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Work on the bridge – studies of officers on high-speed ferries

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The purpose of this paper is to describe the present conditions for officers who work on high-speed bridges, where manoeuvring and navigation are supported by highly sophisticated technical systems. Moreover, we wanted to explore the kind of support the information environment and the interfaces on the bridge provide an officer, who wants to drive safely, detect targets early and achieve efficiency. The officers have been studied at work, to investigate and better understand the interaction between humans and technical support systems in this environment. A control engineering approach has also been used in subsequent interviews with officers.

The paper describes conditions on the bridge related to manoeuvring, navigation, the computer support systems, information presentation, and the way information is acquired and used by the crew at work. Moreover, the interviews have been analysed according to a control-engineering framework. Finally, the elements of a trip have been explored to identify similarities with other means of transportation studied previously.

We conclude that the four general preconditions required for control of any system according to control theory are too broad, and need to be decomposed further to provide a correct representation of all the conditions revealed in the interviews.

From our findings, we argue that the way which information is integrated and presented to the officers is inappropriate. The present conditions are related to how computers are introduced in these environments. Single instruments are replaced with individual displays and control panels. Moreover, without second thought, menus, mice, display hierarchies, etc. are transferred to ship bridges that have completely different demands on operations than, for instance, an office environment. The task to increase the range or track an approaching ship on the radar display is at present performed in an interaction dialogue similar to that of a desktop computer program. The information required on the bridge is available, but sometimes the integration and layout of information is inadequate. With a better integrated information environment, it would be possible to reduce the number of displays and key panels related to navigational devices on the bridge. A more appropriate and integrated design would improve the officers’ ability to operate safely, since captains otherwise may devote significant attention to information search and manipulation of controls.

Keywords: Human–computer interaction, human–machine interaction, interface design, bridge layout, high-speed craft

1. Introduction

The work illustrated in this paper involves descriptions of how people interact with computers in environments that share many of the characteristics of previously studied control room operations (see e.g. Bentley et al. 1992, Suchman 1993). The work includes for instance a shared information space on the ferry with communication,
computer support systems, instruments and active information gathering. In addition, the crew, often the captain, communicates with traffic control centres and other vessels that may get in the way of the ferry’s planned route.

Furthermore, the driver environments have qualities like sometimes being noisy, rumbling, vibrating and shaking. The bright sunlight and enlightened instruments at night cause glare and reflections that complicate the interpretation of displays.

An intention with these studies was to investigate how the present bridge layout and information presentation on high-speed craft (HSC) influences on officers’ ability to control the ship, to make goals operational and to turn domain specific knowledge into practice. Accordingly, we wanted to explore which kind of support the information environment and the interfaces on the bridge provide an officer, who wants to drive safely, detect targets early and achieve efficiency. A theory of control supports such studies to a certain extent. Later on, the results from such an analysis can be used to hypothesise on suggested changes to a future bridge environment.

The studies have been performed on a number of high-speed ferries in Sweden, Norway and Hong Kong. The crossings in our studies lasted at least 35 minutes and at most three hours.

In the following section, we will first briefly describe the technical systems that support officers on the bridge, and how work on the bridge is performed.

The final discussion aims at shedding light on some general difficulties involved in judgements and decision-making in this particular environment, which is dynamic and often time critical. New ways of information presentation that consider cognitive workload are discussed. The suggestions are particularly important in the transportation sector where demands on increased safety are permanently on top of the agenda.

1.1 High-speed craft

The high speed on the studied ferries is achieved by water jet propulsion. Water is inducted at the forward end of the ship, passed through high-pressure pumps, and then exhausted at the stern through one or more nozzles that produce high-speed water jets (Jet Propulsion, Microsoft® Encarta® Online Encyclopaedia 2004). The thrust can be moderated by partially engaging reversing buckets, which regulate the amount of water flowing through the nozzles.

1.2 Officers on the bridge

The term officer is used to refer to the crew on the bridge (helmsman, captain) in this report, unless it is important to note differences between the roles. Moreover, these people may also be referred to as the users.

The staffing on the bridge may differ between shipping companies. A smaller ferry (~200 passengers) may have a single captain on the bridge responsible for navigation and control (see figure 1). Medium-sized and larger ferries (300–900 passengers) have a captain and a helmsman on the bridge (see figure 2) and often a chief engineer who sits either beside or behind the officers. The captain controls the ship; the helmsman is responsible for radar and backup lookout. They often have a pilot-co-pilot watch system. The helmsman often operates the ship when confined waters are left and the ferry enters the open sea, providing calm weather and sparse traffic conditions. The captain might sometimes give the helmsman an opportunity to train on embarking/berthing as well. Other crew members may accompany on the bridge as, e.g. an extra lookout. Some shipping companies have predefined concepts such as red zones (confined waters) and green zones (at sea), which determine the level of staffing and operation routines on the bridge.

On some ferries the captain and the helmsman take turns at being responsible for operating the ship, and alternate in command from one trip to the next; they. For instance, night trips outside Hong Kong harbour in the area...
controlled by Hong Kong Marine Department, the captain and the helmsman must be accompanied by a third officer on the bridge, with the sole responsibility of controlling the night watch device. On larger ferries, other members of the crew may have double roles such as work in the cafeteria while at sea and work as a mate at arrival and departure.

Apart from communication with the crew on the bridge, engineers and deckhands, captains on high-speed ferries in coastal traffic typically communicate through phone and radio with harbour offices, neighbouring ships and the head office. Arrival and departure with high-speed ferries is often confirmed with the harbour office, to make sure that the situation is safe and undisturbed by, for example large and slow ships.

The crew on the bridge notifies colleagues of actions as a confirmation of their appropriateness; they discuss observations of the surroundings and interpretation of instruments in the same way. From the observations on the bridge, it is clear that the crew need to share instruments and information. From that perspective, a strict separation of information and controls on different places may be awkward.

To the outsider, work on the bridge is often routine in line with the findings of Bentley et al. (1992), but the captain must always be alert and on the watch for the unexpected, because deviations from the normal occur frequently. Unforeseen events have to be dealt with rapidly, before they develop to serious incidents or even accidents.

1.3 Bridge layouts

The bridge on a high-speed ferry comprises a mix of computerised instruments controlling navigation, position of the ship and surrounding vessels as well as controls for operating the ferry (see figure 3).

Observations of bridges and interviews with designers (Olsson forthcoming) and crews have revealed that bridges on high-speed craft often are one-off; they may look similar but are never identical. In general, neither captains, nor any other potential users, revise the layout offered by the manufacturer or ship designer before a new ferry is delivered. The International Maritime Organization’s (IMO) regulations stipulate mandatory equipment on HSC-bridges. They also provide standards that may guide design of displays, but the complex environment created by all these controls and instruments, and integration of instruments to support efficient and safe navigation, is hardly discussed.

1.4 Radar

Captains have a number of displays and instruments on the bridge to aid them. The radar is the main instrument. Radar displays may be simple, showing traces of land, other ships and objects in the water indiscriminately, and up to the captain’s interpretation. Sophisticated radar devices may identify other ships, show trails of neighbouring ships, and include a predetermined route with waypoints that the autopilot may follow, show estimated time to arrival, exert warnings on collisions, and enable simulations of traffic situations that may develop when neighbouring ships are closing in. Some radar displays may enable overlay of the radar information on an electronic sea chart. Radar systems combined with other navigational aids such as differential/general positioning systems (D/GPS), transponder systems (AIS) and electronic chart display systems (ECDIS), support navigation and awareness of surrounding traffic, but the accurateness and utilisation in itself may be problematic.
1.5 Electronic chart displays

Marine charts are used for planning and displaying the route for an intended voyage and continuously monitoring the ship's position throughout the voyage. All ships are required to carry adequate and up-to-date marine charts under Regulation 20 of Chapter V of SOLAS (issued by IMO). An electronic chart display (see figure 4) is often present, but the frequency with which it is used varies. Sometimes it is placed to one side of the captain's seat, that is, not in the line of sight. The chart may contain a lot of information related to land, objects, paths, buoys and lighthouses. The ship is often depicted along with heading, speed over water, speed over ground, etc., planned path, waypoints on predetermined route, etc.

Electronic chart displays can sometimes be integrated with radar displays. This enables additional information to the master, such as the ship's position, the tide or water level, the flow of a current, ice coverage, visibility and the location of other ships, which are beyond visual but within transponder range. But our interviews reveal that the officers find that the display becomes too messy with the radar overlay, and thus avoid this feature. The ECDIS also enables the officer to plan the route accurately and enter it into the electronic chart, and to monitor the ship's position with great precision.

The interaction dialogue is often complex with hierarchic menus. Differences between various ECDIS manufacturers' display systems can induce an inability to operate the system for an officer facing an unfamiliar system, e.g. a pilot that temporarily conducts the navigation.

1.6 Conning display

Another common display is the conning, which contains all sorts of information related to the steering of the ship, its motions and the technical systems. Data from different sensors present information as speed relative to ground and water, lateral and transverse, fore and aft heading, course over ground, water depth, current status of thrusters force or forces, propulsion, rudders, wind speed and direction, plus many other things.

1.7 Joysticks have replaced the steering wheel

To control the movements of a ship is often referred to as manoeuvring. In their description of the maritime work domain, Petersen and Nielsen (2001) distinguish between manoeuvring and navigation, since manoeuvring relates to short-term change of position and heading while navigation refers to long-term planning when a ship is conducted from one place to another. On high-speed bridges, control levers or, 'joysticks' have come to replace the traditional steering wheel (see figures 5, 6 and 7) used to manoeuvre. Typically, two joysticks regulate two or four engines. The controls integrate both speed and rotation.

The joysticks involve computerised algorithms, which in turn affect the control of the actual technical systems such as engines, nozzles, rudders and thrusters. The control system has different modes (in which different algorithms

Figure 4. Electronic chart with menu system to the right.

Figure 5. Integrated joystick.

Figure 6. Joysticks in front of the officer.
are activated) to adapt the exerted power and steering to different conditions, as for instance in harbour mode, sea going mode and autopilot mode. Buttons, knobs and switches are used for shifting between different modes and activating the thrusters.

In for instance an autopilot mode, the position and heading are automatically controlled, sometimes heading is fine-tuned with a smaller joystick or knob on the armrest from one of the officers’ seats. Other modes allow engines to be controlled, e.g. separately by each joystick lever or integrated, e.g. in one joystick lever. Control can often be transferred between different steering positions on the bridge, i.e. the captain’s and the helmsman’s seat, and control consoles on bridge wings. The actual control mode is activated with buttons (see figure 5), but the rotation of the joystick may also affect the present mode, e.g. if a joystick (of a certain brand) is rotated more than 30 degrees, the mode is changed.

Thrusters, controlled by separate levers, are used to give a boost to a rotating motion, and thus increase the ship’s ability to quickly berth or leave the quay. The light hull of the ships and water propulsion increase the manoeuvrability a great deal in comparison with traditional vessels; some can, for example, rotate around their own axis and move in a sideways direction.

The different joystick modes are elegant from an engineering perspective. The same device provides different functionality, hidden on the surface, effectuated by computer-driven algorithms. From a cognitive perspective, the mode solution is less pleasing, with the involved risk for misunderstandings and mistakes.

1.8 Obstructed view from the bridge

The bridge on high-speed ferries is often placed on top of the ship, which makes it difficult to watch the immediate surroundings of the ship from the bridge. Instead, video camera-monitors support the crew with images on the ferry’s exact location (see figure 10) from stem to stern, which is essential at berthing. We have seen how different captains use different monitor-settings on the bridge; the helmsman always has to adapt to the present set-up.

We have also seen how captain and helmsmen share the command in this situation, one of them working with the joysticks and the other controlling the thrusters. Communication with the lookout on a lower deck is usually maintained through intercom–radio systems. On the ferries with bridge wings, the control is transferred from centre control to wings (where the view of the quay is superior) according to predefined procedures, often involving a mutual repetition of commands between helmsman and captain.

1.9 Traffic in different waters

Traffic in Hong Kong harbour is busy (see figure 8), and the high-speed ferries are frequent. On an average day there are around 100 ocean-going ships working in the port, and some 600 river trade craft entering or leaving the port. Ferries are an essential transportation mode for outlying islands and a complement to buses and railways. One of the high-speed operators who service outlying islands carried 37,700 passengers per day in 2000 (Information Services Department 2000).

On the contrary, the traffic density in Norwegian and Swedish waters is low except for seasonal congregations of small pleasure boats. The high-speed ferries that perform crossings between the mainland and the island Gotland carries, for example, 1.4 million passengers in a year. In Norway, high-speed vessels perform commuter-like traffic along the coast.

1.10 Human errors and safety

Including all kinds of vessels, most of the accidents reported to the Marine Department in Hong Kong harbour, were collisions (40%). Most of the accidents in Norwegian waters were groundings (35%). Swedish statistics from 1993 to 2002 also show that groundings are more common than collisions; the statistics from 2002 report 39% groundings and 25% collisions (Swedish Maritime Administration 2002).

So far, there have been few accidents with high-speed craft. Although, in an accident in Norway in 1999 a high-speed craft was grounded and sunk, and 15 people lost their lives. One of the conclusions made by the investigation
commission was that the officers failed to use the navigational aids (Justis- og politidepartementet 2000). Prior to the grounding, both officers were busy, adjusting their radar devices, which distracted their attention from navigation based on visual observation of lights and course. See appendix 3 for a few examples of incidents related to navigation and manoeuvring of high-speed ferries.

The ferries often have a light hull to enable the high speed, which makes them more vulnerable than traditional ships. This means in turn that the safety could be at stake in collisions and groundings (see figure 9). The catamaran ferries, which are common, often have a big windage and low displacement and therefore become susceptible to drift in strong wind. This inflicts on manoeuvring in harbour.

Accidents with high-speed as well as traditional ships are frequently related to navigational mistakes and manoeuvres with an unexpected outcome, often in situations when visibility is decreased, and they are therefore referred to as human errors.

Errors occur in all types of work and with all sorts of personnel. They may be the consequence of many different circumstances, often related to the characteristics of systems poorly adapted to humans’ ability to handle information. A serious error is typically accumulated from a number of minor problems, both technical and human (Reason 1988). Similar thoughts are expressed by Wagenaar and Groeneweg (1987), who conclude that accidents appear to be the result of highly complex coincidents, which are difficult to foresee by the people involved. Engineers have developed the bridge control system, often by implementing a specification that someone else has written. Moreover, there are certainly other people involved in the development process, who have decided on and written procedures for how control should be carried out. Consequently, there are many potential intrinsic sources of error in a system; such errors are called latent in Reason’s (1990) terminology.

Awareness of how a situation might develop seems to be a crucial part of the accidents. From accident reports, it can be concluded that the officer sometimes has had erroneous information concerning the exact location of the ship (see e.g. Lützhöf and Dekker 2002). Evasive manoeuvres have been initiated too late, and sometimes the outcome of evasive manoeuvres has not been what was expected. The reasons for the latter have in some incidents been related to mistakes related to misunderstandings of current joystick mode (see appendix 3).

It is impossible to predict what will happen in a dynamic environment like the maritime, which is influenced by many external factors. New and unexpected events will always take place. Human ability to adapt and learn involves skill at finding solutions to manage unexpected situations; the ability progresses continuously by trial and error. Erroneous actions are suited to the purpose, leading to increased knowledge and adaptation, but they may be inappropriate in the situation they occur. Since humans are flexible and adaptable, they try to adapt work to fit their own abilities, instead of changing abilities to fit the situation. This is an economic way of handling the situation (see e.g. Rasmussen 1990).

This line of reasoning should not be interpreted such that accidents or incident are purely incidental. We constantly extend the limits for what systems and humans may perform through demands on increased efficiency, productivity, swiftness, etc. Whereas a captain may cancel a trip due to bad weather, the decision is influenced by external demands, for instance from the shipping company that demands that the timetable is kept, and passengers who are anxious to arrive in time.
More and more systems and tasks are automated. Lützhøft and Dekker (2002) attribute the reason for the introduction of automation on the quantitative promises in the reduction of human error, workload and increase of efficiency. The underlying thought seems to be get rid of the human and the problems are gone! In spite of that, there are systems that are im-possible to automate fully, for instance because they comprise too complex tasks or because they include unpredictable elements that may lead to situations that only the human with the ability to improvise can handle.

With a greater extent of understanding of why people act erroneously under particular circumstances and in different situations, the conditions increase to change work where critical situations arise. Thus the work environment can be adapted to and make human conditions grow to succeed in preventing critical situations to a higher degree. What we know is that the relationship between a system and its user is circular. The system influences the user and the user influences the system. Control systems on ship bridges are complex and provide immense opportunities for different settings and adjustment, and choice of actions. Consequently, the ambition must be to construct a system where mistakes and errors are minimised, and when we make mistakes, the damage must be highly constrained and possible to remedy.

Unfortunately, new technology is sometimes fitted without caring for the officers on the bridge. The possibility of officers’ learning about all the opportunities that new technology provides seems to be less than adequate. In our studies, we have seen how radar systems provide innumerable settings and functions, which are seldom used in practice. When the need for advanced functions is at its greatest, there is no time to start investigating the opportunities that the devices provide.

Another example from our field studies shows how lack of knowledge on the technical systems results in unexploited systems. In comparison with conventional ferries, the requirements on rapid stop, a so-called crash stop, increases with the high speed. On a ferry with water jet propulsion, a crash stop is performed by pulling the joysticks full back, and reversing the buckets, to redirect the flowing water at the rear of the ferry. Thus, the speed rapidly decreases. Interviews with captains in Hong Kong revealed that no-one had crash-stopped a ferry, not even the captain who had been exposed to a collision. The crews shared the opinion that it would be harmful for the passengers and the water jet propulsion, and suggested a soft crash stop, when the joysticks were first pulled to the neutral position, and shortly after that pulled full back. A high-speed craft supplier in Singapore asserts that this attitude is erroneous; a crash stop would have no negative consequences. In fact, every ferry is subjected to crash-stop procedures at delivery. Correct operation in a hazardous situation could gain valuable seconds.

2. Theoretical perspectives related to work on the bridge

In the following section, a few theoretical perspectives, which are related to judgements and decision-making in dynamic work environments underpinning officers’ ability to conduct a safe trip, are described briefly.

2.1 Situation awareness and mental models

Situation awareness (Endsley and Garland 2000) is a compound concept comprising a human’s perception and understanding of the present situation, and the ability to make projections of future events. Endsley and Garland outline how situation awareness can be available on three different levels, dependent on skill and experience. On the lowest level, information is detected and registered. On the next level, the understanding of the significance of particular information is higher, and on the highest level, the ability to draw conclusions from present information to a future state is developed. An officer with the highest level of situation awareness would thus be able to project the traffic scene forward in time, predicting the motions and future positions of surrounding ships.

To create an image of how, for example, a control system functions, which is practical in daily work, we develop an internal representation, a so-called mental model (Johnson-Laird 1983). To develop the model is not a conscious or deliberate task, and we are unaware of the process as it advances. An officer can accordingly have a model of how the propulsion of a ship works, while another officer has a different model. This does not mean that one of them manoeuvres the ship more proficiently. An erroneous model may, however, induce erroneous actions and thereby cause problems.

Situation awareness is related to well-developed mental models, and the way information is presented and provided matters a lot in this context. An important research issue is, therefore, how different ways of information presentation may affect an officer’s ability to develop a high level of situation awareness. Further theoretical and empirical research is needed to supply accurate answers to such issues.

2.2 Making judgements from situation awareness

The work environment on a high-speed ferry is complex, dynamic, and from time to time, it demands high and directed attention. It can, for instance, involve a rapid decision on an evasive manoeuvre or making plans for actions in case a situation develops in a particular direction.

The consequences of inattention may be fatal if the ferry is
in the wrong position or if a ship on a collision course is detected too late.

To be able to work efficiently humans use various shortcuts to deal with large amounts of information, and make judgements and decisions. Particularly in situations when the stress level is high, we use rules of thumb – looking for information that confirms hypotheses we already have, rather than looking for information that proves that we have misunderstood the situation (Kahneman et al. 1982). We choose the first reasonable solution, rather than evaluate which one would be the best of a number of solutions. We direct our attention towards what we think is important in a particular situation. These strategies are often most efficient and work very well. We save our cognitive capacity, and the cognitive load can thus be kept on a reasonable level.

Research on naturalistic decision-making (Klein et al. 1993) has also shown that judgements are connected to previous experience. The decision one makes is dependent on if the situation is familiar and if previous actions in similar situations were successful. Situation awareness is related to decision-making. Poor quality of situation awareness can lead to erroneous decisions.

Judgements can also be less successful if important details in the present situation deviate from a situation that one recognises. Information displays should therefore be designed to lead the officers’ attention to important information, instead of making unessential information salient. Such examples are easy to find in any display on the bridge, where, for example, the supplier’s trademark is more conspicuous than any other information, or the position is displayed with an accuracy of four decimals, only because it is possible.

2.3 Proactive or reactive control

Control can be seen as reactive, proactive or as comprising a mix of these strategies. A reactive data-driven control style only responding to a system’s demands on activities or breakdowns involves high risk in safety, whereas a proactive, goal-driven control style aims at avoiding the breakdown situation through planning and preventive actions. The latter style results in an increased vigilance and readiness for unforeseen events. An officer on the bridge can thus increase advance planning and get a chance to avoid hazardous situations and thus increase safe control of the ship. Situation awareness makes a difference here too. Information environments that increase situation awareness increase the possibility to be proactive.

The actions we perform are decided from our recognition and understanding of the situation at hand (Klein et al. 1993). Systems developers have an understanding of the work the system must support, and a notion of how the work should be performed. Those who use the system in their work develop a mental model of the system through their work and their interpretation of the system, and adapt their way of working to that model. The model does not necessarily match the developers’ model; consequently, actions do not always match the actions the developer intended.

The understanding is influenced by our expectations, as well as our ability to learn and to generalise. If the understanding of a situation is poor, the quality of judgements will be affected. Humans and computers have different strengths; it is more effective to complement human abilities, rather than trying to replace them (Roth et al. 1997). The systems we build are binary, boring and often incomprehensible, while humans are flexible and easily adapt to new situations. Humans thus have qualities that are required to control dynamic systems.

3. A theory of control as a framework for workplace studies

Operations on the bridge are constrained by dynamics and delayed feedback, even if officers on high-speed craft suffer less from these conditions than do crews on traditional ships. Klein et al. (1993) have described decision-making, in such environments, as complex and dynamic. A conclusion from this research is that it is important to show dynamic information, for instance information regarding how the controlled process will develop in time, sometimes in combination with the possibility to simulate different outcomes with different actions. This would allow officers to develop better models, and work preventively rather than just waiting for critical situations to develop.

The user’s understanding of the situation in terms of goals, means and constraints, will, according to Hollnagel (1997), influence the quality of work. Brehmer (1992) proposed the use of a general framework, based on control theory, to organise research in the area of dynamic decision-making. Brehmer (1992, p. 218) suggested that:

\[ \ldots \] the most general formulation of the problem for research, therefore, is that it is concerned with people’s formulation of goals and models as a function of the observability and action possibilities of the system to be controlled.

Inspired by the control theory, we have used such an approach to analyse officers’ work on bridges. The human can thus be considered a self-regulatory system. The human is the owner of goals and mental models, while observability and controllability are characteristics of the system. The following four general preconditions required for control of any system according to control theory (Kelly
1968, Powers 1971, MacKinnon and Wearing 1985) are explained from a captain’s perspective:

- The goal condition. A captain has a goal or more typically a set of goals. Such goals are: a safe trip, a comfortable trip for the passengers, arriving in time, and so forth. For natural reasons, goals may be conflicting, as for example, weather and wind may cause safety goals to conflict with productivity and comfort goals. The captain assumes full responsibility in such situations.

- The model condition. A captain has a mental model of the system, which gives guidance on the outcome of different actions, for example, how a ferry with two water jets and an integrated joystick will behave in different joystick modes. This does not necessarily mean that two captains have exactly the same model; both experience and personality seems to influence the model.

- The controllability condition. The captain must be able to change the state of the system. A joystick is a typical example of a means for changing the state of the system on the bridge.

Moreover, the controlled process is often dynamic, i.e. the state of the process changes spontaneously because of influences from surrounding factors such as weather and traffic. Control actions do not only have instantaneous effects; they also influence the future state of the system.

4. Method

4.1 Interviews with officers working on high-speed craft bridges

Our workplace studies on bridges include participatory observations, observation interviews (Aborg et al. 2003), open interviews and semi-structured interviews. Bridges have also been documented with video recordings and digital still images.

A number of interviews have been performed with captains and helmsmen. Most of the interviews were made at the officers’ work places on the bridges of Swedish and Norwegian ferries. A number of open interviews made in Hong Kong largely support the results obtained in Sweden, although the results may be less frank, since some of the crewmembers did not speak English and an interpreter was used on three occasions. Moreover, two subsequent interviews were performed with the whole crew being present at the same time (three people and two people, respectively). Differences relating to a hierarchical work culture may also have affected the officers’ openness.

In addition, two engineers and a few managers from shipping companies and two ship bridge designers were interviewed. Initially the interviews with officers were open interviews where we wanted people to tell us about their work in their own words, only interrupted by follow-up questions in one or the other direction. Later these interviews and the observations motivated the framework for semi-structured interviews, where three officers and a first engineer were asked open-ended questions about the nature of and problematic aspects of their work. These interviews were performed in an office environment in Sweden. Images of displays from the bridges where the crewmembers worked were brought as reference material, to simplify detailed discussions related to contents on displays and integrated joysticks and back-up systems.

The authors performed the structured interviews, taking turns where one was responsible for conducting each interview while the other filled in with follow-up questions when needed. All interviews were tape-recorded and transcribed.

4.1.1 Using a theory control to analyse work on the bridge.
The theory of control described above has been used as a framework for participatory observations on bridges. The same approach has furthermore been used to develop a framework for semi-structured interviews. Finally, the transcribed interviews have been analysed. The transcriptions of three structured interviews with officers on the bridge were thoroughly analysed according to the control engineering approach to enable a description of the officers’ work on the bridge.

4.2 An analysis of the elements of a trip

In previous research (Kecklund et al. 2003, Jansson and Olsson forthcoming), we have identified how a train driver’s work can be divided logically into three consecutive phases. In accordance with our previous findings and those of Koester (2001), similar phases have been observed in the manoeuvring of HSC in coastal waters in Scandinavia as well as in Hong Kong. In addition, Koester (2001) related the different phases to different levels of attention and cognitive load. A trip with a high-speed ferry in commuter traffic has been analysed by reviewing video recordings. The officer’s manoeuvres and visible behaviour has been noted and time stamped.
5. Results

5.1 Conducting a safe, efficient and comfortable trip – analysis of structured interviews

Work on the bridge concerns the control of a dynamic system, conditions that can change spontaneously because of external factors influencing on the system, or because of actions performed on the bridge. Decisions and action do not only affect the instantaneous situation, they may have consequences that become visible much later. Thus, the current state of a dynamic system and its development depends on its history. If the officer on the bridge is unaware of the dynamics in the control system, e.g. how a situation has developed, it is very difficult to make correct judgements regarding the control of the ship. These judgements must often be made under severe time pressure, and comply with rigorous safety requirements – conditions that are related to increased stress.

Below are the conclusions from the interviews associated with the four control conditions: goal, model, observability and controllability. During the analysis, it turned out that the conditions were too broad to reflect all the information that was available in the interviews. The material has thus been further subdivided with subheadings given by the findings. A more detailed compilation of the phrases, which are the grounds for the conclusions, is found in appendix 1.

5.1.1 Goals – the officer’s intentional interaction

Overall goals The most important overall goals are related to safety, passenger comfort and profitability, in that order.

Goal conflicts and degrees of freedom The conflicts identified are related to time optimisation and environmental concerns, time optimisation and passenger comfort, safety and profitability, passenger comfort and profitability, work environment and profitability.

Concrete goals and realisation of goals Obviously, the different concrete goals are connected with particular actions. The judgements that the officers make are based on models of different situations and the associated events. The results support the decision-making in action theories that previously had been suggested by, for example, Klein et al. (1993). The basic assumption is that decision-makers in similar environments (i.e. controlling a dynamic process) establish an understanding of a situation in the form of a mental model.

5.1.2 The officer’s models and strategies – interaction from the understanding of the system

Mental model of the ship’s characteristics At least two of the officers have a well-developed understanding of the ship’s behaviour under different conditions, and know which actions are required to maintain manoeuvrability in all circumstances. Obviously, it may be difficult to establish full control in all circumstances, primarily due to factors such as the ship’s sensitivity to wind. Other problems are related to technical control solutions, i.e. that the officers judge the computer algorithms that control propulsion and nozzles to be less effective than manual control in certain situations.

Mental model of ship control As established above, the officers have a very good understanding of the ship’s behaviour under normal conditions, and they know how to maintain full operability in different situations. High-speed craft render possible an immediate interaction with the surrounding elements by using speed as an option for fast manoeuvring to avoid risky situations, rather than the cautious planning required on traditional vessels. The officers learning time is considerable, and includes mistakes. Nevertheless, all crews have advanced and exercise control in a safe way.

Mental model of the route The results show that all officers have established a mental model of the route; they plan their driving according to the model, but sometimes they chose alternative routes, depending on, for example, weather conditions. The officers’ model of the route shows that they combine the instantaneous observation (included in good seamanship) with domain knowledge concerning waypoints. Moreover, the results show that the use of the electronic chart involves a factor of uncertainty, and that the officers are aware of this.

Cognitive load – mental load Technology has provided the officers with a powerful tool, which means that they do not have to work continuously with all parts of the control and steering. For instance, the autopilot lets the officers focus more on keeping watch than on the actual control and steering tasks. The increased stress level when the autopilot does not work is pronounced. Berthing in rough weather is particularly demanding depending on the tight margins in such situations. It should also be noted that the bridge layout does not always fulfil ergonomic requirements in a comfortable workplace. Examples include ships lacking bridge wings and where the officers need to use video images at berth. Even if the cameras function, the task of integrating the images mentally to an image of the ships position increase cognitive load significantly. Moreover, an extra lookout is often needed astern. The different joystick modes may also lead to mistakes occasionally.

Mental image of the traffic The officers consider surrounding vessels to experience problems with the high speed. The crew on a high-speed craft can and do often use speed to escape from a difficult situation. The consequence may be
that slower vessels misunderstand the situation and initiate regulated evasive manoeuvres anyway.

5.1.3 What the officer observes – output from the system as interaction

**Overview of the ship**  The results give the impression that navigation at sea seldom causes any problems, given that unexpected events are tracked down, and regulations are followed. An officer remarks that you should never trust the instruments too much; you need to keep watch continuously. As in many of the other control conditions, the officers identify the harbour, and the berthing, as problematic areas. To manoeuvre with the video cameras as the only visual support (see figure 10) is difficult, even if you learn to master the situation effectively. Other complaints occur, for example that the thick centre window frame blocks the starboard view.

**Overview through instruments and cameras**  The officers have learned to use the different instruments’ advantages, and when the observations from instruments needs and surroundings, respectively, need to be reinforced. The radar is the most important instrument at sea, even if the electronic chart is considered to offer additional information. They try to avoid the possibility to overlay radar information in the electronic chart since the display becomes too messy if the information is integrated. On ships without bridge wings, it is particularly important that the cameras work at berthing. The crews have got used to the cameras. An impression from the results is that officers need to work hard to maintain an overall picture of the ships’ position, by trying to integrate information from different media to a whole. This information is easily accessible on ships with bridge wings.

**Visual feedback on actions**  The impressions are similar to those on instruments above. Ships without bridge wings require the officers to work against a two-dimensional image given by the instruments, whereas officers on ships with bridge wings immediately perceive the position of the ship. It can thus be concluded that these officers do not have to perform the instantaneous interpretation of the position under great pressure, which is required on the ships without bridge wings. The analysis also shows that information from different instruments sometimes is used to diagnose, for example, distance. The autopilot is occasionally used for this purpose. Different electronic charts, where routes and waypoints have been marked, also provide an instant idea of where the ship is positioned.

**Layout and integration of instruments**  The results are promising as concerns the prospects of an enhanced integrated bridge design. The first aspect relates to the great number of alarms on the bridge; these are experienced as tremendously disturbing, occasionally. Most of the alarms that the officers experience as superfluous can be traced to the chief engineers’ support systems. The frequent alarms tend to deaden the officers, so that in general, they stop paying attention to all alarms. Whether officers in fact disregard their own important alarms because of these habituations is highly uncertain. The second aspect concerns the poor integration of different instruments, and the sometimes-unfortunate layout of instruments. Moreover, the information presented in graphical user interfaces (GUIs) is sometimes poorly designed and unfinished; some have unnecessary functions whereas others lack needed functions.

5.1.4 Controllability – the officer’s actions on the bridge

**Controlling power and getting feedback**  The results show that there are mainly two problems with the integrated joysticks. In one of the ships, the officers consider the algorithm in use to be constraining, and provide lower effect on manoeuvrability (not power). It does not allow the officers the optimised control that is possible to be gained with separate joysticks. The freedom of action while using the integrated joystick thus becomes limited, in comparison with the separate joysticks. In the other ship, the problem is that the joystick may pass on to a different mode far too easily while operated sideways, and the ship thereby suddenly moves in an undesired direction. This behaviour causes a particular kind of insecurity in the officer concerning the reliability of the functionality. Consequently, an alarm has been installed, which would have been redundant, with a better fitting design of joystick functionality.

**Start-up procedure and turning over command**  The result shows that the routines at start-up and turning over command are relatively good. The officers are aware of the potential risks involved, when the command is turned over, and transferred between different locations on the bridge. Nevertheless, the procedures need to be kept up continuously and demand training.

![Figure 10. Video camera-monitors in the roof.](image-url)
Controlling the ship  Fine-tuned manoeuvring is required particularly in rough weather, and constantly in the harbour.

The results show that manual steering is the preferred alternative when the situation is most demanding, for example in harbour and at berthing. The officers are not worried at losing one of the engines under such circumstances; they have routines to manage such situations. But at least one of the officers experience speed that is constrained and a rise in stress level under such circumstances. The autopilot is used at sea (in green zones). The control is to a great part divided between autopilot and seagoing, and manoeuvring in confined waters.

Controlling the ship and surrounding traffic  Two officers say that the option for fast manoeuvring is an important reason to initiate evasive manoeuvres even if the regulations state the contrary. All the officers report that they establish contact with an approaching vessel if there are any difficulties.

5.1.5 Analysis of a trip between two stops for passenger exchange  The results show that, in agreement with previous findings on trains, a trip can be logically divided into three apparent phases: the departure, on the route and finally the arrival. The corresponding procedures and actions in each crossing are obvious from the video recording. The time-stamped notes made from a video recording of a particular captain’s manoeuvring during an actual trip are recorded in appendix 2. Next, the different phases of a typical trip with references to the trip will be described in appendix 2.

Before the departure, procedures and sometimes, checklists, are reviewed to make the ship ready, checking cargo, passengers and technical systems, checking with the harbour office that the departure is okay, checking with the chief engineer that power is obtainable and so on. How extensive the procedures are, depends on the size of the ferry and the number of passengers.

Departure  Loudspeakers are turned on to allow the captain to listen in on activities on the passenger and cargo decks, and in that way update himself on the current situation on deck. When the loading of goods and passengers is finished, this is confirmed through the intercom. Often, a lookout on deck communicates with the captain. Here the co-pilot (helmsman) checks the landing and arrival of passengers. The captain often has to welcome the passengers onboard and share information about weather, etc. with them as he manoeuvres from the port.

On this trip, the captain is alone on the bridge at departure, sitting on the right side of a centre console. The ferry is manoeuvred with two separate joystick levers. This captain, like many others, has chosen not to use the integrated joystick mode. He explains that this gives him better control over the ferry. No extra time is needed to fiddle with buttons. In case of sudden evasive manoeuvres, no extra time has to be spent on thinking about which mode the joysticks are in at present, and in which mode he would prefer them to be. In our interviews, a number of captains have also confirmed that this way of manoeuvring renders them the best control of the ship.

The first phase involves the manoeuvring required to leave the port. The captain is alert and does not sit relaxed in his seat (see figure 11). The situation may involve stress since an HSC is vulnerable at this moment. Wind and currents influence the behaviour and make certain manoeuvres less predictable than one would want. It is obvious that the crewmember on the bridge acknowledges the significance of performing the correct activities. The communication on the bridge is obviously affected by the seriousness of the situation. There are no jokes or discussions concerning leisure activities during this phase.

On the route  The next phase begins when the ship has left harbour and goes into a more relaxed situation. The decision of whether both the captain and the co-pilot remain in their seats through the trip is dependent on the characteristics of the water, surrounding traffic and visibility. Here they were present on the bridge, but only the captain remained seated in his chair throughout the whole trip. When the visibility decreased later during the day, the helmsman entered his seat as well to monitor his radar screen.

Usually, only minor course changes are required during this phase; the speed might also have to be adjusted due to surrounding traffic or semi-detached objects detected in the water. By now, the captain often leaves the command to the co-pilot. The control mode is sometimes switched to integrated joystick mode or autopilot by now. Here the
heading is fine-tuned with one of the joysticks, mainly the one to the right, which is closest to the captain.

**Arrival**  The third phase begins when the ferry approaches a destination where passengers and cargo will be unloaded. The stress level on the bridge rises. Plans are made and sometimes there is a confirmation of procedures to be used according to changes in weather, visibility, or surrounding traffic. Here the co-pilot leaves the bridge to watch the approach and care for passengers.

If the captain has left command to the helmsman earlier, this is the point when command is returned to the captain. Fine-tuning is required to approach the quay often through separate joysticks and sometimes in combination with one or two bow thrusters as well, while keeping watch on surrounding traffic entering or leaving the harbour. When the ferry is moored to the port, a moment of relief arrives.

6. Discussion

Our aim has been to study normal work on the bridge, not to find exceptional cases of work. Furthermore, our primary interest is not to use design as a tool to suggest remedies for human errors of the past. Instead we want to explore and ensure that human strengths and capabilities, which according to Klein (1998) have been downplayed or even ignored, from here on are considered in the design of technical support systems.

6.1 Dynamic systems transform human strategies

The strategies used by the officers indicate which kind of information they need instantaneously. Taking this as a starting point, the surrounding environment, and the officers’ interest in certain aspects of this environment becomes important. When we have identified these strategies, they will direct us to the most interesting parts of the environment from the officers’ perspective. The officers’ inherent strategies are automated to a degree that is beyond awareness; such knowledge is often termed tacit (Polanyi 1958). The approach, including observations of officers at work, in combination with observation interviews and structured interviews may at least partly derive such knowledge.

On the route, high-speed craft often travel at maximum speed (up to 40 knots), which means that the distance covered in a few seconds will be considerable, and that slower traffic ahead is easily caught up with.

High-speed ferries allow rapid manoeuvres. Other vessels are often slow, heavy and have an extended feedback; indications of a manoeuvre might not be visible until several minutes later. As a result, one of the conventional strategies for good seamanship has been set aside on high-speed bridges. Normally each ship has a large ‘private’ area on which no one intrudes. But the interviews show that the officers’ attitudes and strategies has changed in comparison with those of officers on conventional vessels. The speed is often used as an option for fast manoeuvring in particular situations, e.g. to avoid dangerously close encounters or to pass in front of slower ships (see figure 12) at distances much closer than would normally be acceptable, as the following statements from the interviews reveal:

You have to assume that you meet an idiot; it is the same as in your car. You had never survived this far if you had not expected to meet an idiot. That is the way it is, particularly when the speed is high and at close encounters.

In principal, we have superseded the seaway rules most of the time we turn, in any case when we are at sea. We do not care to turn when they come from starboard or port. Otherwise, we take the initiative and turn in plenty of time; we might turn 5 degrees when we have 10–15 kilometres left.

We are going so fast, we have to take into account that we must turn for everything if we run into trouble, even if they come from the port side. It is much easier for us; for a tanker it is a big procedure. Then you can be nice and show that you will take care of the situation, and he can continue straight on.

![Figure 12. A high-speed ferry at full speed passes 60 m astern of another high-speed vessel.](image)
The number of high-speed craft is rapidly growing; in areas like Hong Kong, it is already dense. This means that high-speed vessels begin to interact with each other. In confined waters and in harbours, it can thus be more problematic to speed up and slip away. A captain must be better prepared and have plans for different scenarios that might happen; there must always be an alternative way out of a particular situation. Accidents in relation to HSC officers using the speed option have already occurred (Marine Accident Investigation Branch, 2003).

6.2 On bridge layout and control devices

Today there are no requirements on a bridge design to be approved by a specialist from a human–machine interaction perspective (Holden et al. 1997). The standards concerning the layout of control devices seem to be insufficient, and to a large extent the design is determined by the technical construction. Bridges with a high potential for improved design have been observed during our field research.

The present bridge layout, with a number of displays connected to different pieces of equipment (a new display for each manufacturer), where the officer has to integrate and interpret valuable information as a basis for decision-making, is not practicable. There are difficulties in both collecting and interpreting information. Computer systems, displays and mice/trackballs are introduced on the bridge, but the systems and their usability have not been adapted to the marine environment. Moreover, the officer has to divide his or her attention between different displays and the reality. These conditions will most likely result in an unnecessarily growing cognitive load, and deteriorated decision-making that takes a longer time.

As mentioned in the introduction, the mode solution of the integrated joysticks is less pleasing from a cognitive perspective. From the results, we can conclude that officers often choose not to use the integrated mode with fine manoeuvring, due to the technical limitations; the use of separate controls for the engines increases the manoeuvrability when fine-tuned manoeuvres are required. Using the ‘separate mode’ when such manoeuvres are required is thus not primarily related to habitual non-use of capabilities offered by technical devices; the behaviour is reasonable from the user’s perspective.

On control consoles, devices from different suppliers are gathered and positioned, sometimes seemingly where there is a free space (see Olsson forthcoming). Through training, the users achieve an awareness of the options of their manoeuvring environment, and increase their preparedness and proper attention allocation. But training can never be used to deal with poor design. Moreover, it is impossible to correct improper design with circumstantial procedures, which most likely will be ignored or simply forgotten in critical situations, due to stress and lack of time.

An approach where different modes are used to implement different kinds of functionality in a device is used on the bridge, for instance in the joystick and in display designs. A mode restricts the operations that the user can perform while it is in effect. One mode is sometimes confused with another, and if the consequences of actions differ notably between the modes, the consequences can be fatal. The use of modes has been observed, both in the joystick and in other support systems on the bridge. It should not be possible to make mistakes related to different modes, and the position of the joysticks. During an interview, one captain answered the question of resulting consequences of control levers in the wrong position when transferring control to the bridge wing:

… if I forget, and the levers are in forward position. The next time I go to the wing and push command request, the ferry will move forward. But that scenario is so unlikely, because it is not included in our routines. First, you push the lever to the position you want it, and then you push command request; it is not failsafe, but pretty close.

Physical barriers that help officers avoid mistakes could be implemented to a higher degree. On some bridges, we have seen, for example, command buttons protected by Plexiglas covers, to avoid mistakes. These covers have often been fitted after an incident.

6.3 Interaction and dialogue design

An officer in control of a high-speed ferry wants to accomplish a number of goals such as providing a safe, fast and comfortable trip for the passengers, while avoiding fire, collision and grounding. The safe trip is dependent on environmental factors such as other ships, and external properties, such as waters, winds, waves and tides that influence the navigation. Continuously, officers need to monitor the position of their own ship, where they are heading, and the positions of surrounding traffic. To help them the officers have devices such as radar and electronic charts, which allow tracking of surrounding traffic and, in addition, the possibility to set alarms on targets conducting potentially hazardous movements. Unsurprisingly, the radar is the primary instrument used by the officers, independently of weather or time of day. Repeatedly, officers on the bridge confirm that they trust the radar completely and depend upon it. In archipelagos and coastal waters it is used to confirm that the ship is on course and that distances to land are correct. It is also used to keep track of surrounding traffic and objects in the water. Electronic charts, if available, do not have the same status at all.

Radar systems provide functions for adjustment of clutter and adaptation of the settings in many ways. The
information systems are handled like any office system, i.e. often with a number of hierarchical screens, menus and buttons, the interaction performed with a mouse or trackball. During our field research and interviews, masters have often confirmed that the information environment on the bridge can be cumbersome and disturbing to decision-making, and depending on its layout and function hinder the crew from keeping a good lookout of the surroundings at all times, for instance when the visibility is reduced by fog or rough weather. Few officers use the sophisticated functionality the radar device offers. On some ferries, the officers only switched between a few different ranges. Unfortunately, the situations where one needs increased support from instruments also seem to coincide with a certain amount of criticality and induced stress. If the officer under such circumstances has to go through several steps that involve using a trackball, selecting menus and pressing different keys, to adjust the screen, valuable time will be lost, and a completely new situation regarding position and surrounding traffic might have developed, since a ship might travel a considerable distance in the meantime. Consequently, the risk of a grounding or collision might have increased. In fact, in an accident report concerning a ship running aground in the Finnish archipelago, it was pointed out that adjustment of sea clutter required the officer to go through five separate steps when using the radar equipment (Accident Investigation Board 1998). Such interventions take time, and while the crew is familiar with the contents of the screen and how to navigate through the information displays, the ship proceeds.

After observing crews at sea and discussing their use of support systems, it can be concluded that the devices in general have more functionality than is used in the daily work. The reason for this may be that the functionality is superfluous, too difficult to use, or too time-consuming to manipulate to allow active use to any large extent. An interviewed helmsman told us that he avoids interaction with the electronic chart at sea due to previous bad experiences:

The ECDIS works very well in fog when we leave the harbour, and until we reach that lighthouse on our way back. I set it in auto-mode and then the proper cards are switched in automatically. Usually I never touch the equipment at sea, unless it starts to malfunction. Only in that case, I try to solve the problem.

The conning display often mimics the physical ship layout with water jets and thrusters. The observations and interviews revealed that the major part of the large amount of information items provided on the conning display was not of any real use to the officers. Most of the information was disregarded or looked for elsewhere. The large ferries are travelling the same route day after day. Therefore, the crew is familiar with, for example, the power and direction of currents; wind speed and direction were checked through other instruments rather than the conning display. When necessary the compass course was checked through the analogue instrument, not via the conning, where it had a central position. The same condition was valid for the display of the water jet status. The status was shown as arrows of different direction, thickness and colour on the conning display, but the crew looked at the analogue instruments to verify the effect of their manoeuvres.

In the end, the usability of a system is determined by the users’ acceptance, the way they employ the system, or for that matter do not utilise the system. The marine environment requires systems to be robust and effective, displaying critical information on top, and not demanding sophisticated operations that might be accepted in an office environment. These perspectives have increased our determination to work more with the layout, integration and presentation of information on the bridge – the ergonomics of the information.

To conclude, the information on the displays is not structured according to the different tasks on the bridge, nor to the common goal hierarchy, as has been documented above in this paper. Current design practices seem to have started out from the subprocesses or the information items contained in a work situation, and then fitted in all those in different systems on the bridge, as for example the radar, the conning and the electronic chart display. Together, these build a more or less coherent workspace. But, the displays need to support the officer’s work in general, that is to control a complex and dynamic system, which includes realtime planning as well as forward planning. An alternative approach to design would be to start out from the user’s internal model of the physical processes to be controlled. Instead of supporting individual subtasks, e.g. as putting a mark on a target, the display should support the task of managing a trip. This perspective on design requires a completely new way of thinking (Vicente 1999).

6.4 Information presentation in the officer’s line of sight

It is important that the information environment does not disturb the ability to pay simultaneous attention to the surrounding world. In an attempt to increase a captain’s quality of situation awareness, we have experimented with an alternative design, where safety-related information is presented directly on the windscreen. Similar ideas have been brought forward before, such as head-up displays in aircraft (Barrows et al. 1999, Fadden et al. 2001) and head-mounted displays in ship simulators (Konda et al. 1997). Information presented on the windscreen would
allow navigators to spend more time looking ahead (Fadden and Wickens 1997) and enhance their situational awareness (Endsley and Garland 2000). Equivalent with Bjorneseth’s (2003) research on synthetic vision, we suggest that the officer on the bridge should be able to use safety critical information as an overlay on the surrounding world and accordingly stay informed on sensor data from, for example, radar, DGPS and transponder systems, while keeping an outlook (Olsson et al. 2002). With this so-called augmented reality, the officer would thus be able to sail along a path, where hazards such as other ships and shorelines were presented on the windscreen, which would be particularly useful in situations with decreased visibility. A simple setting has also been evaluated in a simulator. The research is still preliminary and potential risks introduced by the novel presentation form need to be assessed further.

7. Conclusions

As our analysis is still at a preliminary stage, we will refrain from making detailed recommendations about design implications. However, the observations and the interviews have generated thoughts on future design on the bridge.

The information environment on the studied ferries is complex with an abundance of information from instruments, presented on graphical or numerical displays, as diodes, or buttons in different colours and shapes. Every device has its own presentation space, or its own way to present data. There is no shortage of information. Furthermore, every bridge is unique regarding layout of information environment. There are standards (IMO regulations), but they only regulate requirements on physical design of bridge instruments, and consequently information, which must be available on different kinds of ships. To date there are few regulations on integrated design of information.

Different kinds of information are often presented on displays that are fairly well assembled around the officers’ place. The deficiencies in the information environment can be traced to the unstructured layout and the lack of ergonomic considerations in the design. Actions are required within many areas to accomplish an environment that supports the captain’s judgements and decisions. A few of these areas are:

- Integration of different kinds of related information, in particular, information related to a safe performance at sea.
- The devices must be extremely effective, efficient and easy to handle; systems compliant with office standards do not belong in the marine environment.
- Information on displays needs to be structured and logically presented.
- Principles of pattern recognition should be used to increase efficiency and the ease with which large amounts of information can be surveyed, in particular to check for deviations from normal conditions.
- Salient cues should be used to make the information, which is most important at the moment, more visible than other information. The status and importance of particular information in the present situation decides which information this is.

An ergonomic information environment is a prerequisite for an officer to stay well-informed without cognitive overload. Such an environment facilitates information pick-up, interpretation, understanding, and cooperation between humans and machines. It must not cause cognitive load, for instance by requiring that one must remember pieces of information (Nygren et al. 1992). All required information must be visible simultaneously, without requirements on tedious interaction. On the bridge, this demands an integration of information from different systems, for instance radar, DGPS-system, electronic charts and transponders to provide an officer with a complete information environment. Moreover, it must be possible to survey this information with a quick glance to be assured that the ship is in the correct position, on track, that the propulsion works properly and that surrounding ships or geography do not constitute threats to a safe trip. The potentials of augmented reality should be explored in relation to maintaining a good lookout while controlling the ship.

The environment on the bridge puts special demands on interaction, both on robustness and regarding precision in actions. The kind of interaction we have observed on many bridges, where officers are required to click on small objects on a display with a mouse or trackball, is inappropriate. The same argument applies for the dialogue design – a hierarchical menu is not a proper choice in this environment. These kinds of interaction force the officer to direct attention to the user interface, rather than operating the ship, which include staying informed on the present position, the developing situation, and making accurate judgements and actions to prevent hazards.

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References


Appendix A – using a theory of control for analysing bridge officers’ work

The phases below are compiled from the semistructured interviews with three officers. Thus, the sentences in a section are not sequential; they are only collected under their respective headings, although from time to time, there may be two or three consecutive sentences. The same sentence may also occur in more than one section, if it has been judged to relate to more than one of the four control conditions. When an original sentence involves domain-oriented jargon, occasional modification has brought more understanding to the non-professional. Finally, the role on the bridge (helmsman or captain) related to the statement is indicated, although no essential differences between the individuals have been traced.

A1. Goals – the officer’s intentional interaction

A1.1 Overall goals

Captain: In general, you make a judgement that you can drive and that it does not affect safety and passenger comfort. I can stick to the timetable with an engine gone. Service should be completed the next morning. We know that passenger comfort will suffer long before we reach our operative limits. For that reason we get a lot of pressure from the office when we want to cancel a trip before we have reached the limit. But we tell them – You will have to trust our judgement – we had better not go out in this situation. We will put a lot of strain on the ship. We will have many cracks afterwards, and we will have passengers that never want to travel with us again. Shipping companies always want the trips to be carried out, but we have a safety perspective and are concerned about passenger comfort.

Captain: The safety margin to other ships is not clearly defined. If it is foggy, it becomes larger; if the visibility is good, it becomes less. Among other things, it depends on the kind of vessel. It varies.

Helmsman: It must look and feel good for the passengers; passenger comfort is important. We always have margins. In particular, when you are dealing with people, you do not expose them to uncertainties. You reduce the speed in good time. The passengers are our cargo, and our source of income. This is not welfare; we run a business. And the customer expects to pay a certain price for a certain service, comfort and treatment. But you would not take the risk of damaging the ship in bad weather. You adapt and reduce the speed if the weather gets bad.

A1.2 Goal conflicts and degrees of freedom in control

Captain: We have a different speed exemption than our competitors, depending on the character of the hull. But our competitors do not use the higher speed allowed because it costs too much. Since the wake wash is larger on this ferry, we have the highest limits. The new exemptions are the result of negotiations with local residents and the county administration. Before, we drove a bit as we wanted – full speed through the archipelago. We cannot do that anymore, unfortunately – that was fun. We had all the options, now we drive slowly through the archipelago at 17 knots. Environmental impact and the wake wash have put an end to that. It was more of a challenge to drive in full speed through the archipelago. In general, you make a judgment that you can drive and that it does not affect safety and passenger comfort. But if it is within reasonable limits you drive.

Captain: If the weather is close to the margin, and we may have trouble, we might for instance have technical problems, and then I cancel the trip. You do not go if the weather is approaching the limits. Some equipment cannot be replaced during a crossing. For a starter, it is too hot around the engine. Next, it is impossible to work in the room when the engines rattle. Our company bought the ships in Italy. What a good price; let’s buy! Therefore, the ferry has to be accustomed to the circumstances here. The operative limits have been approved, because the Classification Society (for example Bureau Veritas or Lloyd’s Register) has approved these peak waves for the ship. Money rules – which is why they want the trip to be carried out.

Captain: I can tell the passengers that we are taking a round trip for the comfort, which means that we might be a couple of minutes late. It is always annoying if an engine stops. Then you have to deal with the timetable and the passengers. I would not cancel a trip if the video cameras or the electronic chart did not work.

Helmsman: We have to plan the route according to the weather. You can always load the ship depending on the weather. You always adapt the speed to the weather. The last thing you want is the passengers getting sick. The concern is for the passengers. In addition, they will not eat and drink if they feel sick. We have a policy that if the weather is very bad we stay in port.

A1.3 When goals become concrete

Captain: But if it is within acceptable limits, then you go. If you accept half an hour’s lateness or an hour late at night, then you go, but not if we approach the limit. We have a limit of 3 m significant peak waves. Wind in particular directions, for example southeast, is also important to consider. You adjust the fins and the trim planes to obtain greater passenger comfort. When the wind comes from the west it has to blow like hell before the passengers notice anything. Regarding incident reporting we have learned to place the rod low. The point is that we shall learn from the system.
Captain: We have different certificate levels depending on if we have 900 or 450 passengers. The safety organisation looks a bit different then, so we go through it before we go onboard. I can pick a different route when the sea is rough, to make it more comfortable for the passengers. Sometimes I tell the helmsman to load a particular way when the wind is blowing in a particular way. When we have technical problems, we move on to operating according to red level. When we have technical problems away, the best thing is to leave the port as fast as possible. On the way back home, we request assistance. The margin to other ships is one or two kilometres if the weather is good and you pass behind, if you pass before the distance increases. If it is foggy you add a couple of kilometres, but it also depends on the angles. Then it depends on who has the right of way.

Helmsman: Three-metre waves are our limit. We have a load limit as well; we do not load over max. In general, we do not switch between joystick and separate (joystick) mode on a green sea. The RPM (rotations per minute) goes down and you lose speed. We cross shallow waters when we are late or we have a lot of cargo. It is important for passenger comfort to avoid abrupt manoeuvres when we leave the port. Generally, I only transfer targets from ECDIS to radar. You have to slow down.

Helmsman: You have to slow down. It is for the passengers’ sake we have the three-metre limit. The captain is responsible for informing the passengers early. It is obvious that the captain and helmsman are busy steering the ferry.

A1.4 Realisation of goals

Captain: We moor faster than our competitors do, but their logistics are 10 times better than ours are. Their infrastructure enables arrival and departure within 20 minutes. We cannot beat that. They easily keep their timetable; we cannot beat that. They keep to speed up, you feel how she curtseys, and then you can make 17 knots on an idling engine. Then you turn the ship. The jets are turned in parallel. But if you pass 30 degrees the ship will move sideways instead. If you turn the jets in towards each other, she will rotate around her own axis. If you want to speed up, you feel how she curtseys, and then you can increase speed again. Then she rises. She has 46000 hp and weighs only 1800 to 1900 tons. Therefore, she acts like a flat-bottomed rowing boat with two outboard motors on 40 – 50hp each. These catamarans have those properties; if you enter shallow water, their speed increases. A traditional ship is drawn down, and the speed decreases, in contrast to catamarans.

A2. The officer’s models and strategies – interaction from the understanding of the system

A2.1 Mental model of the ship’s characteristics

Captain: Our ship is long and the bow thruster is weak, thus power has to be divided in another fashion. The computer does not manage that completely, which means that you have to drive the ferry in a more conventional way, but with water jets. She is over 100 metres long and 17 metres wide, and the draught is 2.7 metres, so principally she flies over the dew. So we have 37000 hp at the stern and a bow thruster on just 600 hp. The minor draught makes her extremely sensitive to wind and the deviation is large. The consequence is that we have to drive the ship in a different way than the catamaran. To me it becomes a problem at first if I lose an engine; then it is an engine problem. You can move the vector in the ship manually more proficiently than with the joystick. In the ride-control system, you can integrate the nylon fins in the same system. You set the present “is – should be” value in percent according to the behaviour you want her to have, from experience. Then she keeps adapting the heading continuously.

Captain: In a difficult situation, when settings for jets and everything start to rearrange, you lose control for a couple of seconds before everything is back to normal.

Helmsman: You can feel how the ship is loaded. You feel it on the speed and if you have trim in the stern and/or stern. You load the ship according to the speed you want to keep. If the weather is bad, we load the stern, so you have the stern in trim. Then it takes the rough sea better. Otherwise, you load the stern, which keeps the speed up. The buckets are opened – on a scale from zero to 10 – and at five, the buckets are completely up. Then you make 17 knots on an idling engine. Then you turn the ship. The jets are turned in parallel. But if you pass 30 degrees the ship will move sideways instead. If you turn the jets in towards each other, she will rotate around her own axis. If you want to speed up, you feel how she curved, and then you can increase speed again. Then she rises. She has 46000 hp and weighs only 1800 to 1900 tons. Therefore, she acts like a flat-bottomed rowing boat with two outboard motors on 40 – 50hp each. These catamarans have those properties; if you enter shallow water, their speed increases. A traditional ship is drawn down, and the speed decreases, in contrast to catamarans.
A2.2 Mental model of ship control

Captain: Then I make a small reverse manoeuvre, to keep the ship against the linkspan (facility that locks the ship and provides access through gangways) and push in the bow towards the quay a little. Then the men lock up the link, and pull in one of the hawsers, stem and stern. In the beginning, it was naturally a learning process. Nowadays everyone is a very good driver. Everyone knows their own as well as the ship's limits. If you use the computer (via integrated joysticks) at arrival, you get a delay. And it is difficult to get full effect to achieve a particular goal. You reach the extremes. A lot of water is set in motion in all directions and you do not know where the ship is going anymore. If you, on the contrary, manoeuvre with separate joysticks, you know exactly how much power you can apply. You may still see if she has a tendency to end up where you want her to go; you can counteract the motion a little to make her approach soft. You do not get that feedback in the integrated joystick. The delay in the joystick is also difficult when gusty winds make her pitch. When you feel her swish away, you can fend off and control the situation much faster manually. With the ride control system, you know the settings by experience. It works up to a force of 20–22 metres per second.

Captain: Like any other ship, she moves more in certain angles. Then you have to adapt immediately. In rough sea, you have to consider cargo loading. It is not that dangerous to lose a turbine at sea. The problem arises when you lose it in the wrong place since the margins immediately shrink. Manoeuvring in the harbour with a strong wind is difficult. But we have practiced the different levels technically a lot. You can feel it in your bones. The first second when the ship does not move as expected may come as a surprise. Then you have to enter another level. You feel if the ship does not behave as expected. In general, we expect that all vessels move slowly. Most other vessels have no idea how to behave when we are approaching.

Helmsman: We get a hypothetical shaded representation of the ship in the ECDIS; we get a hypothetical movement there. With that support, we can park the ship, if we can trust the ECDIS. The ship stops in a short distance – three ships lengths. It is a phenomenon that when we approach at 30 knots closing in on X, and braking down, the speed can still increase because she surfs on the wake wave. You have adapted to the speed. You wiggle the joystick a bit and she answers immediately. You get the knack of it; you can feel in your bones how to manipulate her into a wanted behaviour. You just turn, and before you are ready, you fend off – then she takes off straight on. In the beginning, we always drove too fast. When the ship is so fast it is easy to manoeuvre out of a situation. You only drive away from it. You do not need to plan to the same extent.

A2.3 Mental model of the route

Captain: We try ‘blind approach’ and those things in the archipelago as well; when the weather is fine we train on bearings and such. We cross shallow waters, but we do not get the same advantage as our competitors. The passage is something like four or five knots faster for them and that is a lot. Catamarans get a lift in the ground water, but monohulls do not. We cross there for weather reasons. With the ride-control system you can predict how to steer and how to move. If I see that it is wrong, if the ride becomes jumpy, then I can pitch her down a bit. When I cross the shallow waters, there is not much water left below her; you better not choose an erroneous way then.

Captain: In principle, I choose a route, and tell the helmsman. We enter a route in the chart, but if the sea is rough, I may choose to go a bit more to the south. The destination port is more difficult.

Helmsman: You have different zones; we call them red and green. Green zones are at sea and red zones are all the way through the archipelago. We know the route, we know how the radar image looks, and we know all the turning points. We have entered that into the radar system. We can move the targets that we plot in the radar to the electronic chart so that we get them as red dots and vectors showing the direction. But you may easily be fooled, to trust too much in the electronic chart. If you fail to plot and move something from the radar, you may believe that it is not there. Because of that, you cannot trust it fully. In principle, you can plot the whole trip from quay to quay. We may even park the ship with this (electronic chart). We plan the route according to the waves. In addition, it depends very much on the conditions when we arrive. How high are the waves? Which is their direction? How strong is the wind? Wind in itself is not a problem for this ship, because it has such engine power compared to the size. In the green zone, we use the autopilot. We can exploit the third wave when we cross shallow waters for instance, because then the wave slows down and we can ride on it. It is like a pillow on the bottom of the sea. It suddenly increases our speed by three to five knots. There are different ways of following a route on the radar – head-up or true course.

A2.4 Cognitive load – mental load

Captain: If you lose the ride-control system, you have to start thinking, and it is tough. You have to find alternative ways to navigate to minimise the effects of the sea. At arrival and tying up in bad weather, it is tight and the deviation is large. In general, you make a judgement. If you control the problem and can handle it with no effects on passenger comfort – more than within reasonable limits – then you go.
Captain: In the beginning, it was extremely difficult to use the video cameras instead of bridge wings, to create a three-dimensional image of what was going on, how the ship moves and so on. You must be able to develop an image in your head that you can work to, but in the beginning, everything spins in your head.

Helmsman: It is a bit tricky if you switch from integrated joystick to separate. The ship behaves completely different dependent on how you use the joystick. If the bow is here and you want to turn, you should turn in that direction. But if you have the control in integrated mode it is the other way round. Most of the time when you go from integrated to separate mode or the other way round the speed becomes high.

A2.5 Mental image of the traffic

Captain: We are trained mentally on departures at 40 knots; the others have a problem with this; not us. Therefore, what regulates the vectors we draw and follow is that the others do not understand our speed.

Helmsman: The most dangerous situation is when a new (inexperienced) captain on a big ship decides to give way to us. That does not work. But I have seen many such situations. Therefore, you need to have a scenario. You need to plan. Often you create that image yourself. And when you have a close encounter with bad weather and a lot of traffic, the bridge is manned with two officers. What matters is to be ahead continuously if they do something stupid. The margins should not be less than nearly two kilometres in front of or one kilometre astern of the other ship. That may sound a lot, but at sea and with our speed, it is not much.

A3. What the officer observes – output from the system as interaction

A3.1 Overview of the ship

Captain: In the archipelago, we have a lookout on the bridge. When we leave the archipelago, we let the lookout leave. Then we have a deck sailor and a cabin assistant. Cameras supervise the car deck, but we have a sailor on the deck as well. When we approach land, we pick up the lookout again who thus becomes watch-out on the bridge. A bad thing is the centre structure between the windscreens, which obscures a sector of the starboard. As an officer, I do not control the weather. You know that the radar behaves. As the construction is as it is, with a nesting box flexible, to watch out of the window and see how the ship moves and so on. You must be able to develop an image in your head that you can work to, but in the beginning, everything spins in your head.

Captain: In the green zone, we only need to have a sailor as lookout and a helmsman or a captain on the bridge. In the archipelago, the basic idea is that two people should sit in front and keep lookout, in case anything should falter or turn up, plus the radio traffic of course. The officer in control never handles the radio; the other does. The one who steers must concentrate on that task.

Helmsman: The harbour office gives us information on the traffic; they tell us which ships are leaving and which are approaching. The cameras on the ship are sensor-activated, which means that there is an alarm on the bridge. Then we see immediately what it is. In addition, the nearest cameras are activated as well. But you must always use the human eye. So you have to navigate according to weather, and adapt both speed and distance to others. In the beginning there were many ARPA collisions – you navigated with the ARPA system. You said ‘OK, I passed 555 metres behind the stern’. That works fine. But the requirements on the radar are a remnant from old devices; the accuracy was 1295 metres. That is a big difference. Perhaps the difference is less normally, maybe 200 to 400 metres today, maybe even less. You never know if the device is a ‘Monday-exemplar’. Therefore, you never get the exact image. It is the same with the DGPS; you never get the exact millimetre. Then these ARPA collisions, as we call them, happen when you trust the instruments too much. Good seamanship includes always having a wide margin. You cannot drive on the margin constantly. You must continuously be aware of what the other officer on the bridge does. So you make use of many senses at the same time. You must watch, listen and drive. We watch the radar, but we do not see behind the islands. Perhaps you meet a ship with the control system out of order. That is the case if you meet a ship with two red lanterns, or if she has three white lanterns in a row. Then you know that it is towage. This is at night; in daylight there are corresponding signals, globes, squares, or flags. You need to use binoculars. Bridge wings are good; it is easier, more flexible, to watch out of the window and see how the ship behaves. As the construction is as it is, with a nesting box on top of the ship, visually you depend on video cameras and monitors. But as a matter of fact I find the ECDIS good.

A3.2 Overview through instruments and cameras

Captain: If the other officer is steering I watch the radar. And if I want to steer, I tell him that I am taking over, and then he watches the radar. That is more or less automated. I do not control the weather. You know that the radar image is poor. The tying up is more difficult because you do not see anything. The computer never communicates the information as quickly as your own visual impression. Our competitors depend completely on the video cameras. They have a sailor at the stern as well. That was probably not planned, but that is their current solution. We have eight video cameras – four in the engine (that is two in each engine room) and four on the car deck (two on the lower deck and two on the upper deck). We do not have any
cameras outside. The cameras are connected in a loop and check automatically at all times. You can freeze the image whenever you want to. That is a great safety advantage. You can detect a fire in the engine in good time. When it comes to the nautical, we have the radar and the electronic chart. All devices are doubled. Then there is the DGPS and the ride-control system. In the latter display, I see the settings and how things move, e.g., fins and trim planes, heading, and something we call route mean square value – a kind of mean value of the tendency. The radar on this ship is very good – large displays and fine to work with. One officer is always designated radar responsibility when the weather is bad or the traffic is intense; we always have two officers. There is also a screen for impeller speed, where you see the rotation speed of the impellers. It goes from zero to 190, and then all the ‘lights’ are lit up, pow, pow, pow, pow, and then you have all four engines. If a light dies out, I know that a propeller has clutched out.

Captain: We have a number of video camera configurations, for instance at tying up and departure. The tying up is slow when the cameras are out of order, and it has happened. We have a number of systems to use, the ECDIS with the accurate predictor, a sailor at the stern, and in both ports we have a landmark that we use as a reference. You can use it if nothing else works on the ship, which is most important as these devices depend on the situation. The cameras are most important when you close in to the last meters on the quay; a bit further out it is the ECDIS, plus you always have the landmark in sight. It is a combination, depending on where in the manoeuvring you are. We have an acoustic alarm that sounds if you pass 30 degrees turning the joystick. It was not there initially, but you need it to get a warning if you pass the limit. Concerning the cameras outside, I must say the quality is good. Even if it is dark outside, you can see better with the cameras than with the naked eye. They are very sensitive to light. The camera at the stern is very important in certain situations, in particular the last meters when we approach the quay. As I see it in my head, ECDIS should correspond with the cameras and vice versa. So if I see a thing in the ECDIS that does not match the cameras, it may be difficult to know where the error is. But I trust the cameras most in that situation. If they should break down, I would definitely put a sailor at the stern. I would rather have two independent systems. The radar image comes in two resolutions – one 3 centimetres and one 10 centimetres. It is up to the individual how to use them. But in fog, the officer in control can have the lower scale while the other has a higher scale. The officer in control can steer according to the radar image; the other officer is checking upcoming meetings in advance.

Helmsman: If the weather is bad, you only use the radar. You have to proceed cautiously. We know all the courses so we recognize the radar image. We see the buoys approaching and then we have entered little marks into the radar as green and red buoys, lighthouses and such things; we get like a fairway. We have also entered a chart into the radar image, so we can switch between a few charts. Then we have the electronic chart, ECDIS, in parallel. So we always check that they agree. Then you can take the radar image and enter it into the ECDIS; you double the information. But that screen becomes so messy, so we always separate them. The radar is like the eye, which is what you ultimately trust. If you fail to plot targets in the radar you do not see them in the ECDIS, thus you cannot trust the ECDIS. We have 54 video cameras. We have a set of different configurations that you reach through rapid-choice, and then the cameras point in particular directions, for instance the tying up configuration. With the ECDIS, you see how the ship moves. You can have a lot of settings depending on the weather. There is a lot of clutter if the sea is rough, and much disturbance in the radar image. If the radar setting is too sensitive it considers waves and anything; there are a lot of light disturbances in white and yellow. Then you can filter away these, but at the same time smaller objects as for instance small pleasure boats and buoys are filtered away. That is why even radar is never 100% correct. Radar is number one, and then comes the ECDIS. We have two radar devices, one 10 centimetres, and one 3 centimetres. What differentiates them is the wavelength. Three is good in the archipelago; it displays more details, but is also more sensitive to bad weather – too much clutter. Ten centimetres is better at sea. They supplement each other.

A3.3 Visual feedback on actions

Captain: We steer from the bridge wing. Others use cameras, a pretty static way of driving. It resembles a computer game. We never look at the joysticks; instead we stand out here and steer, and then with the bow and so on. Our way of driving is a little more fine-tuned. To have a bridge wing is most important. They have a distance measure device (landmark) that they operate to. I think it looks static when they approach the quay. We stand on the bridge wing and have thus a faster approach at tying up. The electronic chart is useful when we cross shallow waters where there are only a few meters depth below the keel. Recently it corresponds pretty well with radar and DGPS. When we cross shallow waters we only use the echo sounder and electronic chart. When it comes to the ride-control system, you know the settings that work best from experience.

Captain: We have no bridge wings. You sit in the centre of the ship and drive at all times, thereby you are depending on the information received from conning, ECDIS and video cameras, plus the distance information you receive from the sailor at the stern. If you stand on a bridge wing...
you get a three-dimensional image in your head, but all their information here is two-dimensional. It took a pretty long time before it became routine on these two-dimen-
sional images (which you find in four or five places) to build a three-dimensional image in your head to work according to. It would not have worked as well if we had not had the simulator. You have to get used to the situation today. We have learned to drive without bridge wings, but I am not sure that it has given us any speed advantages as planned. The problem is that you become entangled in a number of technical devices; you come to depend upon them and have to adapt to them. From a bridge wing, you see everything, if the visibility is not too bad. You do not need much more.

**Helmsman:** We always have a camera on the water jets – to see their direction. You can do a lot with the radar. You can get a lot of information. Here you have submenus; you have different charts to enter. You can make your own charts, enter stuff and work on it – plot buoys with symbols, lighthouses and such things. Then it is easier to spot the fairway. In the beginning, the charts were largely tailored. Now we have fixed charts on the routes; you just select 1, 2, 3 or 4, if you are approaching or departing. Complete routes are entered, waypoints and the course.

### A3.4 Layout and integration of instruments

**Captain:** We hear the engineer’s alarms, all of them. They appear on our screens and there are a lot of corny lights pointing out the concerned area. We have no idea what the alarms mean, but we hear them all the time. Then we have our own alarms on radar devices, water jets, and watertight and fireproof doors. Our alarms do not have the same priority level, whereas the engineer’s alarms are loud and of course very disturbing. If you are driving in the archipelago, the visibility is poor, and the traffic is intense – then the alarms become really annoying. They are irritating. Finally, you filter away the alarms – those that are less important. You do not hear them after a while. But you hear if there is a real alarm. We can combine radar and charts, but only as a pure source of information while we drive. Because the targets we plot are in the radar, they also occur in the chart. So we see our own ship and then all other echoes that are plotted. But it is only for pure information reasons. We always drive according to the radar. The charts are not completely correct; there is an error percentage – the result is that you can never trust them completely.

**Captain:** You have the conning and the ECDIS in front of you. The displays for buckets and nozzles are placed in the roof above you – electronics with all due respect, but it is limited; if it breaks down you must have a conventional instrument to see. That goes for RPM and vectors for nozzles and buckets. You cannot find that information in the conning display. You do not use the conning very much; it does not provide all information. I should not go as far as to say it is completely useless, but some parts are more or less interesting. These are the supplier’s own ideas. There are no standards for such screens. The idea is that you should have the ECDIS in front of you and the radar devices by the side of the ECDIS. This does not comply with how you use them. Since ECDIS is not a standard, the IMO has not been able to make a decision, and thus it has not become a primary device. To enter radar information into the ECDIS does not work. We have discussed the conning display. For instance, the latitude and longitude have an accuracy of four decimals. This is completely irrelevant. On the other hand, we have thought a good deal about entering the image here, with the gas turbine when it slows down. If we have a shutdown, we will see it immediately since the turbine becomes red – and you get an alarm.

**Helmsman:** The ergonomics of the workplace is a bit messy in my opinion. There are so many tasks. Most buttons concern the camera settings. Look here (pointing at picture)! The buttons in front are warnings related to the gas turbines. Here a red button is lit up – no warning, no nothing. We have complained about that. We want to have the alarm on the display. As it is, now you easily fail to see it. There are so many things that are lit up, and no acoustic signal, while other devices may lose signal, for instance the echo sounder. There are too many alarms here; they sound all the time. On a crossing, alarms may sound 10–15 times, anything from level alarms when we cross depth curves. Sometimes it is difficult to switch between three displays – the ECDIS, radar and conning. When you switch between displays and change things in menus, you have to let go of the steering. Regarding the radar, we have the direction here. You can set it in different modes. Here we have course-up. They have put it in head-up or north up. You can also put this in centre or off-centre mode. You always do that. Since we go so fast, nothing interesting will ever pass us. When you have north-up you always have that direction straight up on the display. Or true course, then she goes with the radar as compass. Now they have said that you should drive north-up, head-up. But that is the old-fashioned way of driving, the direction towards the stem. When you turn, the radar image moves. But more recent beliefs say that true course works better, and then you have it as a map. You drive forwards, but according to that, it may look as if we drive backwards. Many people cannot turn it around. You can also have different kinds of filtering – automatic or manual. For instance, it says gain here. There is a cable in the way. Gain between five and six – that is the force – and then you have the yellow measurement indicators here. Now you are driving in the channel. Then you have – it says CS here – and then it says A as in automatic. So there is an automatic reduction if the sea is rough and there are a lot of disturbances – then it will...
reduce. Sometimes you go into manual by then. Then you have error, rain – it is nearly always zero. If it is raining – then you can see the intensity, how much it rains. Then you can reduce the rain, so the echoes occur instead. If you look at the ECDIS, it is badly located. It should be placed in your line of sight, so you can look straightforward. The number of operations required should be as small as possible. I should have preferred to have the radar in the line of sight and the ECDIS to one side, not the way they are placed now.

A4. Controllability – the officer’s actions on the bridge

A4.1 Controlling power and getting feedback

**Captain:** The joysticks are used in separate mode rather than integrated, particularly when the weather is bad and in confined waters, when full control is required. The crews feel that they do the job better than the computer algorithms employed in integrated joystick mode. In that way they feel that they determine the heading of the ship rather than the computer. Typical expressions are, ‘better to direct the power from the hand to the water jets than leave it to the computer’.

**Captain:** In principle, they only have two modes, and it is obvious which range they are in. When you leave port, you use the joysticks, the moment button and the bow thruster. You have no special joystick mode; in plus or minus 30 degrees you have seagoing, and that is manoeuvring mode. Then the jets are directed outwards. You can enter this mode by accident, but in that case, you get an acoustic alarm; it beeps. Of course, it easily happens, I mean, you do not look down on the joystick, but it is no problem. The alarm was not installed from the beginning; we required the installation. I think the joysticks are very good, but the shape could be more ergonomic.

**Captain:** When you turn it, you turn the ship with the water jets turning in parallel. But when you pass 30 degrees (indicated by a clicking sound), something else happens. The water jets turn out, and one goes forward while the other goes backwards, which means that the ferry moves sideways. So, you have to be aware about the consequences when you go from a turn, and pass that 30 degrees click.

**Helmmsman:** When you leave the quay, you do not use the moment button, not the bow. Instead, you turn the ship a bit; you go backwards until you get lose (from hooks at the back). Then you go forward slightly, turn the joysticks to one side, and increase power. The ship moves sideways, diagonally. With the same power, you use the moment button and turn around. Release the moment button. Increase power and accelerate forward. Now you leave, very quickly. It is difficult to explain. The operations are not sweeping, only fine-tuning adjustments are required. As for instance, the bucket, earlier 3 was full bucket 1 compared to 5 as it is today. Previously it meant that you only had to touch the control lever before the ship became a wild horse; it answered immediately. Now it is a little more fine-tuned – another thing with this combination of driving, holding the joystick, steering. In addition, at the same time you must switch between different scales, plot other ships, and keep up with the navigation. I think it had been better to separate the tasks, such that steering was performed with the left hand at all times and then you can work the displays with your right hand. Then you use both hands. It should be a double function; since you have two hands, you should use them. In the beginning, it is more difficult to master the flipping and navigation functions; handling this is more difficult than steering initially. The steering is simply steering. But as it is now, it happens that you sit there and steer, and then you must shift to the trackball, or push there, or switch between the monitors and change things in the menus. Then you have to let go of the steering.

A4.2 Start-up procedure and turning over command

**Captain:** When we approach the port, we sit at the centre console until we pass the pier. Then we run the checklist and I step out on the bridge wing. We synchronise the joysticks on the wing and those at the centre consol. Then the turnover command procedure follows. I say ‘I take over’; the helmsman replies, ‘You take over’; I say ‘I’m in control’; he says, ‘You have control, the joysticks are in neutral’. The helmsman sits down at the centre console and says, ‘Helmmsman finished in the middle’. When it is time for the helmmsman to take over, I say, ‘You take over in the middle’, while pressing the transfer request button. The helmmsman answers, ‘I take over in the middle, I have control’, and I reply, ‘You have control, and then I put the joysticks in neutral’. There is a similar procedure when we have left port and reached open water. The helmmsman sits down in the middle and says, ‘Helmmsman ready in the middle’. From the wing I (the captain) request that the helmmsman take control with the transfer request button and say, ‘You take over in the middle’; he answers, ‘I take over, I have control’; I reply ‘You have control, then I put the joysticks in neutral’. When we leave the quay, I communicate with the chief engineer. When I have checked that the bow thrusters are working, I tell the engineer, ‘I clutch in’, and then I clutch in the gears. Usually the captain does the manoeuvring. When you have left the port, the helmsman takes over. You say, ‘Do you take over?’ Then he connects the controls so that he is in command in his seat. One simply says, ‘Now you take

1Ferries with water jet propulsion are powered by water flowing through pipes. The ‘bucket’ is used to regulate the amount of water flowing through a pipe and thereby determine the speed of the ferry.
Over', or 'Now you drive', and then the other takes over and says, 'OK, I have the control'. And then you try and it works. In the morning we run a checklist on all devices, including the water jets. The list is long, corresponding to that of the engineer. The engineer enters something called manoeuvring mode, i.e. he starts the help engines to get the full effect to enable the bow thruster. Just before departure we have a number of procedures to go through. You pull the joystick levers forward and hold here in position until everything is closed and you can detach the linkspan because it is the last thing that holds her back. But sometimes the helmsman and captain switch positions. Then the helmsman controls the departure. It depends on where you are seated; you can only sit and drive on one side. The manoeuvring at quay has been laid out that way. Even if there are controls on both sides, it is terribly awkward to manoeuvre with your back against. The only thing that could happen is that the handing over does not work. But you see that immediately. Then you say, 'I have not got the control'. Either the other still has it, or you have to switch to the backup system. We never discuss who should drive – there is only one switch so to speak. You have three situations, the control is in the starboard position, or the port position, or in the middle, and then the integrated joystick is in control.

**Helmsman**: We have written-down procedures for start-up and handing over command. But we do not have a checklist. In principle, the captain handles the departure, and then he hands over the command to the helmsman, who may drive all the way out. You always ask the other, 'Do you want to take over here?' and the other answers, 'Yes, I take over'. 'OK, you have control there'; 'Yes she is following', you say. You always feel that you have the control. Sometimes we speak aloud on the bridge as well; for instance, 'I turn'. It depends on the situation. If the traffic is dense, you always have this kind of conversation. You tell the other what you do, to avoid surprises. In principle, it should work equally, irrespective of the particular crew on the bridge, but I cannot promise that it works exemplary in every situation.

**A4.3 Controlling the ship**

**Captain**: When you have three water jets, you drive pretty well anyway. There is a certain amount of redundancy. But it is tricky if the weather is bad. Therefore, I cannot understand others that only have two water jets. As an officer, I find it difficult to understand how you can construct such a weakness in such an advanced system. The sensitivity to wind in the harbour increases dramatically if one water jet is out of order and the wind is strong. From experience, you know how many minutes it takes to tie up, and we are significantly faster than our competitors are. They use twice our time to tie up. The bridge wing is important here. You have the ride-control system, which is an advanced autopilot that uses large nylon fins, and the trim plane at the stern to maintain the course. If the deviation becomes too large, the jets move in and correct the course. You work with the ride-control system pretty often during a crossing to always achieve the best conditions for the passengers. Through the ride-control system, you make the ship behave as you want, assuming you have the weather and wind situation under control. You make basic settings when you enter the archipelago and set the trim plane and fins. If the ride becomes too jumpy, you pitch her down, keep the bow down and increase the roll; that is the ability to stay in the roll plan.

**Captain**: We steer equally well with one water jet as with two, but the speed decreases to 20 knots. But we also enter the red zone manning. With that procedure, you go from integrated joystick to separate joystick levers. You send over the manoeuvres; there are procedures for that too. If you are driving near the 30 degrees, you need to get the information that you turn into another mode, because the water jets behave completely different then. If the situation is difficult and the water jets start to adjust without my intention, you lose the control for a couple of seconds before they have returned to the intended position. Therefore, that alarm signal is vital. Sometimes you get a joystick failure and then you have to go down to the next level – separate joysticks. That is no problem. We use them practically every week, to keep up the skill. The joystick works so well that it is fastest and most comfortable to use; you come to use it for that reason. Others have joysticks that are complete crap; they have to use separate joysticks. I do not know what the difference is. The joystick we have is a one-off; the only one existing is this one.

**Helmsman**: The control lever in the middle is called the joystick; these two controls are integrated in that lever. They are called separate levers and each controls a water jet. If you turn the thruster knob, the water jets go (in) towards each other. One is flushing forward and the other flushes backwards, and the ship rotates around its own axis. Some officers use that, if you combine the turning of the thruster-knob at the same time as you maybe use the joystick. Then you can only use it to increase speed since the thruster overrides the joystick. Different people use them in different ways. Some want to drive forward, out with the jets and then push sideways, and then back up into the anchoring position. Others want to go forward a fair bit, and then back up directly into the anchoring position. This ship is so much easier to maneuvre than a propeller-driven ship; the water jet is so convenient. It is so easy to maneuvre and to vary. When we reach the green zone, we turn on the autopilot.
A4.4 Controlling the ship and surrounding traffic

Captain: Those who have the option for fast manoeuvring have an advantage. If your option is high speed, you can do what you want in a short time. The predisposition is that you give way to anything. If you have the slightest doubt, you call them up and tell them to maintain speed and course, and instead we will give way.

Captain: We give way to all except other high-speed ferries.

Helmsman: The harbour office tells us about surrounding traffic – arriving and departing. We have to call up the ships we catch up with and come to an agreement. We do that to make sure we know what happens, to make sure that they do not turn suddenly. If there are ships that do not appear on the electronic chart, the human eye comes into play. We use the autopilot in the green zone; otherwise, we steer manually.

Appendix B – analysis of a trip

A trip with a high-speed ferry in commuter traffic has been analysed by reviewing video recordings. The officer’s manoeuvres and visible behaviour has been noted and time stamped. The results show that a trip can be logically divided in three apparent phases – the departure, on the route and finally the arrival. The corresponding procedures and actions in each crossing are obvious from the video recording. The following section contains the notes from a crossing.

B1. Departure

59:01 Fastened safely at quay, relaxes, stretches arms over head, landing noises through loudspeaker from cargo deck.
00:39 Clear from captain to cargo deck.
01:34 Clear from cargo deck, captain confirms.
02:05 Manoeuvres slightly to check position of control joysticks.
03:29 Starts to move joysticks to straight up position.
03:43 Clear from co-pilot (at the landing), captain confirms.
04:00 The captain uses both joysticks to manoeuvre from the quay. He has assumed a position on the left side of the seat that is not completely comfortable; he is facing forward holding both hands straight to the left of his body.
04:13 Co-pilot enters the bridge, does not take the second chair, remains standing.
05:09 Turns off loudspeaker from machine, which has been very noisy and disturbing, moves joysticks to straight on position.
05:30 Moves joysticks to upright position, lets go of the left joystick, controls direction with the right joystick.

Sets himself comfortably in the chair, facing straight forward.
05:55 Releases the grip of joystick.
05:57 Puts on glasses.
06:20 Checks with his left hand that the left joystick is in upright and straightforward position. Control heading with the right joystick (with his left hand). Releases the grip completely from time to time. Starts a short conversation with co-pilot regarding other high-speed ship.
08:59 Increases speed slowly to maximum with both joysticks.
09:40 Releases the grip of both joysticks, corrects direction of one at a time, and returns to the joysticks from time to time, adapting direction.

B2. On the route

10:19 Co-pilot asks for document and gets it.
10:56 Maximum speed forward, uses right joystick to adjust direction now and then, the left hand remains on the right joystick most of the time.
12:07 Windshield wipers.
12:25 Windshield wipers.
13:55 Reduces speed temporarily, check with left hand that the left joystick is in straight on position.
14:45 Uses both joysticks to manoeuvre.
14:56 Increases speed again.
15:19 Full speed, manoeuvres with the right joystick.
16:18 Document returned from co-pilot, conversation follows.
18:34, 18:44, Checks the time.
19:00 Reduces speed temporarily, uses both joysticks to manoeuvre.
19:55 Back to full speed.
20:00 Tries to make phone call twice.
23:40 X enters the bridge, conversation.
24:40 X leaves the bridge.
25:00 Starts conversation.

B3. Arrival

27:10 Changes the grip of the joystick, all fingers forward
28:14 Approaching the next harbour. Moves to the edge of the chair to reach both joysticks more comfortably, manoeuvres actively with both joysticks.
28:29 The co-pilot leaves the bridge.
28:33 Checks the time.
28:40 Reduces speed.
29:22 Turns on loudspeaker to listen in to activities on the cargo deck, noise from landing, etc.
29:23 Intensive fine manoeuvring at quay.
30:28 Ferry fastened at quay.
30:33 Finally succeeds with phone call regarding last stop conditions, sits back and relaxes.
Appendix C – Extracts from incident reports

A few incident reports, mainly from Hong Kong Marine Department, have been examined. Next follows short extracts from the conclusions made by the investigators. The reason for adding this information is not to criticise crewmembers. Instead, we want to shed light on some of the risks involved in high-speed craft transportation as discussed in the introduction and in the conclusions.

Collision between HSC and ro-ro passenger ferry, January, 2002

As the vessels approached each other with a speed of 29 knots and 21 knots, respectively, the bridge team on the HSC assumed, incorrectly, that they would pass another with maintained course and speed.

On board the ro-ro passenger ferry, the bridge team fully expected the HSC to keep clear, because of a perceived unwritten rule that high-speed craft will keep clear of all other vessels in all scenarios. However, as the distance between the vessels decreased to 1 kilometre, they realised this might not be the case and then altered course to starboard. The master of the HSC, assuming the danger to be on his starboard side, altered course to port. The result was that the vessels collided.

This accident raised three important safety issues: firstly, to the perceived unwritten rule; secondly, how operators should determine a safe speed and close quarter situation in restricted visibility; and, thirdly, the extent to which reliance can be placed on radar for detection in restricted visibility.

Grounding of HSC, November 1999

The accident was caused by erroneous navigation. The navigators did not know the exact position of the ship when it ran aground. To a high degree the navigators neglected to use navigational equipment and established routines. Before the accident, both navigators were entangled in adjusting the settings of their radar displays, which distracted their visual observations of lighthouses and sailed course.

Collision between jetfoil and wreck, May, 1998

The cause of the accident was due to the lack of adequate monitoring of the vessel’s position with a consequent unawareness of the ship’s exact position after an alteration of course. The bridge team did not positively identify the position of the wreck nor did they positively monitor the progress of their vessel. As a result, when the master saw the fishing boat, floating debris, etc. ahead on the passage he just altered course to starboard to avoid them. He did not realise that the vessel was approaching very close to a dangerous wreck. In the final alteration of course to avoid a wooden pallet, the vessel ran over the wreck. Contributing to the situation was (a) the bridge team’s inadequate experience with the route, and (b) the superstructure of the wreck had been unknowingly cut down to the level of the sea at low tide.

Collision between catamaran and warship, August, 1996

It is considered that the major factor contributing to the collision was the failure of the HSC to observe rule 5 of the COLREGS on maintaining a proper look-out at all times. The radar sets were not operated at a range higher than 5.5 kilometres in the period leading up to the collision and the clutter controls on the set being used by the master were not properly used by him. This is considered to be a significant contributory factor in this casualty. (The warship was sighted probably at a distance between 500 and 900 metres. The master of the HSC took action to avoid collision on sighting the other vessel by putting the joystick controls to the full-astern position, but this action was taken in insufficient time to avoid collision.)

Collision between jetfoil and large floating pipeline towed by a tugboat, July, 1993

The bridge team of the jetfoil was unable to detect the pipelines being towed by the tug, or identify her as a towing vessel. Such pipelines become semisubmerged when towed and showed that the VAS (night-vision device) is not sufficiently sensitive to them in rough sea conditions. The tugboat used floodlights to illuminate the semisubmerged pipes. These were not able to illuminate the pipe adequately for them to be seen by the officers on the jetfoil, neither did they comply with the light signals for attracting attention as prescribed by international regulations. On the contrary, the floodlight confused the officers. The master mistook the tug to be a fishing vessel, which are very common on this route and regularly use their floodlights, even when they are underway and not engaged in fishing.

Near miss incident between jetfoil and mono-hull HSC, May, 1993

Jetfoil crossed the bow of the HSC with less than 100 metres distance between them. According to the master of the HSC, he saw the jetfoil fine on the starboard bow at a distance of about 200 metres. At this time there was another river trade ferry fine on his port bow and he saw the jetfoil land on her hull. The master then altered course to starboard and reported to have sounded one short blast on the whistle. The master then saw the jetfoil increase his speed and was foiled again. The jetfoil then crossed his
vessel’s bow from port to starboard within 100 metres. The master stopped the engine of the HSC when he saw the jetfoil speed up and was foil borne again.

**Collision between two mono-hull HSC, March, 1988**

Fog restricted the visibility to about 900 meters. Both vessels were proceeding at an unsafe speed in the prevailing circumstances and conditions. Both masters were not fully conversant with the operation and capabilities of the vessel in their charge. In particular, they were not aware of procedures to achieve minimum speed or to execute an emergency stop. The masters of both vessels had very little knowledge of the safe operations and use of radar, including its limitations.

**Incident, September, 1987**

Joysticks were not synchronised when changing from common (integrated) to separate control mode.