfils a requirement or not. When it comes to ergonomics and Human Factors this is harder. Although there are standards today they lend little guidance to what is to be done and how. Granted, this may not be the role of standards, but if we want to make the workplace more cognitively ergonomic we may have to devise ways to write standards and requirements that do not depend just on numbers, and can help specify what is really 'needed' on board.

Alternatively, we may ask researchers to unpack the terms in the standards that seem to need it. As an example we will look at an excerpt of the SOLAS (International Convention for the Safety of Life at Sea) regulation V/15. Only a few of the 'thick' terms (in bold italics below, emphasis added) will be discussed here:

**Principles relating to bridge design, design and arrangement of navigational systems and equipment and bridge procedures**

All decisions […] shall be taken with the aim of:

.1 facilitating the tasks to be performed by the bridge team and the pilot in making full appraisal of the situation and in navigating the ship safely under all operational conditions;

.2 promoting effective and safe bridge resource management;

.3 enabling the bridge team and the pilot to have convenient and continuous access to ***essential information*** which is presented in a clear and unambiguous manner, using standardized symbols and coding systems for controls and displays;

.4 indicating the operational status of automated functions and integrated components, systems and/or sub-systems;

.5 allowing for expeditious, continuous and effective information processing and decision-making by the bridge team and the pilot;

.6 preventing or minimizing ***excessive or unnecessary work*** and any conditions or distractions on the bridge which may cause fatigue or interfere with the vigilance of the bridge team and the pilot; and

.7 ***minimizing the risk of human error*** and detecting such error if it occurs, through monitoring and alarm systems, in time for the bridge team and the pilot to take appropriate action.

The three terms in question here (although this short regulation is teeming with others) are:

- Essential information.
- Excessive or unnecessary work.
- Minimizing the risk of human error.

How should a Naval architect or an instrument manufacturer even start to decipher what these terms mean? How should they go about finding out what is "essential information"? Some ships sail many types of waters, and how is a designer to compromise between the needs for the various kinds of voyages? Technology manufacturers say they get the least amount of feedback from these types of ships. What is excessive or unnecessary work and how is it avoided? What may be unnecessary in one situation may be imperative in another. This is a question which unfortunately is easier to answer after the fact. How do we find out what the mariners think, and whether this is in agreement with the views held by manufacturers? Finally, the hardest question of all: how to minimise human error. This decomposes into several other questions: is there such a thing as human error, if so, what is it, when and where does it occur, can it be reduced at all, and in such case, how do we minimise it?

Mariners are said to have two tools to manage risk: the practice of good seamanship and informed judgement derived from experience and expertise (National Research Council, 1994). Seamanship is a set of general 'rules of thumb' that define 'best practice' on board ship – for example to perform passage planning before departure and to try not to disturb other ships during navigation or manoeuvring. Both these 'tools' are basically similar, judgements made on experience, either your own, others' or both. The situation in congested waters has been described as error-inducing (Perrow, 1984) and further can result in information overload, a break-down of the decision making process (National

Research Council, 1994). It is clear that mariners need more assistance, as their traditional tools to manage risk are no longer enough. One suggested solution is to design piloting expert systems using input from bridge instrumentation and heuristics (Grabowski, 1989; National Research Council, 1994). However, as mentioned earlier, we still need to get past the problem that mariners are assisted by technology more often in calm circumstances than in high-stress and time-critical ones. Furthermore, finding and recording the heuristics may well be one of the large challenges, but also one which could give considerable returns in the form of useful information for designers and legislators.

What we may deduce from here is that mariners have a lot of experience they put to use in their daily work and that industry does a lot to get user input, but industry is still not addressing the issue in all the potentially useful ways. Bea and Moore (1993, p. 227) conclude that:

> "In some cases we engineer marine systems that cannot be constructed and operated as they should, so field modifications and short cuts must be developed. The engineer rarely hears about these problems until they become critically evident…"

We know that people adapt new technology, or adapt to it, in various ways (this is also discussed in chapter 4). Another effect of working with tools of any kind is emergence - when we get functionally valuable side effects from the interaction of heterogeneous components, e.g. organism-environment interactions, in other words: the total can be more than the sum of the parts (Clark, 1997; Hollnagel and Woods, 1983). This is not due to design intentions, but rather occurs when certain aspects of design or the environment afford innovative uses, helpful to the current task. For example, there could be a slot between two instruments which is discovered to be useful to hold a map, or switching on a (currently) not useful display to remind yourself of something else in progress. Such incidental features are at risk of being erased from the evolution of technology, as they seem to add no fitness value, if the manufacturer knows about them at all.

The ways artefacts are used can only be observed and their significance discovered in actual use. It may seem, to an engineer, that there is no harm in changing the look of a display or changing the underlying metaphor for an instrument's display of information. However, if we do not know enough about how technology is used in practice, what added functionality end users may have discovered or adapted the technology to afford, and what work-arounds they have devised, we may lose many direct and indirect emergent effects. Such effects are found both in the use of instruments, in tasks and routines, and how we see the tools (Hollnagel, 2003). There is a stance that there is nothing problematic in engineering change, which rests on a model of human Information Processing (IP) that is straightforward to explain, to teach, and to study. This stance assumes that the social world can be decomposable into handy little pieces in handy little micro-worlds using problems that have a fixed set of known alternatives and a stable goal, and studied in the contextlessness of a laboratory experiment.

But it is natural for the technology-driven community to want formalistic models – after all, how else can human behaviour be predicted and technology designed? Classical cognitive science claims that 'we cannot be sure that we understand it until we have built a working model'. It is then assumed that in order to model human cognition, a computer (or programs) must be used. To build a program, formal specifications are needed. IP models are very formal, since mental representations are supposedly in the form of symbols combined into rules. Consequently, IP models are preferred for the design and development of new technology, because it is relatively easy to move from rules to code. Code or rules are what programmers mainly use, what engineers feel more comfortable with and what designers therefore seek. These rules are purely syntactic, and an extensive and as yet unresolved debate even within the IP community is how the symbols are 'grounded' i.e., how they acquire their semantics and meaning for a human agent. In contrast, researchers that subscribe to the 'contextual revolution' believe that the world itself grounds our representations, i.e., context-dependent meaning is attained through interaction with the world (Brooks, 1991a, 1991b; Bruner, 1990; Clark, 1997; Clark and Chalmers, 1998).

Such meanings, acquired in interaction with the world and artefacts therein, are highly dependent on both the historical and the present context. For instance, Clark (1997) discusses action loops, and suggests that most of our early knowledge is tied up in such loops, something that IP would be hard-pressed to explain. An example of such a loop is the way infants that have yet to learn walking will with experience learn just how steep an inclining plane can be for them to be able to crawl there without falling. When they start walking, it seems this knowledge is 'forgotten' as they launch themselves onto slopes that they apparently knew before were too steep to crawl down. The knowledge, it seems, is not stored in some database of 'long-term memory', but instead, closely and intricately coupled to the action of crawling. Therefore, if we want to unpack meanings and find out how the interaction between the human and artefacts (for example automation) really works, we must study the real (social) world, people doing real tasks with real consequences under real circumstances.

### 1.3 Issues (what next)

A central work in establishing the state of practice of current navigation and piloting, including the identification of areas for future research and development in the maritime domain is *Minding the helm* (National Research Council, 1994). One theme in this volume is that research on technology has been performed one-sidedly, focusing on technological issues, and researchers now need to consider humans and technology from a systems point of view. Today, the IMO and many other organisations are putting extra effort into taking what is called the ‘human element’ into account. Another important point is made in *Minding the helm*: the authors come to the conclusion that ultimately, field trials are needed for new technology, on the same class or type of vessel for which the use is intended and under the range of operating conditions that will be experienced.

User-centred evaluation is sometimes mentioned as a solution (Aldridge, Brooks, Moreton and Smeaton, 1997), but this may put too much pressure on the mariner to act not only as an informant but also as an evaluator and designer. It is not clear that this use of informants is reasonable or appropriate. It may be better to have them help us uncover the usefulness of the tool or device in question for bridge work. User-centred evaluations are a good start but perhaps even better would be a user-centred (and use-centred) integration and design. A positive example of this is Ritmiller, Davis and Zander (2000), where Human Factors specialists and a representative of the vessel operator were part of the same design and manufacturing team for a high-speed ferry. Wilkinson (1971) also points out that studies on board and in co-operation with ship’s crews need to be performed. Furthermore, an important point is made – we are not only dealing with mariners or other operators and their relationship to the equipment manufacturers – there are other links, more or less strong. There is the connection to the Naval Architect and the shipping company’s representative. We also have to consider shipyards, standardisation committees, legislative bodies and international maritime agencies, and there may be many other stakeholders.

This thesis argues that ethnography can make a contribution as a method for data collection, focusing studies, analysing data *and* providing guidance for design. Over and above the increased understanding ethnography can give to the various stakeholders, I want to increase the mariners' consciousness about their own practice, using ethnography. The reason is that they hopefully, through a better understanding, can be predisposed towards technology that will be supplied to them, wanted or not. Therefore, it is better for them to be prepared *and* to have a say on the design. This is an acceptance of the reality of the present century and not what Harper (2000, p. 243) suggests, that many ethnographers in CSCW (Computer-Supported Co-operative Work) have a "tacit agenda that is opposed to technology in general and technologically-driven change in particular." If ethnography, or any other field method, is to make a difference for the users of complex systems, it must start by being explicit about certain issues. A study might not be performed in order to replace humans with technology, or to push more technology onto already reluctant users, but some results may be used that way. And technology will not stop coming – thus we should accept this fact, but also remember that when the rate of adoption for a technology goes up, experience of its use increases, more research and development is performed, and the better the technology (hopefully) becomes (MacKenzie, 1998).

Remember, integration work is a concept that covers the work humans do to construct a system (of various 'parts') that helps them perform their work. So, if integration means putting back together, what does disintegration mean (also known as allocation)? We look at Merriam-Webster's online dictionary[5]:

Main Entry: **disintegrate**
1: to break or separate into constituent elements or parts.
2: to lose unity or integrity by or as if by breaking into parts.

We see that disintegration means to separate into parts, but it can also mean losing the integrity of a system. Is it possible to create, sustain or recreate the integrity with design or should this responsibility be left to the user? This issue will be discussed throughout the thesis. This chapter has introduced the 'is that so what next' of this thesis. What follows is a chapter discussing the method and how to judge the quality of ethnographical studies. I also describe my research strategy.

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[5] http://www.m-w.com [2004, October]

# 2 Method

This chapter starts with a methodological background and continues with a discussion of ethnography and epistemology. In section 2.3 the research design is described and section 2.4 discusses the drawbacks and benefits of being an insider. Finally section 2.5 discusses some methodological issues of this study, and the usefulness of ethnography for the maritime domain.

> "Science has no royal road…If lab experimentation involves any essential disturbance of the phenomenon, the psychologist must lay aside his plans of formal simplification and study the event under its natural conditions accepting whatever complication the change introduces into his problem."
>
> MacDougall, 1922, p 351-352.
> Cited in Gillis and Schneider, 1966.

## 2.1 Methodological background

If context and meaning are not taken into account when designing new technology, there is a risk that a device or system does not fit the users and their tasks. As we are moving from tools that are used to enhance our physical performance to cognitive artefacts that perform much of the work automatically, the effects are hard to predict and even harder to measure. What methods and perspectives will get us there?

Cognitive science and Human Factors (HF) are starting to do today what organisational psychology initiated in the 50's – going into the wild, acknowledging the importance of empirical studies in the field and to take the environmental variables seriously. There are now discussions in the HF community on the importance of concepts similar to those found in the 50's psychological literature. Examples of this is the "total situation" (Lewin, 1951), the "functional unit of behaviour" and "ecological validity" (Brunswik, 1952) and organisational reasoning and decision-making (March and Simon, 1993). The aim in these studies was to describe the totality of interacting humans and technology and the dynamics and processes of complex systems. One goal was to predict change to some degree. Chaiklin points out that when old theoretical and empirical traditions receive renewed attention within a research community, it often reflects the inability of currently dominant traditions to resolve their own objectives in satisfactory ways (1996, p. 382).

Today, a large group of researchers from diverse disciplines are studying the issue. Bruner (1990) and Weick (1995) have developed their thoughts on sensemaking and the construction of meaning. A pivotal study of work in the HCI (Human-Computer Interaction) community is Suchman (1987) with the introduction of situated cognition. This is followed by anthropological studies by Hutchins (1990, 1995a, 1995b, 1996), in the aviation and maritime domains, leading up to an approach and a research agenda called distributed cognition. Andy Clark puts body, brain and world together again (Clark, 1997; Clark and Chalmers, 1998), and Woods, Johannesen, Cook and Sarter (1994) develop bounded rationality into local rationality. Recently this concept is connected to ecological approaches by Vicente (1999), who calls it context-conditioned variability, and claims that context should be the focus of ecological task analyses. Klein and colleagues claim we have to look at decision making as naturalistic instead of rationalistic (Zsambok and Klein, 1997), and Hollnagel (1998) develops Neisser (1976) and many other strands into a theory of cognition and control. All the above argue that situatedness and variability are valid concepts and that going into the wild can lead to useful findings.

Thus, research is in many cases focusing on how humans make sense of the situation they find themselves in. Methods are concerned with contextual factors, and researchers come from non-experimental disciplines. This is not to say that traditional experimental or statistical methods do not resolve anything, but rather that the HF community has recognised a need to use methods and techniques which complement these longstanding methods and the models they support.

For instance, interviews performed in this project show that some technology manufacturers claim that questionnaires are too expensive and yield little that they can use pragmatically. There is also the academical critique: Westlander critically discusses standardised pre- and post-test questionnaires used to assess the effects of change in the workplace, both organisational and technological (2003). A general conclusion is that the reliability of the measurement can be compromised by the influence of the change itself on the respondents' interpretation of the contents of the questionnaire. Earlier work in the maritime domain indicates that questionnaires are not well liked by informants (no validity) and get little response (no generalisability).

Using tools or methods designed to quantify behaviour or to write laws will not yield the richness and complexity of the work situation, and will seldom tell technology designers or manufacturers what they need to know about the 'human element'. Further, some behaviours can only be observed in a natural setting. Whatever is stripped away in an experiment or a questionnaire may be just the cue or reminder used to structure work by the participant. Furthermore, an important point when choosing a methodology for a research project is to carefully design endpoints and not resort to red herring arguments like cost (Nyce and Löwgren, 1995).

Research aims at identifying the presence or absence of something, but this does not necessarily mean that it is possible to measure the exact degree to which this feature is present or absent (Kirk and Miller, 1986). The present study is ethnographically informed and as such can identify the presence of something, and at the same time it can identify and take into account factors that may cause change or account for it in the situation studied. The researcher can talk to the operators, ask them to consider the researcher's interpretation of the work situation as derived from data, and thus allow the operators to change their own view of their work in the process. Giddens (1979) explains that this is what leads to the perceived lack of causal laws in the social sciences. He argues that all causal laws operate within certain boundary conditions, and that in the social sciences part of these boundary conditions is the knowledge that actors have about the circumstances of their actions. Thus, coming to know about the circumstances of their work, and the laws specifying relations in a certain situation, may alter these very relations and ultimately cause any attempt to write laws to result in failure. This is because operators may use these laws both as guiding resources and as a rationalisation of action. Given that this kind of loop exists between behaviour and the boundary conditions of the 'laws' governing behaviour, it is difficult to reduce the 'laws' that govern the social order to simple causal laws. If causal laws cannot handle human interactions, what are the options left to us if we want to study human interactions? It is suggested here that ethnography can help us handle this problem as well as provide results and analysis not achievable with classical positivistic and quantitative approaches. Therefore, when researchers undertake participatory, naturalistic research, they should not expect to find or arrive at archetypal causal laws, and they must be prepared for and aware of the effect they may have on the studied situation.

Ethnography is in fact often used in the HCI community, but there is a tendency to use it in a 'quick and dirty' manner (Bader and Nyce, 1998; Dekker, Nyce and Hoffman, 2003; Nyce and Löwgren, 1995; Rouncefield, Viller, Hughes and Rodden, 1994). This tendency is criticised more or less harshly by various researchers, for instance Forsythe (1999). I would argue that what you do is what you get – if you use a quick and dirty ethnography, you often get quick and dirty answers or data. There is also confusion here between ethnography as a field method and a method of analysis (Dekker and Nyce, In press). The issue that HCI tends to neglect is that ethnography is fundamentally an interpretive endeavour. It is not as most of its practitioners in the HCI community would have it, just a data collection tool.

What is often forgotten is that raw data, however it is collected, does not speak for itself but needs a thorough and careful interpretation and analysis by a researcher. Having said that, performing 'quick and dirty' research may of course serve as a means to focus on issues within a large problem space, and provide knowledge about operators and their work that the researcher did not have before. If we compare analytical ethnography to experimental research, the planning put into the design of an experiment and the work put into analysing and interpreting data after the experiment is no less demanding, and is often as implicitly subjective.

Even so, this is not acknowledged; whoever heard of a 'quick and dirty' experiment? And who would publish it?

The knowledge operators have about their circumstances, which guides their decisions and actions, is also known as the local rationality principle, described by Woods and derived from Simon's bounded rationality principle (Simon, 1957; Woods *et al.*, 1994). To understand the operators, the researcher must understand their circumstances, which also implies being where the operators are and participating to some degree in the practice, everyday as well as in unusual circumstances. Experiencing the context can also result in a description of the perceived constraints of the environment, work domain and work practice. A constraint is not necessarily a negative thing but a scaffold or limit to what can be done given a particular set of circumstances. Essentially, a constraint is something that reduces the number of operator responses from infinite, and as such, a description of constraints of the context of practice can give genuine assistance to technology designers in a particular domain. Some of the constraints may be fixed or naturally inherent to a context of practice as suggested by Vicente (1999). Many constraints may be constructed knowingly or not by the operators as part of their daily work, also seen by Hutchins (1996) when navigators devised mathematical shortcuts to deal with an urgent situation. Constraints may also have different life spans; some exist only a moment, others are or become part of the system, or exist for any time in between.

Researchers suggest that if we want to observe change due to the introduction of technology, we should be there a) immediately when it is introduced, b) when it is in use, and c) when users have adapted to it. In the case of a) Cook and Woods (1996) assert that some instances of system and task tailoring only are visible during a short time until the new technology has been 'merged' into practice. In case b) Tyre and Orlikowski (1994) describe how users become part of the innovation process and contrary to what innovation research suggests not in a continuous way but rather in an "initial burst of intensive activity" *and* also through later "spurts of adaptive activity" (p 99). Finally, in case c), Rasmussen (1992) tells us we need to go into the workplace when people have adapted to the new technology. Other authors find similar effects, but on various time scales, for instance Göranzon (1984) describes models of change due to technology, in which it can be seen that certain types of problems predominate during certain time periods after installation. This indicates a need for more than one empirical encounter and to track innovation paths over quite some time as well.

To summarise, this is not meant as a suggestion that all future work in Human Factors and HCI should only be ethnographic research. Nor that ethnography has always been misused. But rather that analytical ethnography may 'pick up' things and make sense of them in ways that other research methodologies are unable to do.

## 2.2 Ethnography: epistemological considerations

This section contains a discussion of epistemology and how to judge the quality of knowledge derived from ethnographic studies. Several concepts will be briefly described, and then applied to this research project in order to determine the threats to quality they pose to this project and what measures have been taken to address them. It will be argued here that in some cases ethnographic methods can alleviate or even remove some of these threats. Interleaved with this will be a discussion of the same concepts from a social science/Human Factors point of view – since applying experimental standards of rigor to observational studies can lead to seeing human observers as just field recorders, when they should be regarded as interpreters, and thus are able to go 'beyond the data given' (Lipshitz, 2000). Forsythe (1999) gives a good example of the former when the physicians involved in her medical informatics research project believed that she (an anthropologist) did much the same things as a tape recorder.

In many studies and in the judging of their quality, there are often hidden assumptions that behaviour can be measured. Even if this were always the case, it does not mean that either the context, actors or the research results have been understood (Nyce and Thomas, 1999). Polkinghorne (2003) presents an alternative kind of quality judgement, the assertorial argument. In an assertorial argument it is up to the researcher to convince the reader that a description is at an appropriate level so that one's findings apply to the whole population even though there is variation within the community. Even though this is an accepted method, the 'classic' judgements will be evaluated briefly here.

### 2.2.1 Validity

Validity can be described as the best available approximation to the truth or falsity of a proposition (Cook and Campbell, 1979), or as a guarantee that systematic errors have been avoided or minimised (Stangor, 1998). On the other hand, validity in qualitative research means the degree to which a finding is interpreted correctly given the data at hand (Kirk and Miller, 1986). In the present study, validity refers more to the soundness of arguments than to the 'truthfulness' of their statements. Observation studies are often criticised as being weak in validity, which, putting it succinctly, is the extent to which a measurement gives the correct answer. The nature of the current research project is such that for the most part, statistical tests are not applicable. Furthermore, many of the validity threats listed by Cook and Campbell derive from the question to what degree it is possible to trust measurements, e.g. standardised statements and numerical assessments of behaviour. Therefore, given the nature of this research, these threats can be ruled out from the start.

Cook and Campbell (1979) describe the two types of validity typically found in most discussions of research methods – internal and external. They subdivide these rather broad terms further into statistical conclusion validity, internal validity, construct validity and external validity. We now turn from the experimental paradigm and its terminology, to concepts more often found in the social sciences.

Kirk and Miller (1986) assert that perfect validity would mean having access to the complete and exact truth, and as this is not even theoretically possible, validity as such can not be used to challenge qualitative studies. In fact, one can ask instead whether measurements have the currency ascribed to them and whether phenomena are properly labelled. They discuss three types of validity: firstly, apparent validity (also known as face or surface) to tell if a tool appears to measure the right thing. The second is instrumental validity (also pragmatic or criterion validity), where observations match those made by another, valid, procedure (or measuring tool). The third is theoretical validity (also construct validity) in which one must be certain that the entire theoretical concept under study is being measured or described accurately. Other of their subdivisions concern the tool/s and the procedure/s used. This plethora of types of validity is not the main subject here given the role that validity can play in qualitative work. Instead what will be discussed are some common terms and uses that refer to validity. Here as well, these terms and uses will be linked to ones more common in qualitative research.

**Internal validity/Credibility**

When it is possible to rule out *other* potentially influencing factors in an experiment, internal validity is claimed. Due to the emphasis on contextual factors in this study it is inappropriate to remove parts of the context in order to try to isolate any of the factors believed to have an influence on any kind of technological change and adaptation. The technology installation is not under the control of the researcher, to be sure, but the study focuses on working with technology, and the problem here is not to establish the direction of change but to track if observable changes meaningful to the participants take place. In other words, again – not how much something changed but that it changed, often in reference to those who make use of this particular technology.

Cook and Campbell (1979) stress that causal inferences can never be proven with certainty as they rest on assumptions that can not be validated either, a predicament that the social and physical sciences share. Fishman (1999) asserts that the goal of credibility is to show isomorphism between the views of respondents and the reconstructions and analysis of researchers. This should be attained by prolonged engagement, persistent observation, and triangulation (of methods, sources and investigators). On the other hand, Silverman critiques two common ways of establishing credibility (validity): triangulation and respondent validation (1993). Triangulation is unreliable since data are situated and make sense only if the context of their recording is taken into account as well – therefore they should not be used to confirm data from other contexts. It is worth noting that Silverman seems to be criticising triangulation of data, whereas Fishman is suggesting triangulation of methods, sources and investigators. In this field study these goals have been fulfilled to some degree; the engagement has been prolonged, observation periods intensive, and several methods, sources and investigators have been used. Having said this, this study has aimed for comparisons across individual cases rather than for triangulation however it is defined.

Respondent validation is questioned by Silverman (1993) on several accounts – can the respondents understand the report or presentation, will they be interested in doing work of this kind and is it compatible with their own world-view, in which case they may simply affirm the proposed interpretation of the researcher. Here, respondent validation has been used, but not as the sole criterion for validity. An alternative validation method suggested by Silverman to use for large data sets was also used in the present study: the constant comparative method. This method is an example of analytic induction. In short, if other cases are available, the researcher compares provisional ideas and emerging hypotheses against them, and otherwise does the same within his or her own data set.

**External validity/Transferability**

External validity concerns generalising, although generalisation is a concept mainly used in positivistic approaches that attempt to construct universally applicable laws. It is supposedly desirable to achieve generalisation both *to* the intended target population, situation or time, and *across* subjects, settings and times. Several researchers claim that it is possible (Mumaw, Roth, Vicente and Burns, 2000; Xiao and Vicente, 2000), but the field of Human Factors needs a discussion of why it is desirable as well as if it is even possible. Furthermore, we need to address and identify clearly what it is we want to generalise: interpretations, conclusions and/or suggestions?

Fishman (1999) uses the term transferability, which supposedly can be provided by a thick description from which generalisation then can be derived. He provides few details on how to perform this, however, and a thick description by itself is seldom useful for system design and designers. Hoffman and Woods (2000) refer to Hutchins in arguing that research must transcend the details of a specific domain to find regularities, which in turn could not have been found without the domain details. Here transferability is essentially reduced to explicitly comparative research, something that Human Factors communities have not given much thought to, or carried out.

There are two subgroups of external validity, ecological and population validity. Ecological validity concerns the validity of the context or situation, and population validity the possibility to generalise to the whole population. Firstly, the problem here is that this enforces a divide that is not in line with Human Factors research of today – the human and the situation should not be studied separately, the ‘ecology’ includes the ‘population’. Secondly, in field research the context-population in question is the area of study, and therefore is by definition ecological.

Even if there is no validation, differences in informants’ views is not a static issue, there is probably a core part on which they agree and an unstable part which for them is negotiable (Nyce and Bader, 2002). Differences in informants’ views is not something to be made to ‘go away’, but rather lies at the heart of ethnographic analysis (Sapir, 1938). Any good social science analysis has to deal with the issue of informant agreement and disagreement in one way or another. In fact, it is these disjunctions that often offer entry into what goes on in the informants’ world. However, qualitative research possesses a certain intrinsic validity; the researchers’ hypotheses and assumptions are continually tested against the field (Kirk and Miller, 1986). One example from this study is how informants’ views were sometimes used to formulate questions: “Some officers have said x, what do you think?” And the answer could be “Yes I know some do that, but I don’t”, which is both an example of validation and a cue for follow-up questions.

### 2.2.2 Reliability

Reliability is the extent to which a measurement yields the same answer every time the same thing is measured in the same way. In short what we are talking about here is repeatability. In quantitative research, reliability thus concerns the measuring instrument and avoiding random errors introduced by faulty procedures. Internal consistency and consistency across time are similar ways of speaking about reliability. Finding consistency or patterns in thought and behaviour of subjects is a form of ethnographic reliability and key to ethnographic analysis (Fetterman, 1998), and in this way ethnographic analysis is intrinsically reliable.

In qualitative research, reliability is the degree to which the finding is independent of accidental circumstances of the research (Kirk and Miller, 1986), and depends on explicitly described observational procedures. Fishman (1999) uses the term *dependability* but prescribes a similar approach: enable tracking and reconstruction of the research process by careful documentation and using a research auditor (informants can be these auditors). Kirk and Miller distinguish between quixotic, diachronic and synchronic reliability – but what is interesting is that they are most valuable to a researcher when they fail.

Quixotic reliability: if a single method yields consistent results. It is a misleading reliability, often due to the elicitation of ‘rehearsed’ information, which for instance may lead to the conclusion that most people are fine, since this is what they answer when asked “How are you?” It is essential to avoid seemingly reliable answers, or at least be critical before accepting them at face value. In this study, this effect is countered by staying relatively long periods of time in the field and rephrasing questions when ‘standardised’ answers are suspected, something which is facilitated by the observers’ knowledge of the field.

Diachronic reliability: if observations are stable through time. Apart from the fact that most social studies find that this is not common in a changing world, this present study is looking precisely for change and its effects. Nevertheless, to look for what is stable would provide a baseline. The kind of research necessary to support this kind of reliability has seldom been carried out in the Human Factors communities. Here, the length of the study (4 years) has provided some baseline in conjunction with the observers’ previous knowledge.

Synchronic reliability: if observations are similar within the *same* time period. Kirk and Miller point out that this involves consistent observations of a particular feature of interest rather than identical observations, and emphasise that the concept is even more useful when it fails, as the researcher then will have to explain how different measurements may simultaneously be true. An interesting twist to this is when there is a difference between the informant's and the researcher's interpretation of a phenomenon or situation. This of course provides the researcher with an entry into how his or her informants view their world and offers an opportunity for researcher to test one view of the social world against another. As such it can be a correction for when an ethnographer thinks he or she has 'got it right'.

### 2.2.3 Objectivity

Interpretation is assumed to be inherent in qualitative research, and therefore, a discussion of objectivity is relevant. Kirk and Miller (1986) describe how qualitative researchers use the concept to mean the quest of finding out how best to describe the empirical (social) world and explaining the consequences of choices made by people that lead to that particular construction of what the world 'is'. They argue that it is no search for an absolute truth, and new views are generally taken as complementary to old views rather than replacing them. According to Kirk and Miller, objectivity can be partitioned into reliability and validity; other authors discuss reliability, validity and objectivity as being separate concepts that have the same conceptual status (Firestone, 1993; Hoepfl, 1997).

Lipshitz (2000) discusses at length the difference between the observer as recorder or as interpreter. An recorder collects and reports 'raw data' – assumed to be objective givens. However, when an interpreter is observing, interpretation is inseparable from observation. Looking at it this way, and distinguishing between collecting and reporting, objectivity may very well be a quality that it is necessary to achieve before being able to show validity and reliability, as Kirk and Miller suggest. If it is acceptable to be an interpreter, i.e., to acknowledge that we do bring subjectivity into the data collection and 'interpretation' (see e.g., Lipshitz, 2000), what kind of background knowledge to bring to the field? Hollan, Hutchins and Kirsh (2000) claim that the researcher should bring considerable technical and domain knowledge. J.M. Nyce (pers.comm. 02/2004) is less certain of this, and argues that the issue is not what a researcher already 'knows' but rather what a researcher can 'discover' that for his or her informants is embedded in or presumed about the social world they live in.

The issue here is how embedded in both knowledge and practice a researcher has to be in order to make sense of a particular work domain, and what kind of knowledge is needed to ‘disembed’ or ‘unpack’ both the practice and knowledge of practitioners so skilled at their work that both have become almost second nature to them. Also, entering the field as a novice has its advantage not the least of which is that it at least temporarily offsets issues of power and entry which can make “studying up” and “across” so problematic (Nader, 1999).

There are also implications for the world-view subscribed to. Is there a ‘world’ or ‘truth’ out there, independent of any observer? Yes, possibly, if the area of study is the natural sciences, but when studying the behaviour, actions, beliefs and constructed realities of humans, it is less likely. If, as in the present research project, the researcher believes that people create meaning, it is not so evident that a researcher can step out of the context, as it were, to observe, record and present ‘facts’ or ‘truths’ (Runciman, 1978). Both Fishman (1999) and Firestone (1993) suggest that to achieve *confirmability*, the researcher has to show that data, interpretations and outcomes are rooted in contexts and persons apart from the researcher. Is this really possible to do? It is unlikely that the interpretations are rooted in a context or person apart from the researcher, especially when one is a participant observer. Participating in one world, for one, makes it difficult, and being in the informants’ world at the same time makes this even more implausible. Furthermore, is it ever possible to attain what Nagel (1986) calls “A view from nowhere”? Perhaps we must instead accept that we are always situated, observing from somewhere with some perspective, as Dreyfus (1979) calls it “always already in a situation”.

The analytical distance, however, is another issue; we must describe our own perspective and background to such a degree that it is possible to judge where, how and to what extent the informant’s world-view and our own overlap and separate, respectively. This is not to say that the informant’s world-view is correct in strict empirical terms, only that that we find it to be consistent. What interests us here is not so much how this world of the view is ‘real’ but rather how we can come to understand the logic that makes a world both believable and tangible for those who inhibit it (Giddens, 1979).

Fishman (1999) suggests that a research auditor can assist with the above confirmability. This method has been used here both with other researchers, and more importantly mariners. For example, on several occasions preliminary results have been presented at conferences and seminars attended by representatives of the maritime community and active mariners. The comments given at those times have been most useful in establishing confirmability, in particular comments from mariners who were not previously part of the study and still agreed with the points being made.

In sum, although many of Cook and Campbell's concepts are not applicable here, this section has shown that they can provide useful guidance when learning how to carry out good social science research. As a contrast, a condensed view of Fishman's (1999) summary of hermeneutic quality-of-knowledge procedures is presented in Table 1.

Table 1: Comparison of quality-of-knowledge procedures (condensed view of Fishman, 1999, table 1)

| Hermeneutic concept | What a researcher should do | How to accomplish this |
|---|---|---|
| **Credibility** | Show isomorphism between respondents views and researchers reconstruction | Prolonged engagement, persistent observation, triangulation (methods, sources, investigators) |
| **Transferability** | Provide a thick description from which generalisation can be derived | Not stated |
| **Dependability** | Enable tracking and reconstruction of research process | Careful documentation, research auditor |
| **Confirmability** | Show that data, interpretations and outcomes are rooted in contexts and persons apart from researcher | Research auditor |

Finally, it is argued that many of the threats listed by Cook and Campbell can be overcome partly or completely by using ethnographic methods and hermeneutic concepts for the judgement of quality. The next section will describe the ethnographically informed research strategy used in this study.

## *2.3 Research design*

The approach was fundamentally exploratory, and the overall framework was ethnographically informed. The data collection and the data analysis were both planned to be mainly qualitative. Qualitative here means that a study focuses on understanding activities rather than measuring in a traditional sense, that interviews and observations are used rather than experiments, and that the data are interpreted and analysed rather than statistically treated and presented (Allwood, 1999). However, the ethnographic method was complemented by other less qualitative methods, described in the subsection ‘data collection’.

Ethnography emphasises the need to perform field studies in order to study the social world and meanings informants construct from and attribute to actions and events within that social world. Under such circumstances it is not uncommon that research questions and strategies are revised or change over the course of the research (see e.g. Hoepfl, 1997). A problem-oriented kind of ethnography was used, a focused ethnography (Rouncefield *et al.*, 1994), in which selected parts of a particular context are studied. From this follows that less time needs to be spent in the field than in a traditional ethnography, and that the study can be directed towards a specific area of interest to both the researchers and the stakeholders. In this case this meant probing and understanding the way that the operators under study see, describe and understand their work and their tools. Of central importance was the way work on board a ship changes over time, and how it did so in natural surroundings. The study was longitudinal and opportunistic: data was collected several times over a period of several years; and if an opportunity to visit a bridge was presented, it was taken. Most often, I was the only observer, but on some occasions two observers were present.

**Field sites**

Over 4 years, 15 ships were visited. Some were visited a few hours and on others up to a week was spent on board. Some ships were visited once and others were visited regularly over the years. The total amount of time spent on board is about 30 days, but the time spent collecting data in other locations is hard to estimate.

The ship types studied were small passenger ships in traffic in the Stockholm and Gothenburg archipelagos, large archipelago passenger ships in traffic mostly between Sweden and Finland, and cargo ships (no tankers were part of the study) in Baltic, North Sea and transatlantic trades (areas in which the ship sails). In order to protect the anonymity of the informants, the ships and the shipping companies, no further details will be given. There are several reasons for this: firstly, some shipping companies were hesitant as to how the press would interpret maritime safety research being performed on their ships. This applies in particular to the large passenger ferries, where mariners told me ‘anything can end up misinterpreted in the tabloids nowadays’.

Secondly, the maritime community is a relatively small community, and 'everyone knows everyone else'. In order to minimise the risk that an informant would not talk about certain issues to either protect his own or other mariners' professional reputation, confidentiality was used. It is likely that informants will recognise their own words, or a group of informants can recognise their own ship, but all the precautions possible have been taken to ensure that it goes no further than that. Thirdly, because the community is so small, maritime researchers depend on maintaining good will and good contacts. If someone were to feel that they had been misrepresented or misused *and* identified, this could reduce accessibility for future research.

**Informants**

On most ships the bridge officers spoke Swedish (the author's first language). These ships were sought after in order to make it easier and more natural for them to talk about their work. When excerpts from the transcripts were used in English publications, I translated them. In a few cases, the officers were from Finland in which case they would speak English or Swedish, or were from the Philippines (English). Occasionally, non-officers would offer an opinion but they were seldom directly questioned (for example look-outs and officers' apprentices). A few key informants were identified in time, and used to 'double check', expand on and/or explain what other informants had told me. Key informants are called just that for a good reason. However, this does not mean that they were the only informants but they were an important source of information. A key informant here could be one who wanted to tell a 'story' and the details could be developed and validated by others. Even when other informants did not validate, in the sense that they did things differently, this finding was interesting and worthy to follow up.

In this project the unit of analysis is defined as a complex system – automation or new technology together with the operators on ships' bridges. However, the target population that the present project aims to research is larger than just the mariners. The sample of subjects studied here represents an adequate cross-section of the maritime community for two reasons. One is that the range of informants is wide; active and retired mariners have been interviewed, as well as individuals working within maritime administration or legislation, technology design, manufacturing or standardisation, accident analyses, teaching and piloting. A second reason is that mariners during their career usually have worked in a number of ship types, in a number of positions, on a number of trades and used a range of technologies. This means that the interviewed mariners can not only talk about the present ship but can also discuss several other types of ships and combinations of technologies or work practices.

The excerpts from the data are coded, so that it is possible to identify on which type of ship the data was collected; C stands for cargo ship, P for large passenger ship in the Baltic archipelago and A for smaller archipelago passenger vessel. The initials used to represent the informants, however, are chosen at random, but the same initial always represents the same individual. Other codes used are ‘Memo’, the letter M for interviews with manufacturers, and the letter O for interviews or observations not performed on board ships.

The selection of field sites and participants was entirely subject to availability and the good will of shipping companies and crews. Consent was always obtained from first the shipping companies (in writing) and then from the ship’s crew. On larger ships a description of the work was sent out in advance, by e-mail to the captain, which explained the project and the crew’s right to decline the visit, and that if they accepted a visit, they had the right to discontinue their participation at any time. The document also informed them about confidentiality and how it was up to the crew to decide at which times studying the bridge would be appropriate. On smaller vessels this information was given verbally directly to the master before starting. About 40 officers on board ships are part of this study, and the number of officers and other maritime experts interviewed elsewhere, formally or informally ranges in the hundreds. Those who participated in the study did not receive any compensation, except for some participants who received a token gift (a T-shirt or coffee mug).

**Data collection**

The observation periods spent on the bridge were often long, in some cases up to 12 or more hours (with short breaks) per day. On several occasions, a second observer (a naval officer) was present. This observer knew the basics of working at sea, including the ‘language’. However, this observer had no merchant mariner experience, and was drawn upon to combat the effects of my being an insider, as well as to check and discuss the data and the interpretations (the effects of being an insider are further discussed in section 2.4). Informal interviewing was the source of most of the data, and in many cases the interviews were contextual, i.e., performed while the informants were working (Blomberg, Giacomi, Mosher and Swenton-Wall, 1993). A similar data source was notes taken while observing interaction and discussions between crewmembers, which often turned out to be very valuable data. Some time was also spent talking to other crewmembers in other locations, for instance when loading and discharging on a cargo ship. But at times one has to know when to shut up. This could be in potentially critical situations, but also when there are sport events on the radio.

Apart from on-board studies, data were collected from various sources: interviews were performed with four representatives of manufacturers of maritime technology, of about one hour each and these were followed up via e-mail and telephone. Less formal interviews have been done with representatives of shipping companies, teachers at maritime universities and with pilots and other mariners ashore. Furthermore, discussions have been held with representatives from classification societies (such as Lloyds Register and DNV, Det Norske Veritas), the IMO (International Maritime Organization), the Nautical Institute, several national maritime authorities and of course at a number of meetings with researchers interested in similar problems.

In addition to this, a seminar on maritime research aimed towards active mariners was used as a research platform, a Maritime Day arranged by the Stockholm Guild of Master Mariners, known as ÅB. I participated in the planning group for the seminar, which took place in the autumn of 2003. The day consisted of several short talks on various subjects, about modern maritime technology or related research. The seminar was held in a large room with a polling system, one used at times by politicians. Each seat was equipped with three push buttons. After each presentation, questions relating to it, as well as three possible answers (and how they mapped to the buttons) were put to the audience by projecting them on a screen on the wall. The answers were saved to a computer file and later analysed and compiled.

A preliminary report exists in Swedish (Lützhöft and Kiviloog, 2003) and an English version is in preparation. Quick informal discussion groups were held in the breaks, where several assistants discussed the subjects with the participants in the group, and took notes. A focus group was held in the afternoon on the topic of AIS (Automatic Identification System), with a moderator and recording of the conversation. The answers have to date been put to several uses: to aid manufacturers and legislators in their work, as information for other researchers and to partly validate the present study. They also provided data used in two master's theses, one on the use of AIS (Blomberg, 2004) and the other on cognitive ergonomics on small archipelago ships' bridges (Nilsson, 2004).

Since accidents and incidents are relatively unusual it is not surprising that none occurred when I was in the field. However, there were opportunities to observe mishaps of various kinds and to track how various crews responded to them. Information on shipping accidents was studied, as well as the analyses of these events, when available. Three events were studied in detail: the grounding of the passenger ship Royal Majesty outside Boston in 1996 (Lützhöft and Dekker, 2002; National Transportation Safety Board, 1997), the passenger ship Silja Europa which touched a sand bank in the Stockholm archipelago in 1995 (Accident Investigation Board-Finland, 1995; Lützhöft, 2002a), and the container ship Janra, which in 2000 collided with a lighthouse in the Baltic sea and capsized (Accident Investigation Board, Finland, 2000). None of these incidents involved any fatalities. The information was analysed to identify possible reasons for the incidents, especially how the human-machine system could have contributed to the event and what was done on board to try and prevent these accidents.

In addition to a literature search, several regulations, conventions and standards are part of the data corpus. Examples of these are the COLREGS (International Regulations for Avoiding Collisions at Sea), STCW (International Convention on Standards of Training, Certification and Watchkeeping for Seafarers) and SOLAS (International Convention for the Safety of Life at Sea). Various navigation handbooks (modern and dated) and sea charts were also consulted.

**Recording, transcription**

For the recording and collection of data, various techniques were used. The main technique was sound recording by means of a minidisk recorder (small ‘CD’). Extensive note taking was used, but not very often in front of the informants but later or in out-of-the-way places after the fact, since the informants would often stop talking, ask or wonder what was so interesting if they saw me taking notes. Hand-written notes were later transcribed into computer files at first opportunity, at which time they were filled out with other things remembered from that particular ship and voyage. A separate notebook was kept for interpretations, ideas and analysis. Also used to some extent were copies of documents and manuals found on board, as well as copying down instructions or notes that mariners themselves had made. Post-it notes attached to technology could be an indication that something ‘interesting’ was going on with that device and were often an excellent cue for further discussions. Still photography with a digital camera was used as a memory aid for analysis: taking pictures of interesting devices, notes or bridge configurations. The camera itself also worked as an introduction to technology discussions as the officers would ask questions about it, and then the discussion could turn to technology development on the bridge.

Video recording was used briefly in the beginning of the study but was soon abandoned, for several reasons. One camera was not enough to capture the whole workplace without being disruptive even when the operator was sitting at his station. At times, when the camera was placed on a tripod on the floor, vibrations would disturb the recording. When the camera was handheld, it made it hard to notice what was happening on the rest of the bridge, and made it very obvious what was being recorded, which often made it hard to ask follow-up questions and ask for explanations. Furthermore, the goal here was not to perform a micro-analysis of moves and actions (Garfinkel, 1967) but rather to understand 'what was going on' on board a particular ship at a particular time. This is difficult to do when also using a camera to follow a person or sequence of events.

Transcriptions of the sound recordings were always made. In a few instances some of the discussions, those that fell in the category of 'off-work' talk were omitted or abstracted and a note of this was made in the transcript. This occurred only when the informants were either talking to each other or the researcher about things not related to work, such as current events, sports or family. The soundtrack from the videotapes was transcribed and notes made about what could be seen on the tapes for later reference.

**Analysis**

Fieldwork ends, but the ethnography continues…(Fetterman, 1998). Analysis is a long process which starts even before the first field visit, especially when doing focused ethnography where the problem one is interested in is at least provisionally defined from the beginning. Having said that, fieldwork is intrinsically bound to interpretation and analysis; to earlier scholarly experience, to the literature and to other people's views and interpretations (Dekker and Nyce, In press). The majority of the collected data were transcripts of conversations, but aiding the analysis was photos, video clips, field notes and drawings (made by both the informants and me), copies of documents and at times, sea charts.

The analysis and interpretation of data often started immediately, while still in the field, with personal notes (clearly marked) in the field notes. After each visit, preliminary analysis was performed on the new data, by noting human-machine issues. Each reading through of the data led to more questions or ideas for follow-up that were noted in separate documents. As mentioned in the introduction, certain issues began to come into focus, because of comments like: “When we really need the technology, it is no help”, “I try to understand how the guy who built it was thinking” and “How will my switching off this part affect the rest of the system?” Statements like these were counter-intuitive, at least when comparing to what regulations, vendors and others had to say about the ergonomics and usefulness of bridge technology. Still, in ethnographic fieldwork you have to follow where the informants ‘take you’.

The transcripts were read through and marked where there were statements and discussions relating to various categories. These categories emerged from the field notes themselves – for example:

- ‘integrated technology’
- ‘learning’
- ‘modes’
- ‘strategy integration’

While going through the transcripts, statements would either be put in an existing category, or give name to a new one (in-vivo categorisation). The categories were written in a separate document and at times they were subdivided into more specific categories (‘choosing information’, ‘trusting digital’) and at times they were combined into larger categories (‘monitoring work’, ‘routines’). The more a category was repeated, the more central it became, and categories like these often helped focus the next field study or follow-up questions. Statements could belong to several categories, but the human-technology focus was the one factor which guided the grouping of all the data. Another method used was writing typical statements or possible categories on large sheets of paper and trying to group them or relate them to other statements or categories. The relations themselves could also become a new category. A further technique was to collect all the comments relating to a certain device and see what was positive, negative or neutral within that corpus.

When the data collection was almost finished, I tried to use computer software for qualitative data analysis (QSR NVivo) to sort through the statements in the transcriptions. It was not very useful to me, except that I quite soon realised that the data I had could be categorised in two large themes: integration issues and learning, hence the two papers (Lützhöft and Nyce, 2004, In press). Others have reported that software like NVivo seldom helps in identifying higher order issues. In fact, Ortner writes that while her research assistants spent many hours coding texts to work with Interview, a program much like NVivo, she never used it. Instead she found that the “Microsoft Windows ‘find’ function actually did everything I needed" (Ortner, 2003). After this experiment with QSR NVivo, the 'manual' analysis continued.

In mid-project, I also tried using the abstraction hierarchy suggested by Xiao and Vicente (Lützhöft, 2002b; Xiao and Vicente, 2000). I was pleased with the categories at the time, but realised I had to perform further analysis. It seemed to me that it was problematic to use this particular method, since the method rests on decontextualisation of the data which stripped away a lot of interesting and significant things. Therefore, I continued with a more 'pure' ethnographic analysis. As part of the analysis, seminars were held with other students and faculty members where tentative conclusions and ideas were discussed and criticised. As more data were collected, categories appeared, grew, shrank or disappeared. Categories could also evolve into themes. Early ideas were presented at conferences and workshops attended by representatives of the maritime community or maritime researchers and they confirmed or disconfirmed a number of tentative interpretations, and especially confirmed the idea of integration work. Later in the analysis, quotes that were typical for a phenomenon or a view occurring often were selected to form the basis of draft papers. Working with building an argument around these quotes either strengthened their status as analytic categories, in which case all was well, or weakened it, in which case they were rethought, reworked or removed. Examples of this way of working with quotes can be seen in Lützhöft and Nyce (2004), appended in this thesis.

The constant comparative method (discussed in section 2.2.1) was useful as well. For example, it turned out that keeping their skills was something universally valued by mariners on all the vessels studied, but on the other hand the perceived usefulness of technology varied by ship type. When comparing the data, it was clear that while all agreed that basic navigation skills were important, they were working in different types of ships with various navigation aids and tools. This was also a possible instance of quixotic reliability – are all the mariners replying the same thing: "We want to keep our skills" because mariners are supposed to believe that, it is the 'right thing to say' or do they sincerely believe that skills must be kept alive, and if so, why is that? As discussed in Lützhöft and Nyce (In press) there are several possible reasons for statements like these, and there may well be more to discover. The research literature was a constant sounding board, both when looking for views or phenomena already discussed, or when finding aspects not well covered by earlier research. Legislation, in the form of standards, regulations and rules, was fundamental for highlighting and discussing many of the integration issues.

Harper (2000) discusses how ethnography consists of two important parts, the fieldwork program and the analytic sensibility and competence of the ethnographer. The material gathered should cover 'enough' of a situated task so as to be able to ground this sensibility. Harper claims that this is not as easy as it may appear, but not as difficult as others have argued. Strong analysis, whoever does it, can uncover important materials and make the difference "between the nearly good and the just right" (p 241). The following section will discuss the ethnographer as an insider, and what this may mean for the material gathered and the analysis.

## 2.4 Insider

What does it mean to be an insider? The maritime domain is special because it combines a particular work culture with a particular notion of a community (much like an extended family). Contrary to what Anderson said: "work is not where you live" (1994), many mariners work *and* live for long periods of time on board ship. Further, they have limited possibilities to go ashore and often see few people for months other than the ship's crew. There are many descriptions of insider research in the literature, but they are mostly about 'going native' (becoming part of the studied culture), and if there is talk about an insider it seems to be mainly in cultural or ethnic terms, and not about persons in a work culture studying their own. There is a notable exception in nursing studies (Asselin, 2003; Hewitt-Taylor, 2002), in which experiences similar to those from this project are reported. When it comes to having domain knowledge without necessarily being a member of the work group, Hollan *et al*. (2000) claim there is no substitute for technical expertise in the domain under study. But still, to understand situated human work, an ethnographer must know what the information or data means to the informants and how it informs their social world. In my case, having worked for many years in the maritime domain (13 years at sea and the holder of a master's ticket) gave me a unique possibility and status. I here discuss some of the advantages and disadvantages of my position as an insider.

An obvious disadvantage is the 'insider bias' – thinking you understand what is going on, so that there is no need to record or analyse it. At times, this can lead to thinking that there is nothing 'interesting' going on. There are a few ways to combat this, and they are all about gaining analytic distance in some form. Firstly, leaving the field for a period of time can give a new perspective. Secondly, getting distance by looking at the earlier research literature describing the domain may help. Finally, getting distance through the eyes of someone else who is not an insider is always helpful. I used all these methods, and some without planning to. In one case I got a real wake-up call. An outsider, a guest on the bridge asked a 'naïve' question that made me realise just how much of an insider I really am. The question was: "How do you know which of the indications on the radar screen are boats?" For me the answer to that fell in the domain of common sense and was therefore never an issue worth pursuing. This was a helpful reminder that it was time for me to pull back. I also made use of a second observer on several of the field visits during the first stages of this research. This observer (a naval officer) had no merchant mariner experience, but knew the field and the 'language'. This observer was recruited to discuss different interpretations of data and to help correct the bias of 'insiderhood'.

Another disadvantage is that many of the informants were ex-colleagues, or had heard of me through others. The main problem I experienced was 'funny looks' when I asked questions that were so obvious they thought I, given my experience, should already know the answer to them. Being an 'insider' also meant the mariners would not always supply details, but assumed I understood what they were talking about. There were some ways to handle this: the first was that I explained to the mariners that I could write this 'story' myself but I wanted them to put it in their own words and terms. I also explained that although I had the maritime experience, many of the technologies in use today were not in use or did not exist when I worked at sea. This made the mariners more willing to discuss pros and cons of the technologies and how helpful the technologies were to their work. On the other hand, it was hard for me not to extend suggestions and advice when I thought I could be of help, or when asked directly. Asselin calls this 'role confusion' (2003), but it could be argued that this is a logical extension of what participant observation is.

In the field, one is often asked in one way or another to help out. In the few instances I did offer assistance, I did so only indirectly. In one case an officer could not get the autopilot to work, and it was in the middle of the night. I thought I knew how to solve it and just waved my hand over a group of buttons and said: "Have you tried…?" He used one of the buttons and got it to work. If nothing else, this shows that mariners do use each other when trouble-shooting new technology. It also shows how much of an insider I became on some ships, an issue I had to consider, as it was clear that I as researcher-insider had an influence on the field at times. Another issue that emerged from my role as an insider was how to 'sort' through and present what I knew and what I thought readers of a thesis needed to know.

The third issue is one of professional pride. The maritime community is a proud, male-dominated one. It is not common to speak of problems or worries, or even to acknowledge that any exist. It is clear that not many of the informants wanted to confess to not knowing how a certain piece of equipment worked, or that there was something they did not understand, especially not to a 'former colleague' and certainly not to a female one. Due to professional pride and the 'constraints' of the community in which they live and work, they do not want to talk about problems and often would not admit to ever being in trouble. An insider has a better chance to detect this, but even he or she can be duped. For an example, two officers once happily told me: "We were a bit close over there but you didn't notice". There is no real way out of situations like this but staying longer in the field and gaining trust. Trying to talk about solutions rather that 'problems' also helped. The issue of professional pride of course also applies to me as I am also (or have been) a part of that community and work culture. This means that I might not always, when necessary, have asked for clarification, elaboration or explanations. The way to handle this was to be aware of it and try to talk to several persons about the same thing or issue. This of course also gave me the added benefit of getting several perspectives on a question.

On the positive side there are benefits to being an insider. One, which is seen in all discussions of fieldwork, is trust. Often the field worker is recommended to proceed slowly, gain trust, and get familiarised with local customs (see e.g., Blomberg *et al*. 1993). By being an insider I in many cases gained trust, if not immediately, then sooner than an 'outsider' might have because I was able to speak the informants' language and they realised that I was interested in, and understood, their work. Knowing the culture, the language and the work gave me many benefits, both in regard to data quality and time spent. By being an insider it was possible to shorten the time in the field. The most substantial saving of time came from not having to spend time gaining a basic understanding of the workplace and the work, including technical details. This is an important point to make, especially when planning research projects – that using an insider on a research team can reduce costs in the project and almost certainly increase the quality of results. Although it is hard to estimate, I would guess that 4-6 months of fieldwork (data collection and interpretation) were saved in this 4-year project.

Furthermore, knowing the community makes it easier to be a participant observer: a newcomer to a workplace may have to spend time and energy on figuring out what to do next and how to act appropriately (Blomberg *et al*. 1993). Instead, I could make better use of the time in the field to study the situation because I seldom had to worry about issues of entry and access. This could also enhance the quality of the data collected, as there was a common language used from the beginning, and the risk of misunderstandings is minimised, which often can increase the validity of the results. A good example is that informants could refer to objects and practices that were not present at the time and assumed that I would understand. A further positive point can be made, one also made by Hutchins (1995). Transcription, although always a lengthy process, is much easier if performed by an insider. The language and idiomatic expressions are known from day one, and therefore transcription takes less time and is often more accurate.

As to the issue of gender, being female in a male profession may have helped and hindered the research, although it is very hard to judge the extent to which it did either. In the maritime community, I believe it was an asset because I was able to ask questions a man might not have asked or even thought of. However, there are two sides to this: in a few instances, when two or more male mariners were present there would be 'showing off' and much "face work" (Goffman, 1982), and I decided I would have to talk to the participants separately at a later time. This could probably happen at times to male researchers, outsiders or not.

### *2.5 Method discussion*

This section will discuss the use of ethnography as a method to study and analyse modern technology in use. There are a few methodological inconsistencies in the appended papers, and this requires some explanation. First, the research topic is slightly different in each paper. This is because the questions and interesting findings evolved iteratively. Second, in Lützhöft (2002b), simulator studies were planned as a complement to the field studies. This idea was later abandoned as I realised the issues that I was interested in were too complex to study in a simulator within the time frame of this project.

I also need to mention here what I did for the informants while on board, as part of building and keeping rapport. It ranges from small things like helping out while on board to large things such as making a difference in their workplace. A few examples are that I took pictures of a safety drill for them to use in a manual, I helped carry provisions and I sometimes helped or encouraged them to explore the bridge technology. I stayed up late, and even went to the bridge in the middle of the night at times, to show interest and that I 'really did want to know'. On the other hand, perhaps I did not explain the purpose of the study as often as I should have, or make certain that people really understood its purpose. If one new person came on a site, I should have done this, which did not always happen, often due to observations or recording in progress. As a result, I found out that some informants did not know what the results would be used for, and some worried that their statements would end up in tabloids. When I discovered this, I corrected the misunderstanding, of course. Later in the study I was at times approached by mariners who had heard talks or read interviews and thought this was a good study, one which would be useful to them.

Let us turn to a discussion of the general usefulness of ethnography for workplace studeis. When technology is introduced into a workplace, there are always trade-offs, for example safety vs. productivity – Reason (1997) calls this trade-off protection and production. It means that there is a possibility that the newly acquired and expanded limits of 'safety' devised to promote safe actions is instead 'used up' to save money and time or gain speed. Another way of putting it is that new technology will always be exploited to achieve a new intensity and tempo of activity, which Woods calls the law of stretched systems (Woods, 2002). A second trade-off, which is found in literature regarding the effects of new technology and automation on operators, is the division in benefits and unwanted consequences (Dekker, 2002; Dekker and Hollnagel, 1999). Both the above sets of trade-offs, as well as informal work procedures can only be studied in the workplace. Cook and Woods (1996) note that people participate in integrating new technology into complex fields of practice – often in ways that are surprising to designers.

When we talk about the audience for research such as this, it is a wide group. It includes manufacturers and designers of technology, nautical architects, shipyard personnel, those involved in technology procurement in shipping companies, maritime legislators and educators. Many of these have maritime experience, but many may have an outdated or incomplete model of practice, including experience of the technology currently in use. As systems become more integrated and seamless, this gap could increase. Conventional methods are helpful to a point, but it may be time to perform more research in the workplace which will involve the prospective users and provide knowledge of current practice.

Research on problems and issues of this kind generally has relied on structured methods, to be used before or after incidents and accidents. Among these methods are task analyses, risk analyses and accident analyses. The endpoint of such research is to categorise and systematically compare these categories by performing statistical analyses, which should lead to a high degree of credibility (see e.g.

Palmgren, 1995). However, we want to suggest here that we instead employ a variety of methods, which would allow us to conclude something other than that people have to act safely and follow the rules. To avoid accidents and error, Wagenaar and Groeneweg (1988) suggest that operators should be supplied with more knowledge, intelligent support systems, improved training, and better working conditions. On the other hand, *Minding the helm* argues that it may also be necessary for marine pilots to adapt to changing technologies (National Research Council, 1994). Mariners have been doing this all along of course but the present pace of technological change and innovation requires that issues like change and innovation be directly addressed in officers' training and education programs.

This takes us to the role end users should play in the collection and analysis of data related to their own work and workplaces. A sociotechnical method for designing work systems on a project involving the redesign of bridge subsystems on a naval warship was evaluated by Waterson, Older Gray and Clegg (2002). Two end users were involved in the project, as were three Human Factors experts and four system designers. The group was faced with four choices on how much to automate the task of navigation and collision avoidance:

1. Traditional.
2. Technology support.
3. Semiautomatic decision support.
4. Unstaffed bridge.

They chose the following order: 2, 3, 1, 4, which approximates how we have seen mariners both work onboard and think about their work. This implies several things. Firstly, it is beneficial to involve users at some level, although the design specifications should be left to professionals. Secondly, not very surprising, their first choice is to perform their work with technology support. Not the traditional way, as anti-technology luddites might have believed. Nor was there much enthusiasm for semiautomatic decision support, and almost none for unstaffed bridges. Thirdly, traditional work ends up low on the list, which can be interpreted as openness to modern technology. However, relying on just two informants can raise the question about just how representative these findings are.
As mentioned above, users, in this case mariners, are not designers. They should not be given or left with the responsibility to come up with design solutions. Their expertise lies elsewhere, and it is this which we must tap into in appropriate ways. Marine pilots, with their extensive experience of

ship handling and confined water operations should be engaged more in research and development of new technologies (National Research Council, 1994). The role they have has to be synchronised with those of researchers and vendors. In effect the whole question of "knowledge claims" and the role skilled practitioners can have in a design and development cycle needs to be rethought. We agree with researchers who claim that we should use methods that capture the dynamics between the field of work and adaptation and development, the continuous change of work conditions and information needs on a ship's bridge, in connection to the change of systems either through product evolution or local settings and preferences available in the workplace (Andersen, 2001; Andersen, Nielsen and Lind, 2000).

What we do not agree with is the position that solutions can be read directly out of informants' claims, or that using informants' statements with little or no work can be equated with analysis. In many papers, excerpts from conversations are presented and discussed as well as actual design suggestions from mariners. This does not imply that the user should be the designer but that the user's voice is heard and their needs and suggestions are made explicit to a higher degree than customary. Then again, is it enough to make their suggestions explicit? Is there a risk that explicit is taken to mean 'certain'? It is argued here that ethnographic analysis can take us closer to finding out what mariners and developers mean and need, rather than provide 'answers' regarding what developers and technology can supply.

Vaughan (1996) claims that an engineering culture does not readily accept qualitative data. According to her, an engineer at NASA said that the requirement for quantitative, data-based, "engineering-supported" positions was the norm (p 222). There is a tendency in such engineering cultures to view 'knowledge' which has been accumulated without scientific measurement as less useful or acceptable. The question then is how to demonstrate 'usefulness'. We will not argue that ethnography can provide what is commonly meant by 'precision' and 'measure'. Instead, the task is to establish a two way interpretive process (argued for by Anderson, 1994; Nyce and Bader, 2002). In this interpretive cycle a researcher stands between end users on the one hand and designers and developers on the other hand, to facilitate translation between what end users 'mean' and what designers and developers need to 'know'.
Furthermore, Vaughan claims that to make a design change to a product and to interrupt the production schedule it has to be more than a marginal improvement (1996). This may not be the case if innovation is driven by the demands of procurers. There are implications that quantitative

research may have taken the development of safe systems as far as it can go, considering the cost of trying again to measure the same thing in a slightly different way. To make more than marginal improvements today to any technology, engineers need to acquire more local knowledge, and regulators need to make new pragmatic rules that take into account the effects of the new technology. In both cases there is a role for ethnographic analysis.

To strengthen officers' training programmes and research agendas in the maritime community, it would be useful to perform comparative work as well. Both researchers and officers should look at the results technology and technical innovation have had in related domains and not just within the shipping industry, for example from aviation, hospitals and nuclear power plants. This has been performed in many other domains with positive results (see e.g., Woods, 2002). Performing cross-case analyses of domains related to the maritime one would mean both looking for what is the 'same' and what is 'different'. In healthcare, for example, Gauthereau (2003) shows the differing views of nurses and doctors on the 'same' work situation. Graves and Nyce (1992) have reported on the differences between novice and expert responses (all of them neurologists) to the same teaching aid, a 3D animated decomposable brain model.

Work of this kind can be used to help us learn more about what is going on onboard a ship. We see that it may be beneficial to build a comparative agenda where we look across different work domains, in order to derive rules, principles and guidelines. The collection and analyses of ethnographic data across different domains and cases is something that we seldom attempt today but it could yield insight and results above and beyond what we get from descriptions of individual forms of work and work domains (Vaughan, 1992).

This chapter has discussed the chosen method and how to judge its quality. I also described the research strategy used and reviewed some disadvantages and benefits of being an insider researcher, and presented a short method discussion. Following this chapter is a review of maritime Human Factors research in the maritime area.

# 3 Shipping research

This chapter reviews previous studies performed on ship's technology, with the aim of evaluating ergonomics and Human Factors research in this domain.

> "[T]here is a public perception that preventing tanker accidents is the major marine transportation issue. Although understanding the causes, consequences, and implications of marine accidents that result in major pollution incidents is important, an understanding of the navigation and piloting of all categories of merchant vessels is needed in order to identify and correct systemic problems."
>
> National Research Council, 1994, p 56.

## *Shipping research*

Research into bridge ergonomics and maritime Human Factors issues got underway in the 1950s. Earlier references to ergonomics (in the 30s and 40s) in trade journals and magazines are brief and infrequent and centre on visibility from the bridge and communications on and beyond the ship. In 1959 the British Ministry of Defence commissioned a study on integration of systems and layouts of bridges (Millar and Clarke, 1978), and a decade later a study was commissioned for merchant tanker bridges by ESSO (Clarke, 1978; Mayfield and Clarke, 1977). The first substantive treatment of Human Factors and ergonomics on merchant ships' bridges seems to be a paper by Wilkinson (1971), which gives a thorough view on the evolution of bridges and bridge equipment, in particular from an ergonomic viewpoint. In Holland, Human Factors on the bridge have been considered and researched since the 1960s, see for instance Walraven and Lazet (1964).

In the 1970s there was a great deal of ergonomics research and development (e.g., Istance and Ivergård, 1978; Ivergård, 1976; Mayfield and Clarke, 1977; the Proceedings of The Institute of Navigation National Maritime Meeting in 1977; and the Proceedings of the Symposium on the design of ships' bridges in 1978). Ergonomists at this time believed that maritime ergonomics had 'made a breakthrough' but the positive trend did not continue (T. Mayfield: e-mail 2004-04-01). According to C. Lindquist at the Swedish Maritime Authority (pers. comm. 05/2004) at least the Swedish ship-owners felt swamped by all the new regulations the Swedish Maritime Authority put out. It was too much, came out too fast, and the development of maritime ergonomic more or less ground to a halt around 1980, in part due to other issues as where ships were (and are) mainly built (Asia as opposed to Europe).

However, the necessity of considering ergonomics on board, in the context of technology, has been written about for at least 35-40 years. The following quote is representative of the stance to the issue:

> "…human engineering needs as much attention as ergonomics and may even require more, until experience and training allows the human computer properly to appreciate and to accept the limitations of the electronic one." (Pain, 1968).

Unfortunately the emphasis was then, and still is, on making the human adapt to computers and technology, whatever their limitations. Still, as new technology has been installed to make work safer by reducing 'human error' or more efficient by removing the 'human factor' (Goossens and Glansdorp, 1998), new types of accidents have started to emerge. Many papers on maritime technology or ergonomics start with detailing how large a percentage of accidents are due to the 'human factor'. It ranges from 65% (Sanquist, 1992), 80% (Blanding, 1987) and a staggering 96% (Rothblum, n.d.). The Swedish Maritime Safety Inspectorate present an apparently well-intended categorisation of causes in the first pages of their yearly compilation of ship accidents. This is reduced to a few factors in later pages of the report (Sjöfartsinspektionen, 2003). In all too many instances the only causes listed are 'human factor' and 'technical factor' or even worse 'other factors'. Some research indicates that such categories are not only misdirected but also ineffective when it comes to increasing safety in general and maritime safety in particular (Dekker, 2004). Accident investigations tend to reflect the view of the research community, i.e., first measure, then evaluate and finally correct any problems. This of course leaves open the question of what one is 'measuring' and 'evaluating'. In turn this makes any attempt to 'fix' the problem rather problematic.

Many trials and studies tend to assume there is a technology that will solve a (or the) 'human factors' problem. There are several examples of how a technological 'solution', even when tested in realistic circumstances, gives small benefits in low-workload situations, and only tendencies of or no benefit at all in high-workload situations (Grabowski and Sanborn, 2001; Kristiansen, Mathisen and Villabø, 1990). Many maritime studies have focused on the impact of new technology. However even here the studies are carried out within the traditional ergonomics framework and most of this research is carried out on simulators, with little or no reference to what goes on aboard a real ship.

**What can be measured, and how?**

Epistemological problems arise when results from simulator experiments are converted into statistics. In this transformation, at least three stages of stripping away potentially important aspects of the context of work occurs – firstly when designing the simulator test, choosing what to include and to exclude, possibly even introducing variables which are not present in a real work situation. Here, the experiment designer himself sets the participants' goals, and the fidelity and performance of the laboratory setting may restrict what goals are possible to implement, determine and report on. The situation may be very different from a real work setting. Secondly, the experimenter chooses what to measure, where measure is the operative word. What can be measured will be measured, without regard to whether this is what we really want to find out. What cannot be easily measured will be given less precedence, and what cannot be measured may be ignored. Thirdly, when the results are transformed or sorted into networks, models, lists, categories, functions, tables, etc., whatever was left of the context in which these actions and events occurred is removed. This leaves the potential instrument designer with ostensibly useful numbers and guidelines, but still they have to be interpreted. This may be difficult due to the contextlessness of the numbers and can in the long run lead to designs ill fit to work practice.

What looks like tightly controlled experiments are in fact almost as qualitative as a field study; only during the brief moments of performing the experiment is there any control over variables. Before and after this window of control, studies like these are steeped in subjective judgements, decisions and interpretations. For example, although one of the most common variables discussed today is workload, together with the related term information overload, a question arises: what is workload and can it be measured or simulated? Many studies performed do not study actual workload – if there is such a thing – but introduce secondary tasks, often completely unrelated to realistic bridge work. This is done with the assumption that workload is additive; if a known entity is added (a secondary task) to a work situation, the whole performance can be measured and then the known secondary task is subtracted from this ‘total’, the rest will be the ‘actual workload’. This decompositional view of human performance has difficulties ‘measuring’ common work events like, for instance, the emergence of co-operation between humans and machines. There is a belief that the whole is no more and no less than the sum of the parts, while recent research indicates that not only is the whole of human performance larger than the sum of the parts, it is also very hard to study this whole with experimental or statistical approaches and methods (see. e.g., Clark, 1997).

Examples of secondary tasks which have been introduced to reach ‘high workload’ are letter-detection, subtraction and mental arithmetic tasks (Kobayashi, 1995; Sablowski, 1989; Schuffel, Boer and van Breda, 1989; van Breda, 2000). Sablowski comments that an initial goal of that study was to “test the limits” of the mates but this idea was discarded since this would involve “creating unrealistically difficult situations” (p.103). Furthermore, Smith, Akerstrom-Hoffman, Pizzariello, Siegel and Gonin introduce a “high but sustainable workload” in a simulator trial in order to get measurable results (1994, p.4). These concepts of workload seem ill-defined, hard to measure and difficult to derive design guidance from.

A common and undisputed assumption is that less variability is better. The results of simulator studies are very reported as track-keeping performance, for example measuring how much the participant or subject deviates from a pre-planned track, or by measuring CPAs (Closest Point of Approach: the smallest passing distance between own ship and another ship or object). Grabowski and Sanborn (2001) combine two rather contradictory assumptions when evaluating decision performance: if post-trip questionnaires show that more alternatives were considered by an individual before a manoeuvring decision was taken it is judged as better, and at the same time a low variability in vessel and team performance is judged as better. This implies that the operators should consider the whole range of possible situations but provides little insight in how situation and work 'lock' together onboard. Such models rest on a formalised and operationalised view of human thinking and reasoning in a context-free environment which leaves little room for studying and understanding human sense-making as it occurs "in the wild". Very few humans make decisions in this way, which has been long known and the issue, succinctly put by Lindblom (1959) is that the literature on decision-making and planning is "leaving [people] who handle complex decisions in the position of practicing [sic] what few preach" (p 80).

Sauer *et al*. (2002) go to extensive lengths to establish ecological validity of the ship simulator environment, but the validity of their results is then compromised when they use students from engineering and computer science as their subjects. Since the goal of a display design study should be to ascertain which types of display are more suited to a task, in this case navigation, it should be based on the needs of the mariner in practice and context. The results of the above study indicate that a certain display has navigational advantages and simultaneously increases fatigue. However, it is not at all convincing that this would be the case with real mariners.

**What is left out?**

There is a significant omission in the maritime Human Factors literature – where is the operator's voice heard? As yet, a few studies have performed observations of actual bridge work, interviewed active mariners, cadets, students and other 'experts', such as educators and trainers. These studies are often, when done, carried out as complements to simulator studies. As a result they tend to be brief and often presented as afterthoughts. When presented, this material is either quickly summarised or categorised. Further, informants' statements or observations are taken for granted. So there are two problems that weaken these studies: what informants actually said seldom appears in print, and what these statements actually meant is never really analysed. Simulator studies do have a potential to be useful but should be complemented with, for instance, interviews, observations and careful analysis of that data.

Rothblum, Sanquist, Lee and McCallum (1995) tested 4 methods for task-based analysis. The analyses are applied to the use of ARPA (radar) and ECDIS (electronic chart system), but no mention is made of participants in this analysis. It would seem that the task analyses have been performed 'dry'. The authors suggest that operational errors could be prevented by improved, human-centred, equipment design and by better training, in order to provide users with better mental models of the equipment. The authors do not further discuss how this human-centred design should be performed.

Another assumption found frequently in the literature is that we already know what the mariner needs or that this is fairly easy for researchers to determine and all that remains to be done is to bring together and present these data to the 'right' audience in the 'right' way. The bringing together is seen as easy – solved with sensor fusion and programming, and the presentation as slightly harder – but solvable with classical ergonomics. Here is an example: "Ideally all published nautical information and other knowledge needed by the conning officer (or pilot) to maneuver the ship safely could be displayed and controlled at one station on the bridge." (National Research Council 1994, p 257).

They do go on to say that even if this could be accomplished often local knowledge is required and not always available, or requires interpretation that current technology cannot manage (National Research Council, 1994). A further assumption is: if integrated bridge systems are "ergonomically designed to be user friendly" and pilots are familiarised with them before using them, they "would be expected to experience no particular difficulty" in using them (p 258). The question of course is that if everyone knows what the mariner needs, why is there any problem with 'fit'? Why do manufacturers and experts disagree on the 'simplest' of things? Wording, colours and shapes, things that can be easily engineered have been discussed at length, but there is little in the literature about meaning and sensemaking that operators have to resort to, to understand and make use of this technology.

Beneath the assumption of 'knowing what the mariner needs' lies another reason for introducing automation: the technology exists, now why can't it be put to good use? This is delightfully evident in this early quote from a member of the Royal Institution of Naval Architects (R.I.N.A.):

> "…of all the real and imaginary advantages claimed for "automation", the one that outweighs all the others is the exciting possibility of producing *really advanced designs.*" (Hind, 1968, p. 3, original emphasis).

In other words, there are solutions ('really advanced') looking for problems. This is naturally not specific to this domain alone, but applies to most if not all technology driven development efforts and targeted domains. The National Research Council report (1994) recommends that performance objectives rather than equipment mandates should be written, in order to leave room for flexibility in how requirements are followed and to allow users to respond both to changes in needs and technology. They also caution operators to not rely on technology without a solid basis for trusting it, but at the same time claim that technology introduction must be accelerated to reduce operational, economic and environmental risk. This leaves the mariner caught between a rock and a hard place; they are not to trust technology, but should be prepared, for more of it will soon be introduced, and faster than before.

Further, *Minding the helm* claims that the marine system is perceived as a safe system, mainly due to the slow speed of development of situations which allows mariners to recognise and recover from mistakes. Mariners work in an environment where incidents usually do not lead to catastrophic results, at least not immediately. Further to help them avoid mistakes there are the nautical rules of the road (Colregs) – if used correctly, and their own conscientious performance – even when mistakes are made (National Research Council, 1994, p 62-63). However, with the above in mind, what has not been researched is how operators recognise and recover from mistakes, which actions help them avoid catastrophic results, why the nautical rules of the road are not always used correctly, and why what operators do is later judged to be a mistake. In other words, what has not been researched is how they make sense of their cultural and social world, what it means to them to be a mariner, how they negotiate meanings between themselves and in interaction with technology and how all this works out and helps to define the social world mariners inhabit.

**How can testing be complemented?**

The interviews performed with the manufacturers in this project show that they use many and varied ways of getting information and feedback about their products, but that they need and want more. Examples of what is used are earlier experiences, customer contacts, trials in simulators and test ships, employees' experiences and data from external bodies. Customer contacts can be indirect, using surveys and questionnaires (although the value is debated), or direct, meeting them at trade shows, in training programs or on key customer test ships. On a few occasions workshops have been arranged. In some cases customers provide voluntary feedback, through letters and phone calls to service or development departments. Test ships may be the company's own vessels or selected customer sea trials. The manufacturers in most instances have some employees with maritime experience, or try to provide them with a 'basic' understanding.

The external bodies used range from standardisation, classification and type approval bodies to maritime academies, although the latter is uncommon. Dealers, service and installation personnel provide some feedback as well. All in all, the variation is great, and the contact with the 'field' is clearly present but in very few instances (if any) is anyone used to help 'interpret' the wishes of the customers. The final decision of what is useful feedback and how it should be implemented is left to engineers and designers. Similar results were found by Willén (1997), who studied 4 manufacturers of machines with combustion engines in Sweden. The study found that, although the companies used ergonomics (or similar concepts) in their advertising, 12 of the 14 interviewed designers estimated they spent less than 5% of their time on human aspects. The results also show that most of the designers had very little or no training in ergonomics but wanted to learn more.

The ethnographical approach provides a complement to the more common static and normative views of work practice. What ethnography does is give researchers entry into complex professional kinds of work that are not easily subdivided and decontextualised. Ethnography helps when laboratory testing and task analyses essentially 'fail' to adequately describe, interpret and to some extent explain aspects of normal work practice. An example of this is a series of studies performed to evaluate the effect of ECDIS (electronic chart systems) on navigational safety. In a simulator study mariners did not prefer radar integration on ECDIS, whereas in a field study the results instead indicate that this may be seen as beneficial (Gonin and Dowd, 1994; Gonin *et al.*, 1993).

Ethnographical studies or analyses of work in other domains include Dekker and Nyce (2002) who critique three studies on air traffic control. Other research like this includes Mumaw, Roth, Vicente and Burns (2000) on what they call cognitive field studies of nuclear power plant operators to study monitoring strategies, and Snook and Vaughan on serious accidents (Snook, 2000; Vaughan, 1996). There have also been studies on the effects of new technology in workplaces (Cook and Woods, 1996; Suchman, 1987). In brief, it is no longer uncommon to analyse what work is in relation to both context and meaning. After following the introduction of a monitoring system for cardiac anaesthesia, Cook and Woods (1996) comment "[P]eople who use new computer systems participate in the process of integrating the technology into complex fields of practice, often in ways that are surprising to designers" (p 594). Here, these issues are studied in another and new domain.

A number of naturalistic studies have been performed in the maritime field by for instance Grabowski and Sanborn (2001, 2003), Hutchins (1995a, 1996), Norros and Hukki (1998) and a number of Danish researchers (Andersen, 2001, 2003; Andersen *et al.*, 2000; Hansen and Clemmensen, 1993; Hansen and Jakobsen, 1993; Koester, 2001; May, 1999). Still, many of them use traditional or elaborated theories derived from the Human Factors tradition of research to frame their data.

This project complements the above studies by using ethnography to study the human-technology interaction on the bridge.

This chapter has reviewed current research in the maritime domain that pertains to ergonomics or Human Factors research. The following chapter summarises and discusses the main findings.

# 4 A problem-oriented maritime ethnography

In order to get an overview and summary of the data collected and the appended papers, this chapter will use the concept of integration as a basis for summarising and discussing the results of this study. In studies such as these, interpretation, analysis and discussion all blend together. There is, however, a short discussion at the end of the chapter.

> "When selecting the equipment, it must be borne in mind that it should be compatible with the other instruments to form an efficient unit as a whole. This is essential not only in the case of totally integrated systems, but also if the integration is to be performed manually by the navigator."
>
> Hederström and Gyldén, 1992, p 2.

### 4.1 Integration work

This section is a summary of the main points of the papers that are part of this thesis (Lützhöft, 2002b, 2003; Lützhöft and Dahlman, 2002; Lützhöft and Dekker, 2002; Lützhöft and Nyce, 2004, In press).

While on board, I did not see many incidents and no accidents, but gradually began to see what mariners did to avoid them and that this had much to do with how they 'got the job done'. From the mariners' 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 operators spend a lot of their time avoiding accidents, whereas for the operators it is all in a day's work. What I did see was what was happening on board, how mariners cope with their work and errors, how they learn and how they perform work-arounds given new technology. I saw examples of integration on several levels: integration of human work and machine work, integration of information representations and integration of learning and practice. I also came to see that the regulations governing the work on the bridge as well as the design of it often seemed to contradict the mariners' view of things. Integration work is about co-ordination, co-operation and compromise. When human and technology have to work together, the human (mostly) has to co-ordinate resources, co-operate with devices and compromise between means and ends. It is often management's belief that technology lowers cost and increases safety at sea, but this thesis seeks to provide information on other effects.

To structure this summary, I will discuss the work performed on board in terms of and in respect to different levels of integration. These categories have surfaced in the latter part of the study during data analysis, but are used here to make sense of data collected throughout the project. However, even in the early part of the study there were indications that integration, or lack of integration was problematic (Lützhöft and Dekker, 2002). Having said that, it is worth pointing out that the concept of integration seems necessary but is by no means sufficient to describe and account for what is done on a ship's bridge.

To be able to integrate on any level, humans must perform adaptations. In integration of this kind there is not any intrinsic idea of 'good fits'. Instead, mariners have to work to make the adaptations, to get various types of technology aligned in appropriate ways that makes getting their work done possible. A lot of the time on the bridge there is no trouble and little overt integration work, but this chapter discusses the 'when' and 'why' of integration work. Whether this means humans adapting themselves or their surroundings, the job of Human Factors and ergonomics researchers should be to make this adapting easier. Examples of what I saw being integrated, or fused into a working whole by the mariners include:

- Representations of data and information.
- Rules, regulations and practice.
- Human and machine work.
- Learning and practice.

The various categories used here are of course not mutually exclusive. I also want to point out that although single quotes are used to make the points in this chapter, they are all backed up by observations and similar statements at other times. Using the integration categories as subheadings here I will discuss why this kind of integration is performed, why it is deemed necessary by the mariner, provide examples of these integrations and connect the idea of integration to the Human Factors literature. There is little on integration work in the literature, as it is defined here. However, many have shown that technology has surprising effects and surprising uses. Handling computers, for instance, is not always straightforward. Wiener has 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 the computer sense. The following quote is from an officer on a cargo ship 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" (1C-212-213).**

Many have shown that new technology often demands a new way of working. However, that it demands a new way of thinking is not always made as clear. This is especially true 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 increase functionality. However, they continue to say that the value of such changes may be small, and unintended side effects can pose significant new work. Here, integration is a process, which is initiated and driven by the mariner who works actively to be ‘part of the loop’, which indeed poses significant new work. The reason mariners perform integration work is to do work it was proposed that technology could help them perform. That is, at some level, there is a difference between the situated tasks and the assumed task. Putting it another way, technology may be solving non-existent problems, and in the process even creating new problems. As many of the interviewed mariners said: “When we need it the most, the technology cannot help us”.

“Machines should monitor people, rather than the converse…[because]… people are poor watchkeepers and…tend to be forgetful”. Roscoe claims that this once radical notion is now a cornerstone of modern system design (Roscoe, 1997). Hind tells us that we have to shape people to adapt to the technology (Hind, 1968), and many selection and training programs have the same view. Bea and Moore (1993) urge engineers to evaluate explicitly how marine systems and humans can be better configured to improve safety. It is not clear, however, that the same type of engineer could perform both kinds of evaluations. Conversely, research on new technology and automation, and especially in complex systems, tells us that this view of machines as superior and humans as shapeable and inferior system parts is not an adequate one (Hollnagel, 2003). I will show here that human is an active integrating component. It is not about ‘being in the loop’, which sounds about as passive as ‘having situation awareness’, but it is about constructing the loop, negotiating common ground, making sense and taking an active role in the loop. Mariners, like many other groups, spend a lot of effort on building and re-building integrated systems.

The Merriam-Webster on-line dictionary[6] defines **integration** thus: to unite with something else, to form, co-ordinate, or blend into a functioning or unified whole. Also, to harmonise and synthesise. In this study, I have seen that 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 mariners’ work, and a unified (perfect) whole may not be possible. There are several ways in which humans construct a functioning whole out of parts. When the mariner’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

[6] http://www.m-w.com [2004, October]

to adapt the most is the human. The mariner is there as an elastic, adaptive component, and performs the integrating work. It is also a part of the mariner culture to be able to 'handle anything', and this has the unfortunate effect that when a burden is added, the mariners frequently adapt and handle it, and then, it would seem, more (inadvertent) burdens can be added.

Cook and Woods (1996) discuss two ways of adapting: system tailoring and task tailoring. They use a process-tracing technique, observations and interviews to track the effects of the introduction of new technology into an operating room. The results contain the relationships between features and characteristics of the new system and the user reactions – how they adapt to the new system and how they adapt it to better fit their needs. Cook and Woods find that 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. Instances of both these adaptations, when they are found in real or realistic settings, provide useful input. For instance, system tailoring suggests redesign needs and task tailoring suggests training needs. 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.

Adaptation from this other perspective is discussed by Hollnagel (1995) who outlines three ways that machines can be adapted to humans, rather than the other way around. 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 it is argued that a dynamic model is probably more adequate. This is a difficult undertaking, but 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 the needs of the operator. This is complementary to adaptation through design, and may be necessary since our knowledge of operators is incomplete at any given point in time, and it is impossible to predict all conditions. 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 for instance providing support and modifying goals and the organisation of work. For this kind of adaptation to work, a continuous monitoring of effects is needed, and this basically constitutes adaptation by continuous redesign. Courteney (1996) discusses a similar issue for pilots in aviation who have to work as ‘human interfaces’. She warns that if standards in one area is changed (areas: design, training and operations) then the others must follow. For instance a change in design must be followed by a change in training.

In sum, adaptation through design occurs at long intervals, during design or redesign. Adaptation during performance is continuous and rapid, but can only handle small deviations that have been anticipated. Adaptation though management is continuous and can handle large deviations. It would seem, given the difficulty of modelling and predicting human performance and not least the environment, that a good way to proceed is to adapt through both design and management.

Another effect we have seen is technology shedding, described earlier by Goteman and Dekker (2002). This is how and when certain steps of a task or procedure are skipped under time pressure. Here, we see how certain parts of a system are shed (less used or even ignored) when basic skills will do just as well. In many instances technology is ignored to lessen the workload, as observed by Grabowski and Sanborn (2001). This has been seen here too when mariners did not know how to work a system or had incomplete knowledge of how it worked in specific situations. A second reason was that they wanted to perform manual work to keep their skills, to stay ‘in the loop’ and/or to alleviate boredom. Many of these effects have been discussed before by several authors (see e.g., Bainbridge, 1983; Kuhn, 1996; Woods *et al.*, 1994).

As an example, before going into the separate categories, we will look again at one of the regulations for maritime technology (also discussed in Lützhöft and Nyce, In press). The revised SOLAS chapter V adopted in December 2000 and entering into force in July 2002 says in **Regulation 19 Carriage requirements for shipborne navigational systems and equipment** paragraph 6:

> “Integrated bridge systems shall be so arranged that failure of one sub-system is brought to immediate attention of the officer in charge of the navigational watch by audible and visual alarms, and does not cause failure to any other sub-system. In case of failure in one part of an integrated navigational system, it shall be possible to operate each other individual item of equipment or part of the system separately.”

As technology gets more integrated there is a hope that mariners will do less work. But, paradoxically they instead tend to do ‘more’ work, or at least different work, for which many of them are ill prepared. The above SOLAS definition implies that the mariner must be prepared for, experienced in, and trained for *operation of the separate parts* as well as managing the integrated system. In order to handle this they would have to have basic navigational skills to manage without technology, have handling and operating skills for the separate systems and have an understanding, if not mastery, of the separate systems as well as of the integrated system.

The question is, could it still be called an integrated system? Mariners would have to know something about what would be the same and what would be different in the behaviour of the parts as compared to the integrated system, and have to reconfigure their plans and idea of what is going on in case of partial or total failure of system. All this adds up to the mariner being expected by manufacturers of technology and legislative bodies as seen in the definition by IMO to re-integrate the navigation system only when and if some part should fail. However, shipboard observation shows that a model in which the mariner is a more continuously active integrating agent is more adequate when describing bridge work in practice. This will now be reviewed in the integration categories.

**Integration of representations of data and information**

The integration of representations is performed by the mariners as they work, mentally or using artefacts such as displays, or pen and paper. In Lützhöft and Nyce (In press) we call this providing an interface. 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) and is also recognised by Giddens (1979). Representations here also include what mariners can perceive of the real world as seen out of the bridge windows. A previous example of such integration is the position fixing cycle described by Hutchins (1995) where navy personnel integrated the outside view with a paper chart, via several devices and techniques.

By information I mean here data that has meaning for the mariner and the task at hand. There are several reasons mariners perform integration of data, information and reality. The most central is that it is seen as necessary, because the mariners want to integrate or compare data to construct a plan-for-action (see Lützhöft and Nyce, 2004). This construction is vital to work onboard but is not always supported by the technology – the machines cannot communicate in ways mariners see as useful or intelligible given the circumstances. For example, the same kind of data may be presented in two different locations in incompatible formats. 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, regulations can also lead to the demand for data integration.

For mariners to construct their ‘own’ integrated system takes a lot of effort, in evaluating and choosing among types of representation and comparing data which were not designed to be compared. This study found that what developers and manufacturers choose to integrate on screens or in systems is not always what the mariners find useful. The comparison of two waypoint lists from two navigation devices is a good example of this (Lützhöft and Nyce, In press). 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 many times over (a waypoint list may contain up to a hundred points, and sometimes more). The two devices that produced these two lists were not integrated and thus did not influence each other in any positive or negative way.

When using bridge technologies in combinations, there can also exist incompatibility between the units used to represent data. For instance, an echo sounder, tide tables and a chart may all use a different system; feet, fathoms or meters. This adds to the workload and demands close attention on the part of the navigator (National Research Council, 1994), and a navigator needs to notice this and perform conversions into a common 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. This could lead to potentially hazardous errors in position, but is a very hard problem to solve as many aids have different manufacturers or publishers. There is no common vocabulary, ‘designer’ or co-ordinator for such issues.

This and other but similar kinds of double-checking is performed for several reasons: at times the mariner wants the manual check and at times the technology cannot do it (or both). Even when the machine can do it, this may, as one officer says, "take too long to perform on the device and then the result is long lists that still have to be checked manually" (Lützhöft, 2003; Lützhöft and Nyce, In press). This also reflects a certain amount of scepticism on the part of the mariners themselves regarding representations of information. This is particularly true when the representations all point to the same thing but not precisely in the 'same' way. This bridging, or filling in the blanks, constitutes double-checking for the mariners and it is an important aspect of what is meant here by integration work. Most importantly, this work is imposed on them by vendors or manufacturers who provide them with technologies that when it comes to representation of data or information do not always tell them the same story in the same way.

When designing bridge technology, it is important to not commit 'designer error', i.e., not to hide interesting changes, events and behaviours (Woods, 1994). A change often indicates that attention needs to be paid and actions perhaps taken. Many maritime displays typically display a single datum in the form of a digital number, from which it is difficult to perceive, infer or track change. For example, for the display of cross-track error on board we have seen two presentations, either a (very small) number "1,4 R" or "0,9 L" (right and left!) or another with an 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 [to which side the drift is]'. This shows that to represent offset distance, an analogue representation collapses the two data points 'there is offset' and 'to which side it is' into one image, whereas the digital requires further explication to arrive at the same point. Further, the rate of change is not directly visible on either, but the analogue at least affords an easier perceptual estimate than the digital.

When operators need exact numbers, digital representations are often regarded as better. For instance, analogue representations of engine revolutions are accepted but to represent speed, mariners prefer digital, as exact speed can be needed to compute arrival times. In contrast, most officers prefer the analogue ROT (rate-of-turn, how fast a ship is turning) dial 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 'space', but to first find out how data are used and which representation 'works' i.e., makes more sense to operators given the task at hand. Does it regard forward speed where they want exact numbers but can accept a lag, or sideways drift where they quickly need to see changes but can accept a lower accuracy? If it makes the job at hand easier – why not use analogue representations?

Exact numbers (often digital) imply that the data are accurate and that the technology that represents them can provide mariners with exact, precise information about a particular thing. Courses are occasionally displayed with a decimal point, and for positions in latitude and longitude up to three decimal points are used. In neither of these cases is there any practical use for such 'exactness' as it is almost impossible to draw a course on a chart this accurately, and the same goes plotting a position with the extreme exactitude of three decimal points. However, people are smart and can put to use even what seems to be 'useless' information. One captain says he uses the third decimal point as displayed on the GPS receiver to estimate the accuracy of the position (or of the receiver). If it is constantly changing (when the ship is not moving), he says, the accuracy is (probably) lower.

Hollan *et al*. declare that "Experts often make opportunistic use of environmental structure to simplify tasks" (2000, p 9). We found, as Hollan *et al*. did, that what is 'environment' varies. It can be reality or man-made representations or any combination of the two. Chart lines and course lines do not have 'real' counterparts in the world, but the officers often use these representations as "things in themselves" (Hollan, 2000 p 185) in order to get a better understanding of both what the world is and what the consequences their actions onboard might have on this 'real' world. In the following example, two officers are looking at the radar screen, and A asks B about the orange line on the screen.

**B: 'That's our planned course line'**
**A: 'Yeah, but where is it in reality?' [Points jokingly out the window into the snow flurry]**
**B: 'No, it's only ones and zeroes' (4C-468-470).**

In this quote we see an example of how mariners make sense of two 'types' of representations, the digital course line and the 'analogue' world, as a part of their plan for action. It also shows the scepticism which mariners (B's last line: it's *only*) have about representations and how there can be some confusion of representations. Are they talking about information or the real world? The quote is not about refusing to use technology or questioning it simply because it is 'ones and zeroes'.

Rather the issue is here is how to integrate representations in a way which helps mariners make good choices about what they need to do next. The line is not ‘out there’ but it is a representation of their plan for action, which they integrate and understand in reference to what they know about ‘out there’. The next two examples show how the same representation of a planned track can be perceived in two seemingly contradictory ways:

**‘When I press this button, the ship is glued to this dotted line [on the radar screen], it will follow this line’ (6P-26-30).**

**‘You see that we have this line with us all the time, it’s stuck on us’ (6P-39-40).**

In these two instances the representation of the planned course line is talked about quite differently: in the first, the ship is ‘glued’ to the line whereas in the second, the line is ‘glued’ to the ship. This shows another bridging of representations and the world; the line and the ship travel together through the ‘real’ as well as the represented world, and which is which is seen as having little importance. Similar ‘confusions’ of representations have been discussed by Hutchins and Palen (1997), where a representation of a fuel system on an airplane panel is used both as a representation (actions made on the panel) and as the system in itself (talking about events in the fuel system).

This leads into the issue of how to represent abstract data and combinations of data that when combined may not have a ‘natural’ representation. Blackwell, Hewson and Green (2003) present an extensive list of guidelines for abstract data, in which for instance the points ‘show hidden dependencies’ and ‘show detail in context’ may be relevant for the maritime domain. There may be larger problems ahead if fused data points or abstractions become even more detached from the world (more abstract). The mariners then would have to address the issue of contradictions in data as well as the issue of trustworthiness of separate data points and fused representations. What should the mariner do when one of the values in some fused (integrated) data turns out to be unreliable or missing? How do we know that a mariner will understand and interpret correctly an abstraction thought up by someone not well informed about maritime work?

An abstraction which it is increasingly important to represent is how automated systems are doing. Due to the nature of automation, often human operators do not know how well it is doing, what it is doing and how it is doing it. Recent research 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 operators in knowing what to do and when, and thirdly, they should be pattern-based, to allow operators to quickly pick up abnormalities without difficult cognitive work (Christoffersen and Woods, 2000; Woods *et al.*, 1994). But all these conditions may differ or require different interpretations, given the task at hand.

We have seen that mariners want to compare and co-ordinate data and information, but in many cases the representations are not immediately correlateable. When sensor data are combined or fused into a single representation, issues of trust, quality, age and traceability of origin will surface and need to be addressed. Data abstraction tends to hide what is 'really' happening behind technology implementations and representations. Further, mariners often claim they want single data points presented and to perform the fusion themselves. However, opinions of this kind are not universal. An example of this is radar returns that are often filtered and strengthened before presentation on a bridge display. In this case mariners talk about them and treat them as "truth" and "reality" and when asked, say they do not mind (or know about) the data pre-treatment.

What makes it non-trivial for mariners to integrate representations is the way various types of representations are mixed and superimposed upon one another. For instance, many interviews show that mariners assign different levels of 'reality' to the radar image and the image on the electronic chart display. Most mariners are reluctant to add something 'less real' (data from the chart) to the 'really real' of the radar image. They want to keep the radar image uncluttered as much as possible, and while adding a few lines to delineate some chart data is acceptable, totally superimposing radar and chart is less acceptable. These 'levels of reality' seem to have both a positive and a negative influence on trust. On the negative side, there are several examples of such representations separating from each other: the chart lines on the radar of the Royal Majesty (Lützhöft and Dekker, 2002), the pilot in the simulator where chart and radar images became unsynchronised and also the captain who does not trust, and therefore does not use, the ship symbol on an electronic chart to manoeuvre anymore (Lützhöft and Nyce, In press).

The above examples and many comments from mariners show there is a resistance to adding more 'non-real' data to the radar. This resistance suggests that questions of epistemology (how to know what is 'really' real) is not easy to resolve. It also represents high cognitive load and is the result of vendors and manufacturers providing the maritime community with different ways to represent the 'same' thing, or different things in the 'same' way. There is not only the issue of combining and correlating, but the issue of what is filtered or omitted. We also see here indications that mariners seem to use other 'categories' of representations than the research and engineering communities. In short, it could be argued that the maritime industry has been providing mariners with information and/or representations that it may not have been necessary for mariners to deal with at all if they had been 'better' thought out and grounded in the mariners' reality. This section also illustrates how ethnography can highlight issues that practitioners do not talk much about, and may not be directly aware of. What we know little about at this moment is when and why the issues of 'truth' and 'reality' and the other issues taken up here are important and when and why they are not. Needless to say, this is an important problem that needs to be followed up if we are to better understand and address mariners' information needs.

The integration of data and information has been shown to be cross-modal as well – mariners use their kinetic sense in combination with visual and auditory data (Lützhöft and Nyce, In press). Essentially what mariners do is integrate data from charts (electronic and paper), radar screens, other displays, the view outside, what they feel (psychologically as well as kinaesthetically), their memory and experience and from others' observations (at the time or earlier) (Lützhöft and Nyce, 2004, In press). But not all these data are internalised, much of the data are still 'out there', distributed and available for rechecking. For instance most of the visual data are accessible at a second glance, out of the window or on the chart. Some information changes and has to be constantly rechecked, for instance how the ship is drifting due to wind or currents, and therefore it would be a waste of time and resources to memorise it.

It is clear that mariners like to have control over certain representations. For instance, on a modern radar screen today there can be as many as 6-7 lines, not counting the chart lines (e.g., course, heading, parallel index lines, curved heading line, track line). Officers like to be able to control these, taking them off and putting them back as the situation demands it. An example: lines on the screen can conceal buoys and other small objects. As a pilot said to an officer in training: "Look, you've got ten thousand lines on the screen right now" (implying 'how can you see anything at all?'). In some cases this removing and adding of lines and markings requires a lot of work, searching menus, pressing buttons, and positioning markers. These actions are all examples of how mariners use

representations, and this might be useful for manufacturers to know about as well as take into account.
When nothing else works the last resort is often said to be standardisation (Norman, 1998). This has also been argued by many officers and others participating in this study. However, it is not clear that mariners understand that standardisation does not necessarily mean everything will be standardised according to their wishes. This is a further reason why it is important to engage users, to help them understand the intricacies of standardisation and design.

Whatever the representation, data must be made observable and not just available. Observability means that a representation helps operators see more than they were looking for or something they were not expecting (Dekker and Woods, 1999). To achieve availability, classical ergonomics can be enough (e.g., colours, size etc.). However, to achieve observability there is the need to use new Human Factors science to make sure the operators notice and can interpret representations correctly (Lützhöft and Dekker, 2002). Knowing more about how mariners conceive of their work and representations in general as well as in conjunction with bridge work can give manufacturers valuable input. An important task, one the maritime research community needs to do further work on, is to find out which representations work best for users to make sense of a situation and for them to integrate all the represented data into a plan for action.

**Integration of rules, regulations and practice**
In the maritime domain there are numerous rules, regulations, procedures and guides imposed by legislation from the 'outside' (as seen from a mariner's perspective). There are so many different legislative systems in the maritime area that it is difficult to carry out a general discussion of reasons for why the compromise between procedure and practice exists. It is equally hard to generate general solutions. Here, rules will be used as a 'catch-all' concept. As shipping has been around for millennia, practice (seamanship) has evolved and is as important as legislation. Further, decreasing margins in economy, safety, time and space intensifies the need for trade-offs and adaptations when it comes to rules and regulations. However, it is clear that little work has been performed on how all these protocols work together. Much can be gained from studying what works in practice, and more importantly what emerges from practice. This subsection describes how rules and regulations are seen from the mariner's perspective, when they have to use them in their work. It is a situated and constantly changing task, with goals and sub-goals competing for space, time and a place in the hierarchy. This may mean

that, for instance, guidelines, bridge procedures or Colregs (Anti-collision regulations) are not followed to the letter.

Many agree that standard operating procedures are "…too rigid and time-consuming to be practically applied in time-pressured, high-workload operating environments" (Pascual and Henderson, 1997, p 223). Snook (2000) warns of a tendency in most organisations to write too many rules, which makes trying to follow these rules at the same time as one performs normal work very complicated. Similarly, Reason (1997) uses the concept of procedural overspecification. He describes how creating more rules (e.g., a new rule after every incident) reduces the scope of permitted actions, and this leads to violations, routinely or when deemed necessary for 'normal' operation. There is a tension between the natural variability of humans and the administrative need for regulating.

At sea, this tension is left to the operators to resolve as best they can. Two recent papers on the Colregs illustrate this. The first, by Stitt, claims it is time for a rewrite of the rules to avoid their 'misuse' by operators (2002). In the second paper, Belcher takes the opposite position; after a sociological interpretation of the Colregs he claims interpretation can never be resolved and suggests that ships be physically separated to avoid collisions (2002). Some of the reasons mariners have to integrate (force a fit) between rules and practice are:

- Rules can be contradictory.
- Rules can be underspecified or vague.
- Rules can be hard to implement in the light of contradictory goals (e.g., time, safety, economy, manning).
- Rules tend to be rigid and therefore hard to fit to a dynamic world.
- Rules can be interpreted differently by mariners and 'outsiders'.

These points will now be illustrated with examples and scenarios. There are many aspects of work and events a mariner has to be concerned with, often simultaneously; for instance there is much more to bridge work than navigation. The bridge on most ships can be categorised as centres for internal communication, co-ordination, and control for the ship's crew (socially and work-related) as well as external contacts (port, pilots, company, cargo owner, family). It is used for preparations for the next port, cargo and ballast management and planning, engine control and monitoring, and planning of maintenance work. Schedule keeping is getting a high priority nowadays, and there are many reasons: the ship must arrive in time with cargo for the owner, and the jetty, tugs, pilot, loading and discharging equipment, including stevedores, are all there waiting. New crewmembers, representatives from classification societies or inspection authorities, repairmen, service personnel, bunkers and provisions may also be waiting. To add to this, there are dynamic aspects such as other traffic, bad weather, heights of tide and opening hours of locks and bridges that have to be considered.

All these considerations at various points in time drive or demand the balancing between rules and seamanship. Sometimes this balancing may be out of conscious control, and a not very urgent issue may take priority temporarily. This could lead to incidents, where an outsider, often after the fact, then decides that another priority was more prudent or appropriate for the operator in question. As an example we look at track-keeping alarms. These alarms go off when the autopilot signals that the ship has deviated from its track or course (by a pre-set limit). However, letting a machine monitor a course is not enough – the rules and regulations dictate that relying only on alarms is not appropriate practice (Lützhöft and Dekker, 2002). On the other hand, many of the alarms were put in to relieve the officer of constant monitoring of both instruments and course. This leaves the officer in a position where he must decide which parts of rules and practice apply at any given time, or when one should take precedence over the other. If, as some officers say, “You have to watch it all the time” (in this case, the autopilot), there has not been a reduction of workload or freeing of capacity for anything else. The balancing also depends on where the ship is. In the open ocean, checking is less frequent than in the archipelago. Still, this is a judgement the officer has to make, which makes it necessary to adapt and integrate rules and practice.

In different ships, different ‘work’ is prioritised. In cargo ships, the cargo is the first priority. This means that learning how to work cargo-handling equipment often takes precedence over learning navigation equipment. This was seen on a cargo ship, where officers used basic methods of navigation, ignored the integrated bridge system and dedicated their time to the cargo handling systems. On passenger ships, navigation is a higher priority task, especially in restricted waters. Therefore, knowing and using modern bridge technology has a higher priority than on an average cargo ship (Lützhöft, 2002b). This at some implicit level ties technology to safety and to the ship’s operation, which has implications beyond what happens on board a particular type of ship.

After an incident or accident at sea it is always possible to say that the operator should have attended to rules or followed seamanship (practice). It is almost always possible to discover at least one broken rule. However, often rules and practice contradict each other and this makes the integration work even more difficult and in turn may call for more adaptive strategies (Lützhöft and Dekker, 2002). Many of the regulations at sea are necessarily vague and open to interpretation, as it is impossible to exactly lay down distances and actions. This vagueness adds work for the officer which is seen, for instance, in Lützhöft and Dekker (2002, p. 93): the Bridge Procedures. These procedures, among many other things, spell out when the officer of the watch should alert the captain. For instance, one procedure states that the captain should be alerted if 'the expected does not happen'.

Let us imagine an officer who does not spot a buoy when expected, but instead is able to plot his position using a distance and bearing to a nearby island. The expected does not happen, but the officer follows practice, which in this case means that he should try to use several means of fixing the ship's position. He judges that there is no danger to the ship in doing this. Furthermore, he knows the captain just went to bed after having worked for 15 hours, and has 6 hours of rest before the next port. There are rules that regulate the minimum amount of rest for a mariner. If the officer decides not to call the captain, the question is did this officer 'follow the rules'? Waking a captain may not seem the best way to proceed regardless of what the regulations say, especially if there is a risk that the circumstances would make the officer look incompetent. However, should an accident occur as a result the officer would be seen as having broken the rules. Often then onboard officers have to try to balance their own actions, practice and rules.

According to Vaughan there are (at least at NASA) two sets of rules in a workplace: one overarching general, and one more specific. The more specific set is changed and/or expanded with experience, and later evolves into standard operating procedures (1996). Pascual and Henderson (1997) suggest that decision makers should be trained to make 'effective solutions'. If these two above suggestions were merged, it might be possible to train less experienced officers and at the same time let experience-based procedures emerge from this collaboration. Closely related to procedures that govern work, there is the problem of deficient system understanding called 'routinizing' by Cook and Woods (1996). This essentially states that by 'shortcutting' across or within a system, an incomplete system view can be built up, which is believed to be 'true' by those involved when it is in fact inaccurate and potentially unsafe. This can happen especially with the changing of operators, where more experienced operators leave a workplace, and the work is left to operators who have not learned the device 'from the beginning'. As mentioned in

Lützhöft and Nyce (In press), maritime operators change both on short and long time scales (watch changes and crew changes, respectively). Reason (1997) argues that crews inherit faults which leaves little redundancy and little room for mistakes. Cross-training with experienced officers would help here, too. All too much research shows that trying to store 'expert' knowledge in databases to replace the knowledge of experienced operators is difficult at best.

Those who construct integrated navigation systems and the mariners who use these systems establish different models of how these systems work. This is in part based on individual understandings of the underlying regulations (Lützhöft, 2003), which entails that certain models of the 'proper' way to proceed exist in for example navigation work. Developers are often not fully aware of mariners' models and practices of bridge work and what they mean, and as a result often build tools for tasks as they themselves see them. This leads to mariners having to infer what developers meant by what they designed; a source of end user 'failure' which has not received the attention it deserves. The mariners have to establish and co-ordinate new sets of tools and aids, which takes additional effort. Further, if rules and practice called upon seem to contradict each other this can lead to more labour. If there was more congruence between rules and practice, between how legislators and developers understand these terms and how mariners understand them, maritime rules, regulations and technology could mean less rather than more work for those who use them onboard.

**Integration of human and machine work**

What does it mean to perform integration work between humans and machines? A good way of describing this is that it is the act of getting into co-ordination with an artefact through expert performance by a person (Hutchins 1990). Many aspects of new technology however make this kind of expert performance hard. Mariners work to build working human-machine systems, to 'integrate themselves' into a co-operational system. Why, when and how do they do this? Firstly, they do it when they see it as necessary. When there is a misfit between humans and machines, mariners have no choice but to rebuild the integrated systems in terms and ways they themselves understand. Secondly, mariners 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 new 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 high time pressure. However, the chart system demands that the operator go through 5 steps to register the position (submenus, button pushes). This at the same time as he has to start turning the ship, call the captain and crew, sound alarms and launch a special MOB lifebuoy. The crew on the ship in question had printed these 5 steps out on strips of Dymo tape and taped them to the frame of the screen. There are others systems that allow this kind of registering with only one push of a button.

When a human integrates he performs what could be called cognitive function or task allocation (called operator driven task allocation in Lützhöft, 2002b). To perform this integration and co-ordination, certain kinds of skills are needed. The officer must know what the goal is in order to establish a working ‘set’ of devices and how the parts he chooses to achieve a particular goal work, by themselves and in combination with others. This issue is discussed at length in Lützhöft and Nyce (In press). However what we still know little about is how constraints, whether ‘ecological’, technological or instrumental (such as regulations) determine what choices an officer makes and how these choices influence his use of technology.

Because technical systems are becoming increasingly interconnected, the way to perform the ‘same’ tasks becomes transformed and perhaps even harder to do, even though for instance manufacturers claim that nothing has changed. Often vendors will argue that after all these technical systems have the same components as before (Lützhöft and Nyce, In press). 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 mariners to see and the underlying principles of these systems may be even more difficult for them to discover.

One 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 by radar) the radar was switched off. Both officers worried though, about what effect this would have on the rest of the system, and especially which of the other parts would ‘stay on’ (Lützhöft and Nyce, In press) which makes the point that something has indeed changed (cf. above). When devices are technically integrated the co-ordination is more ‘hidden’ and ‘invisible’ to users than before. This means that mariners often have to employ more work and effort to reconstruct and understand the system. It also requires more effort on the part of vendors 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. Feedback from automated and integrated systems can be weak (Lützhöft and Dekker, 2002; Woods and Sarter, 2000), and what feedback there is may not be what the operators need or want to know at a particular time, but is instead what the manufacturer imagined they should know. Since tasks and situations are not stable, what is needed and wanted when it comes to technological aids keeps changing over time. This is something else that manufacturers perhaps have not taken into consideration as much as they should have.

Even when technology works ‘as intended’ (a question often not answered is: intended by whom and in what circumstances?) integration work is needed. In archipelago piloting, large amounts of data, information and strategies have to be co-ordinated. To pass the piloting examination, more than two years of studying and training is needed. The effort put into this is extensive, which is discussed in depth in Lützhöft and Nyce (2004) and passing the exam is not the end of the learning. Rather this learning process continues throughout the career of a pilot. However, in these waters the officers say they would not want to leave all the work to the technology, because as the officer O says:

**O: ‘You can’t just sit here and relax…you have to look the whole time’ (7P-187).**

They prefer actively working to simply monitoring. This active work may represent the same or even more effort than just monitoring, but actively working affords better control and integration than monitoring and taking over as necessary (at certain critical times) does (Lützhöft, 2002b; Lützhöft and Nyce, In press). Therefore, the officers feel that they ‘get more’ out of the ‘same effort’. To give another example: on a cargo ship with a very modern integrated bridge system, officers did not use all the available functionalities their automated devices possessed. Here too 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, 2002b). In short, off-loading or sharing 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 mariners work in their own ways.

Mariners do not choose to adapt systems only for personal reasons or work strategies, but often because contextual factors drive them to. For instance, in restricted waters and archipelagos, mariners do not want to keep all the lines on the radar screen since this makes it very hard to see the radar returns of buoys and navigation marks. In an earlier section we discussed how humans adapt to new systems, for instance system tailoring (Cook and Woods, 1996). This entails changing the system, and performing work to make the system compatible with the operators’ 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 new. Rituals like these may also lead to a lower understanding of the system. A second strategy is task tailoring, where operators instead adapt their strategies to carry out tasks, so as to accommodate constraints from the new technology. Neither of these adaptation strategies is effective in the long run, for constructing better systems, as earlier examples have shown here.

Another solution could be adaptive systems, that supposedly change according to the operator’s state (e.g., Alty, 2003) or the state of the world, which might be called an attempt to ‘situate’ machines. However, Hollnagel and Woods (2005) claim that adaptive systems are not the solution they were once believed to be. This is because humans do not like it when displays change ‘by themselves’, and more importantly, this reduces predictability. If a system is not predictable, humans cannot adapt to it. There is, for instance, a problem if automated or semi-automated systems can respond to input given by both human or machine (Lützhöft and Dekker, 2002; Sarter and Woods, 1995). This makes it hard to predict the machine’s actions from which follows problems like automation surprise (when a system starts acting strangely as a consequence of something that may have happened a long time before) and loss of mode awareness. It further becomes difficult to regard the machine as ‘an added crewmember’ if it is not clearly indicating what it is doing (discussed in above subsection on data and information) and not indicating who or what prompted it to carry out this action.

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 they still perform 'work' as well as look and feel trustworthy. Mariners try to integrate these new devices into the working human-human system (Lützhöft, 2002b; Lützhöft and Nyce, In press) but what makes this difficult to do is that machines are not situated. They are not situated or embedded in 'reality' because computers and technology have an impoverished, incomplete or faulty view of the world.

The view of the world that they *do* have is pre-programmed and quite static and hardly ever matches the dynamic picture of the world that the practitioner constantly reconstructs. The machine image is unsituated because it is hardwired, programmed into a machine by someone who has perhaps not 'been there' and into a machine that can never 'be there'. Someone else has chosen what the mariner needs and wants to see and know about the world and the system. An engineer has decided that these are the useful aspects and variables, sensors and data that the mariner needs to do his job. Mariners are in a sense sailing with "black boxes", whose rules they can neither deduce nor change. A machine does not 'know' where it is and what the effects of its actions may be. The most important problem here may well be that it is never 'ahead', can never anticipate (Lützhöft, 2002b; Lützhöft and Nyce, In press) Being ahead' is fundamental to maritime safety (Lützhöft and Nyce, In press).

We know that building common ground between people can be hard (Lützhöft and Dekker, 2002) but between humans and machines it may be impossible given that machines are neither social nor situated. Some officers call the autopilot the electronic helmsman, but at the same time they can call it a 'ruthless' crewmember (Lützhöft, 2002b; Lützhöft and Nyce, In press). How can we offload or delegate to such a machine, and what can be delegated? Several aspects of work are relevant here; task, knowledge, authority, responsibility and accountability. There is too little discussion and research on how (and if) we can 'break' up these different components of work and how (and if) we can 'assign' them 'correctly' to human or machine given that not only are the categories interrelated but what they 'contain' can vary from moment to moment and task to task. Of further interest is what aspects that make operators decide to offload, and what happens when technology offloads operators (takes work from users) without them being 'aware' of this.

Many suggestions have been made about how to solve this problem. There are some things that are central to achieve good 'teamwork', though. First, machines need to be 'situated' which might not be possible in the foreseeable future. Expert systems are still very dumb when compared to the local rationality of people. 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 integration in systems makes this hard. Third, some system of sharing or trading of control between humans and machines must probably be negotiated. This issue has been discussed by among others Hedenskog (2003) and Inagaki (2003). But control is not all that needs to be 'shared' or negotiated, there are multiple issues; knowledge, authority, responsibility (Suparamaniam and Dekker, 2003; Östberg, 1988) that also need to be taken into account. As an example, it has been shown that team performance is better if a computer is used as a 'critic' instead of giving 'expert' advice. This means that there is the same knowledge allocation between human and machine, but different roles (Cook, Woods and Miller, 1998). It is becoming increasingly clear that allocation strategies, static divisions into 'physical' tasks are not working well because of the complexity and dynamism of the work situation.

In some instances the work is shared and mainly at the initiative of the human. In many ships, the courses to travel are pre-programmed into an autopilot system by means of routes and waypoint lists. In most ships the autopilot does the job of piloting, i.e., following these courses, as long as nothing happens that requires a course change. However, in the large passenger ferries studied here, the officers and the autopilot 'share' the work of course keeping. The courses pre-programmed into the autopilot are just a starting point. To these courses officers then apply corrections routinely and continuously, due to perceived needs such as wind or current drift and meeting ships (Lützhöft, 2002b; Lützhöft and Nyce, 2004) The mariners do not delegate completely, as they prefer to expend the same 'amount' of effort but perhaps a different 'kind' or 'level'. In brief, they take over work from the machine so as not to be reduced to being a spectator onboard. This wish to keep control is also supported by the example in Lützhöft (2002b) where research shows that captains routinely bypass an integrated docking controller, no matter how 'good' the controller may be. For another example of the sharing of work, officers still rely on manual checks when machines could have just as 'easily' and as 'well' done this work (also discussed in Lützhöft, 2003, and in an earlier section here).

A further issue for mariners who try to integrate the 'new crewmember' is the role of communication. Communication has an important role onboard but this tends to be either built out of or neglected in the design of new shipboard systems. For example, we see the risk of losing access to 'public information' with the introduction of AIS, a transponder system which provides ships with other ships' identities. Before ships had AIS they would establish communication with another ship on the VHF radio by using the other ship's position to identify it. Today, many call each other by name, as supplied by the AIS, and ships that lack AIS ('third parties') cannot identify who (and where) the communicating ships are. This leads to a loss of information that was available before ('publicly', on the radio). Third parties may for instance not be able to find out who has agreed to perform a certain manoeuvre or action, and where (Blomberg, 2004; Blomberg and Lützhöft, In preparation). In relation to this, there is a widespread notion that mariners 'can do much better with electronic messages' (National Research Council, 1994). This notion persists largely because "communication" is classed with other kinds of labour that designers and developers see as 'unnecessary' or 'easy enough to perform'. Before accepting notions such as these at face value, more research on the role of communication on board is needed.

Technology is often used to replace parts of or all of human work and to make work safer, more efficient or less costly. This 'replacement' is not always straightforward, which is known as the 'substitution myth' (Dekker and Hollnagel, 1999). Research shows that a lot of effort has to be expended to get the 'new' system to work (Lützhöft and Dekker, 2002). 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 bring in existence new strategies, as for example an electronic chart system which not only helps to 'fix a position', but also helps mariners plan trips in different ways than before. The following two examples show two aspects of electronic chart use from small archipelago passenger ships. A positive aspect is that it is possible to insert photographs of the jetties the ships visit on their schedule, which makes manoeuvring easier in the archipelago. A negative aspect is poor implementations such as menu systems that are hard to use at high speeds when steering with the other hand. So in the end, whatever

the technology, it can be difficult to add up the bad and the beneficial in any way that looks like a cost benefit analysis.
One of the effects of new technology is that some tasks on the bridge are 'implicitly' disappearing. Before the age of electronic charts, voyage planning was an extensive task that had to be carried out before every trip. Basically, 'dry' navigation was performed, and every possible (conceivable) contingency was considered and in some way prepared for. The electronic chart and display systems of today include much more than 'copies' of paper charts. Information that used to be searched out in tide tables and pilot books is now being integrated into the electronic chart system, which ostensibly makes the task of voyage planning easier. Mariners now do not need to be able to, for instance, compute or even understand about tides and tidal currents. This technology changes the job so that mariners now are once removed from the 'real' job, because now 'all' they have to do is work with the computer and not for example with tidal prediction. This does not necessarily mean less work or thought, but another type of work now has to be performed, one that may permit or allow less insight into how ship, course and plan interrelate.

In this way, technology can become a 'barrier' to work. A device can become something to be 'worked through' in order to for example navigate, which adds more 'work' to the 'real work' (Lützhöft, 2003). This research confirms the axiom that when tools become 'visible' (when they malfunction) and an operator has to focus on the tool instead of the work, the tools are ineffective for performing work. Bødker (1996) calls this effect focus shift. This effect must be researched further and solutions investigated so we do not to add to the operators' workload at the same time as we hinder them from performing their real tasks. The alternative is to redesign the tasks to include working with the technology, which is the agenda of Cognitive Task Design (Hollnagel, 2003).

The way the workplace is designed also influences work. In design or redesign of the bridge for example, some work may also be 'lost' to the humans. For example, today's integrated 'cockpit' bridge does not allow much work with paper charts due to lack of dedicated space. On many bridges there is hardly even room for a notebook, and this sends a strong message about where and what kind of work should be carried out on today's bridges (Lützhöft and Dekker, 2002). In short, where work should be performed today, is with and inside the machine.

**Integration of learning and practice**
A remarkable example of the integration of maritime learning and practice is discussed at length in Lützhöft and Nyce (2004). A few key

points will be mentioned here, but it is clear at the outset that this area requires much more research. On board, there is much integration of learning and practice taking place, both formal and informal. In fact, for many officers their career as well as their identity as officers rests on a never-ending learning process. Why is this? The mariners themselves want to integrate learning and practice, because they want to keep their skills, their basic competence. This is done to retain something of what it means to be mariner. Elements of this competence also include being able to figure out how to use new technology and knowing how to handle navigation if the new technology breaks down (Lützhöft, 2002b). Further, they have to determine for themselves which parts of the job the new technology just cannot do (Lützhöft, 2003; Lützhöft and Nyce, In press). Most of the mariners are interested in and want to learn about new technology. For instance one experienced captain talks about how he uses the electronic chart to find leading lines easier than with paper charts (although he stresses he needs the paper version as well). In short this study shows that mariners would rather ‘re-skill’ themselves than run the risk of becoming de-skilled spectators.

They need to learn and to teach themselves, because there is little training provided by anyone for new technical systems. There is a recognition that there is a need for more training on board, especially in certain types of ships where unique skills are needed. There is as of yet no consensus as to how this problem is to be solved. We know that many maritime colleges and academies cannot keep up with the annual market cycle of revision and ‘improvement’ of maritime technologies, and can not afford to renew their equipment every year. Therefore, even if having the right technology is just part of the solution, it is hard keep up with what needs to be taught. Training and education in this domain have traditionally been subdivided into theory and practice, but many maritime academies now more or less routinely instruct students to make ‘projects’ of a whole sea journey instead of learning navigation in one class, maritime law in another and stability of cargo and ship in a third, which takes the students closer to what the real work is like. However, formal training in schools is just part of the answer.

On top of formal learning, practice and experience has to be added. One way of linking practice and experience occurs through an apprentice system, where captains or officers train novices onboard some ships. This used to be more common, but today reduced crew sizes has meant that learning more and more has to be done alone and on your own time or on watch. However, the companies with the best safety records are the ones who use the pilot – co-pilot system with two officers on watch at all times

(Lützhöft, 2003) which is also a learning opportunity. An issue that requires further research is how to best tie practice and formal instruction together for officer candidates, and how to do the same thing for officers with different levels of experience and training. This leads into another set of issues regarding recruitment of officers for the future. Is there a need to have more than one officer on the bridge, at least when learning? Should apprenticeship be moved from deck to bridge, from able seamen to 'half-finished' officers? Quite possibly we need to institute "cross training" (Salas, Cannon-Bowers and Johnston, 1997) between novices and experts in ways so that both can learn from each other.

Most manufacturers do provide training for their systems, but this is not inexpensive. Attending these courses also means that officers would be kept off the water and duty lists for some period of time. Furthermore, quite understandably, manufacturers do not want to focus on what can go wrong in their own equipment. The issue is further complicated by the fact that on many bridges equipment from several manufacturers are used, and at times interconnected. This is quite common, especially on existing ships that are retrofitted or upgraded in response to new technology being made available and/or regulations demanding it. Whose responsibility it is in situations like these to provide officers with training has not been well resolved. At present, it is common to get little or no preparatory training for new technologies, except for what you teach yourself (Lützhöft, 2002b; Lützhöft and Dekker, 2002). However, in the larger passenger shipping companies there are more structured means of orientation and introduction, as in some sub-domains such as archipelago navigation the job demands specialised training both on and off the job. We would argue that this should apply to most ship types equipped with modern technology.

A pilot interviewed on a ferry says they (the crew) want to balance the knowledge level on the bridge between the pilot and the officer (in the pilot – co-pilot system), so that both know the same things and 'have' the same knowledge or at least both know 'enough' to be able to work together competently. Between people that may be possible and desirable. An example of this was observed on the same ferry where a pilot and an officer together reasoned about how the autopilot system worked. The pilot already knew how it worked but made the discussion into a co-discovery. How to get this kind of interaction between people and machines is today not yet clear (but for a discussion of gradual shifting of responsibilities and control from operator to automation in radio network control, see Hedenskog, 2003).

There are additional as well as optional training courses available to mariners. For example, Bridge Resource Management (BRM) is an organisational tool of which some aspects are seen as very helpful. BRM teaches officers about working as a bridge team, as in the large ferries studied here. One thing most mariners who have attended this course mention is that they have become aware of different ways that humans think, solve problems and work in teams, particularly mariners of various levels of experience and those tasked with different jobs and responsibilities than their own. Such training may help mariners anticipate what other mariners might do. The downside is that even if a strong bridge team has been formed this does not mean it can easily expand to include a new member (temporary or not), for instance a pilot (or, for that matter, a new technology). Nor can every team always continue to work well when one of its members leaves. A team should have redundancy in knowledge (Hutchins, 1995) and flexibility in roles. However, what we also need is BRM for changing what machines do, making them more directable and situated, making them more into team members.

There is a prognosis for a lack of officers in the near future (Proceedings of the International Maritime Educational Conference, 2003). On the other hand, automation is often introduced to reduce costs (i.e. manning). This looks like there is a simple solution, to replace officers with automation. However, aside from the earlier discussion here, showing that this is not straightforward and can lead to no reduction in workload, we do not know how this will affect the skill levels of officers in the future. What we do know is that high technology bridges still need skilled officers to manage them. How should this dilemma be solved? It is evident that several effects follow the introduction of automation, many of which have been discussed previously.

One short-term effect is understimulation, the risk that there is too little for the officer to do. There are also clear long-term effects: the mariners may not be able to handle situations that require take-over, since these situations will happen less often and probably be more difficult to handle (Bainbridge, 1983). Another risk is that recruiting officers will be much harder, for what may then become perceived as a boring job. Mariners are aware of the risks and some resist the introduction of automation or are slow to accept it (see e.g., Dickens and Dove, 1995). At present, the task must be to engage mariners and engineers into a process which will turn around these effects and at the same time work to turn around the perceptions. This may mean redefining the officers’ job or redefining what machines should do on the bridge.

The mariners who do not like new technology (some say they do not) may be caught between hierarchy and technology. Many of them have extensive sea experience. The task, it seems to them, is the same as before and can be performed with the tools and aids they already know. Furthermore, they believe that with their experience and rank it should not be necessary to start learning 'again' as if they could not perform their tasks. Therefore they do not see any apparent added benefits with the new technology. The main problem seems to be that they have not perceived that the task has changed, so what they need is not new technology but information and training on the change in their tasks, and then they may come to see the use and need of new tools. All mariners should be made aware that life-long learning does not mean you cannot do your job, but is a way to continually improve. The strict hierarchy still in use on many ships makes this a difficult message to convey. To sum up, what is basic work today is not the same as basic work yesterday and certainly not the same as basic work tomorrow. On an Atlantic crossing just 15 years ago, the satellite navigation systems would sometimes provide no more than one good position-fix a day. The sextant had to be used, and may still be in use occasionally today, but what will be used tomorrow?

## *4.2 Discussion*

The main force driving the installation and use of navigation technology today is economics, and to a lesser extent safety (National Research Council, 1994). Other potential driving forces are competition, technology development and innovation. Constraining forces are partly the same: economy, technology development, regulations and 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. In this regard, it is not inappropriate to say that the aviation industry and the maritime industry share many of the same problems. How to solve this is unclear, but continued Human Factors work can help improve the situation. A promising way forward is to study how designers and engineers use the information they do get, how they construct 'user models' (Busby and Chung, 2003; Busby and Hibberd, 2002; Dagwell and Weber, 1983; Lloyd and Busby, 2001) and how to improve on this process.

In a 1989 paper, Captain Gill (1989) describes at length the usefulness of the new INS (integrated navigation system) they have received on his ship. But in these same pages, descriptions of new types of workarounds to get the system to work well for the bridge crew appear again and again. In short there is often a tension between belief and practice that is unacknowledged when it comes to the introduction and acceptance of new technology. There is already here in 1989 an indication that issues like this need to be taken seriously. For example, we can read that ”due to an error by the previous Second Officer, the entire electronic memory had been wiped out” (p 650). Granted, this was an early system, and hopefully this particular problem would not happen today. Nevertheless even today when we read between the lines of what informants tell us, they still fear that all their information work could disappear when they need it the most. This tension between belief and practice can be responsible for fatal errors, and what relieves this tension falls into the category of what we here call integration work, which is mostly carried out on board. Human Factors and ergonomics research need to help make this integration easier.

For new navigation technologies to realise their full potential, validation of systems must be made and these technologies must be accepted by the mariner community. Evaluation 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 or be flexible enough to accommodate technological innovations and ‘improvements’ whether they are deliberate or unintended. Further it needs to be stressed that technology of whatever kind is not a panacea for all maritime safety issues.

There is an assumption among designers that adding 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, and this can put the responsibility of appropriate use of design choices directly on the users’ backs. From this follows the problem of interference, as extra features can get in the way for at least two reasons. The first is that there will be a need to sort through features given the task at task. The second is to figure out why an engineer built these particular features in, and in both cases, time is spent, which could and should have been spent doing the ‘real’ work.

Flach *et al*. (2003) point out (using an aviation example) that although their perspectives may overlap, the engineer and the operator (in our case the mariner) 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?” The mariner 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, in this case how mariners construct, maintain and repair an integrated bridge system of which they themselves are a part. We need to ask the question that many mariners will recognise: “What are your intentions?”, before we resort to design, redesign or simply assume that human fallibility causes systems to fail.

This chapter has presented and discussed the results of this study. The following (and final) chapter contains conclusions, a summary of contributions and a section on future work.

# 5 Summary

The following three sections present in a condensed manner the conclusions, and these conclusions rewritten as contributions for various audiences who might be interested in this research. Also, some of the research agendas that have emerged and how they might be continued in the future are discussed.

> “We are stuck with technology when what we really want is just stuff that works. How do you recognize something that is still technology? A good clue is if it comes with a manual.”
>
> Douglas Adams, 2003, The Salmon of Doubt.

## 5.1 Conclusions

- Ethnographic method and analysis is valuable because it provides a useful way of collecting information on what users ‘mean’ and what designers ‘need’. Ethnography can also help ‘fuse’ the two together and thus improve a development and design cycle and the products that would emerge from such a cycle.

- There has been much research carried out on other complex work tasks and contexts. Therefore, the maritime domain could profit from cross-case analyses of related domains, e.g., from aviation, medicine, military applications and the nuclear industry.

- Earlier research has shown that to try and fix ‘human error’ by incremental improvements can be ineffective. This can be because the ‘fix’ is local in scope and narrow in time, and/or due to the adaptive compensation (gap closing) by users.

- Many ostensibly technically integrated maritime systems are neither well integrated from a human co-operative point of view, nor from a technical point of view.

- Human operators have to bridge these gaps of non-integration. We show that mariners to close these gaps through integration work, by adaptation, tailoring and shedding (or co-operation, co-ordination and compromise).

- Integrated bridge systems are not use-centred – they are not at the present time constructed with roles and tasks that take into account what it means for mariners to work on a bridge.

- Technology can become a ‘barrier’ to what the mariner perceives as his work. This can happen when an operator focuses on the tool instead of the work, which in turn happens because the tool becomes ‘visible’ (malfunctions). At such a time the tool is ineffective for performing work and this increases operator workload.

- Machines are not like new crewmembers. They cannot anticipate or plan for action. However, if the total system and task are designed correctly, human and machine can do much better together that either can do alone.

- Work cannot be broken into pieces and then put back together again in any principled way. New ways of designing for and thinking about the workplace are already in use in other domains. In reference to maritime technology, we suggest that cognitive tasks and social tasks (although analytically it is hard to separate to them) should be the focus, not engineering and devices. An obvious example is the role of communication.

- Many of the problems experienced with technological systems today are perceived by designers, vendors and industry to be of a technical nature, and are too quickly translated into design solutions. However, taking such a stance undercuts the role that cognitive and social factors play in 'end user failure'. In brief, technology alone cannot solve the problems that technology has created.

- It is central to have a holistic and comprehensive view of the system when making changes. If demands in one area (e.g., design, training, operations) are raised or changed, there must be compensatory changes made in the other areas as well. Also, cross-connecting these areas can provide further benefits. For example, training can stimulate design.

- Training on modern technology is often done in practice, by on-the-job experience. Earlier research and this study and shows that this may compromise the integrity of watchkeeping.

- To enhance training, mariners need to learn how to 'work the system', not just how the system works. Operationally realistic scenarios should be used for mariners to learn how to use a system's new capabilities.

- To further enhance training and design, manufacturers could reduce the cost of their courses, or find new ways to educate the practitioners about their technologies. If this was done, mariners could get better training and manufacturers would have established an additional and valuable feedback channel regarding their technology.

- Maritime pilots should be engaged more in research and development of new technologies. The addition of mariners and other insiders to the research team, can give valuable input and thereby save time (and costs) in any design and development project.

## *5.2 Contributions*

This section briefly outlines the contribution of ethnography, the yield of insider research and the value of the results of this thesis can have for the academic community and for the maritime communities.

**Academia**

The main contribution to academia is the argument for a method and a kind of analysis (problem oriented ethnography) that has received little attention in the Human Factors community so far. It also demonstrates how in qualitative research methods, theory and evidence mutually influence each and therefore can lead to better results. The last contribution is that this research has collected new empirical evidence from a relatively under-researched domain.

**Practitioners**

The mariners are provided with insight and argument regarding both what constitutes appropriate change in their work domain and the role they should play in it. Many of them have here been part of a feedback cycle at work, checking and rechecking findings, which aids their self-reflection, and makes them worthy and useful participants in the process of designing their work and their workplace. Further, this may be a way to provide manufacturers with information they otherwise might not have been able to obtain.

**Shipping companies and procurers**

Those who order and pay for ships' bridges can use this thesis to find talking points, or leverage, in discussions with vendors, shipyards and legislators.

**Manufacturers and regulators**

This thesis can provide those who construct technology, whether tangible or abstract, with more, and more accurate, 'close to the practitioner' knowledge. They will also gain insight into the conflicting notions of integration, from the technical, policy and design specifications view and the pragmatic mariner view. Further it illustrates the value of choosing between test conditions and actual conditions, depending on the research question and the rationale for choosing the appropriate one.

**Ethnography and design**

There is a limited amount of research in print on how to link ethnography and design. What we suggest here is that ethnography has to 'go both ways', to be able to translate back and forth between what informants 'want', given how they work, and what designers and developers believe about mariners' work, given their own training and work circumstances. Ethnography is about inside-out research, taking a member's point-of-view and seeing the world as perceived from 'within' (Blomberg *et al.*, 1993; Dekker and Nyce, In press; Harper, 2000). The reason for this, Harper clarifies, is to make behaviour understandable not just to the informants themselves but to those who design and develop technology for them. In doing so, they should be involved in not just first but second exchanges of knowledge, a more reflective view of knowledge. Here follows a summary of some of the benefits of using ethnography:

- The designer will understand the work practice for which devices are being constructed.
- The designer will understand how the context of use influences the user.
- The designer will not impose his or her own world-view upon the user.
- Ethnography can be performed concurrent with design and can provide insight into the design process that has yield for how technology is developed for a particular set of users.
- It can be used to evaluate systems before and after implementation.
- It can be used to re-examine previous work studies.
- It can be the basis of comparative studies and help evaluate the yield they have for work domain under study.
- It can help identify key informants who can be called upon by concerned parties, as these informants are interested in and understand a great deal about the issue.

In sum, it can help link end users (informants) and designers and developers in ways that can provide designers with more accurate knowledge about the work domain and work practices one is building for. A closing point is made by Dekker and Nyce (In press): ethnographic analysis is not about averaging out differences between informants, but rather to investigate and analyse what the differences are and how these differences and our understanding of them may be put to use in a design cycle. Further, the main reason to perform ethnography is to try something new, and not cling to the experimental view that more of the same will lead to something different. This view often argues that if just one more controlled experiment is performed, we are sure to find measurements that will explain human behaviour, at least in this one particular domain. However, as both Harper (2000) and Nyce and Thomas (1999) warn, ethnography is not just fieldwork, but applies what the literature has to say about social theory and analysis to a particular problem. This strengthens the argument for this kind of insider research.

Finally, here is an example of how the findings in this thesis could be used. There were two ways of representing information in the waypoint lists which were discussed in (Lützhöft and Nyce, In press) and briefly in chapter 4. The mariners clearly wanted to double-check these lists and routes in an undemanding but safe (error-free) way. If the information in the lists had been presented in a more appropriate way, given what happens on the bridge, less work would have to be put into the comparison, i.e., reconciling these two waypoint lists. Another suggestion is to combine the two instruments technically. A third is to make the automated checking system easier to handle, so that it firstly does not impose its own schedule on the operator (wait for one hour) and secondly presents the results in a way that does not entail further work (it is a lot of work to check all the anomalies in such a report). These are three suggestions derived from one observation, which tells us something important about what it is mariners want to do and leaves the details of how to come up with a solution to the experts.

### 5.3 Continuation

This final section outlines some future areas of research. Perhaps the most important to follow up on is education and training issues, and to provide a link between users and manufacturers, without giving the users responsibility for design. We need a research agenda in which a dialogue encouraged, to further mutual understanding between mariners and technicians. Such a dialogue would also provide valuable data and be a good 'laboratory' in which we could address the problem of translation and interpretation that often goes on (and not well) between end users and vendors.

Harper (2000) suggests a study program where previous studies of workplaces are re-examined to look at the effects that change has had in a particular workplace. In the same vein, MacKenzie (1998) warns that we can expect technology-specific problems as well as sector, application or domain-specific ones, and therefore we need more research across the various domains that make up a 'single' workplace.

Furthermore, there is more work to be done onboard. For instance, we should analyse the use and meaning of the omnipresent (but often ignored by researchers) memos, signs and instructions, post-it® notes and checklists. In many of these there are clues to the way work should be performed and technology could have helped. Some of these are automated reminders but many are home-made. For example, on one passenger ship, the crew needed to be reminded to retract the stabiliser fins, so they put a picture of a dragon with wings on the engine controls. When the speed is reduced (using engine controls) it is usually time to retract the stabilisers. Looking at ad hoc solutions like these could tell us a lot about the gaps between what technology can do and what operators require. It can also tell us much about how we as humans devise solutions and solve problems 'on the fly' using the resources at hand to make things work.

Finally, we have seen that end-users have tried, often with very little support, to figure out what is going on and how systems aid or do not aid them. Users have to carry out a kind of detective work, working backwards from technology onboard to find out what its designer meant it to do or represent. Hollnagel (1995) believes that to be successful a human-machine system has to have the common goal of maintaining system performance. We claim this should be a goal that operators should be able to work towards without too much effort. But if the operator first has to figure out the intention of a designer in order to get his own work done, this raises questions about how successful this particular human-machine link is. There is a strong and intimate link between the representation schemes, logic, rules and principles embedded in any technical system and what a designer thinks about how the particular end-users work and the role technology could and should play in this work. What we need to do is open up these logics and representations and revise them on the basis of what informants do and need at work. This takes us back to the problem of translation: how to best mediate between users and developers.

There is no conspiracy at work here. If designers and developers are not given what they need to build artefacts, they have nothing else to resort but their own common sense and understanding of how others work (Bader and Nyce, 1998). But this does raise the issue of how well the Human Factors community serves its own end-users. What do we know at present about what developers and designers do with what we give them? It could be argued that we have spent too much time trying to understand the work informants and end-users do and not enough time on looking at how developers and designers make use of this knowledge in the work they do. One could argue that it is time to look at how the Human Factors research community constructs knowledge about user needs and to ask questions about how well and how often research findings inform the work designers and developers perform.

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