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# **Joint Cognitive Systems at Sea: A Study of High Speed Craft Operation**

Thesis for the degree philosophiae doctor

Trondheim, June 2007

Norwegian University of Science and Technology  
Faculty of Social Sciences and Technology Management  
Department of Psychology



**NTNU**

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## **Executive summary**

This thesis presents a philosophical, theoretical, practical and methodological discussion of the relationship between humans and technology in relation to technically assisted movement. The themes are investigated in five articles. In particular, the philosophical foundation of different perspectives on the relationship between humans and technology are discussed with a special emphasis on movement. The thesis then proceeds to present a case study of high-speed crafts in military service. The empirical data is gathered through the use of participatory observation. The operation of this type of ship is characterised by hazardous and uncertain conditions. High speed craft operation is considered very demanding for the navigators in terms of maintaining safety and efficiency. The observation accumulated over 120 hours of video recorded material of the crew during ship operation. This serves as a basis for a discussion and explication of specific theoretical frameworks for conceptual modelling of ship manoeuvring, as well as design of prototypes of new technological artefacts intended for the operation of the ship class. Further, this thesis addresses the issue of methodological challenges when studying elaborate human-technology systems by discussing the use of video in field observation.



## Article overview

### Article I:

Øvergård, K. I., Bjørkli, C. A. and Hoff, T. (In press). The Bodily Basis of Control in Technically Aided Movement. Technical Spaces of Mobility: Essays on the Planning, Ethics, Engineering and Religion of Human Motion. S. Bergmann, Hoff, T. and Sager, T. London, UK, Equinox Publishing: xx-xx.

### Article II:

Bjørkli, C. A., Øvergård, K. I., Røed, B. K. and Hoff, T. (2007). "Control Situations in high-speed craft operation." Cognition Technology and Work. 9(2) 67-80

### Article III:

Bjørkli, C. A., Røed, B. K. and Hoff, T. (In review). "An Activity Theory Analysis of High-speed Craft Operation." Computer Supported Cooperative Work.

### Article IV:

Bjørkli, C. A., Røed, B. K., Gould, K. S. and Hoff, T. (2007). "Activity theory as a supportive framework in design of navigation equipment." Activites: Revue Electronique 4(1) 179-187.

### Article V:

Bjørkli, C. A., Røed, B. K., Gould, K. S. and Hoff, T. (In review). "Using video in field observation: A case study." Cognition, Technology & Work.



## **Preface**

This thesis is the result of research conducted in collaboration with fellow researchers that I have had the honour of working together with. The thesis consists of five articles and an introduction presenting the association between them.

The introductory chapter outlines the perspective taken in the approach to human-technology systems in this thesis. Special emphasis is given to human-technology systems associated with transport, and the domain of maritime transport is introduced.

Article I presents the philosophical and theoretical basis for understanding human-technology systems with emphasis on how technically aided movement may be approached. This article is written in collaboration with two co-authors, where my contribution was theoretical contents and secondary writing.

Article II presents a development and application of the control situation framework originally formulated by Petersen (2004) to the domain of high-speed craft navigation and manoeuvring in military service. The article is written in collaboration with three co-authors, where my contribution is theoretical content, data collection, analysis, and primary writing.

Article III presents a cultural historical analysis of activity (AT) of high-speed craft operation in military service. The article is written in collaboration with two co-authors, where my contribution was theoretical contents, data collection, analysis, and primary writing.

Article IV presents a design process based on the analysis presented in Article III. A design mock-up of a course- and track pilot is described. The article is written in cooperation with three co-authors, where my contribution was theoretical content, participation in the design workshop, workshop documentation, and secondary writing.

Article V describe and discuss the use of video in field observations with special emphasis on observing Joint Cognitive Systems (JCS). The use of video is described as stages of refinement and elaboration, and a case study of observing high-speed crafts in military service provides empirical examples. The article is written in collaboration with three co-authors, where my contribution was theoretical content, participation in field studies, handling of video technology, analysis, and primary writing.



# 1 Introduction

## *1.1 The Emergence of Human-Technology Systems*

The synthesis of human operators and technology into functional systems has a rather short history, but an elaborate past. Humans have from our earliest origins applied tools and primitive technologies, but the last hundred years have shown a remarkable development of the relationship between humans and artefacts. Flach (2000) outlines the short, but condensed development during the past century during which the human capacity for work has undergone vast changes.

The first efforts in modern time to coordinate humans and machines emphasised the rationalization of human effort through detailed work procedures in pair with mechanical machines (Taylor 1911). However, the perspectives on human-technology interaction were soon challenged as the nature of work changed from primarily physical labour to more cognitively mediated work. The Second World War spurred a ‘technological sprint’ involving a rapid development of weapons and defences. For example, airplanes exemplified a qualitatively different setting for workers. The pilots were embedded in a technological context (the aircraft and cockpit) that placed demands on the subjective understanding of the system in a quite different way than workers at the assembly line of the Ford factories. The key to efficiency and skilled operation shifted from physical strength to cognitive skills. Here, accidents and incidents seldom originated in lack of physical strength, but rather in lack of understanding of the system – exemplified by accidents where fully functional airplanes crashed into the ground. The research paradigm of American researchers Fitts and Jones established human performance and technology as a defining theme of human factors (Fitts and Jones 1947; Flach 2000).

Since the era of Fitts and Jones, the last fifty years of technological development have accentuated integration and entwinement of humans and technology into unitary synthesis able of coordinating vast physical forces and informational streams, and this

new synthesis is by many labelled as ‘complex sociotechnical systems’ (Dörner 1996; Casey 1998; Perrow 1999). The classic examples of modern complex systems are control rooms, air traffic control, electric grid management, offshore installations, stock market exchange, railway systems, personal vehicles and traffic structures, and nuclear power compounds.

The theories and perspectives on the handling of complex human-technology systems have changed in many ways during this period. It has become clear that we have created systems that hold qualities not foreseen in formal engineering and design. There is a widespread consensus today that the characterisation of complex systems should include descriptions of the entire system behaviour that emphasise the non-linear and dynamic aspects of system operation (Woods 1988; Rasmussen 1997; Vicente 1999; Hollnagel and Woods 2005; Woods and Hollnagel 2006). The patterns of work in complex systems reveal features such as abrupt changes in tempo and rhythm of operation, intermingled and cascading effects, progressive escalation from routine to non-routine situations, unexpected coupling between subcomponents, automation surprises, uncertain data sets, and changing temporal constraints (Norros 2004; Woods and Hollnagel 2006).

A central feature of modern societies is the deep integration of complex sociotechnical systems in the constitution and functioning of social structures such as economy, transport, military operations, and politics (Kallinikos 2005). This implies a deep-rooted dependence on the safe, efficient and productive operation of these systems.

The modern human-technology unity based on the constellation of operators and artefacts yield functional entities that demand extensive coordinative and regulative measures to be taken. However, the challenge is that the establishment of coordination and control in complex systems evades much of the theories provided by classical psychology and engineering (Vicente 1999; Hollnagel 2004). The explanatory deficiency often become lucid in accident investigation of failed operation of complex systems in which the inclusion of characteristic features of the interaction between system and context in question is difficult to come to terms with (Dekker 2005; Le Coze, Salvi and Gaston 2006). Here, the ‘modern accidents’ indicate that the

relationship between humans and technology in complex systems have changed drastically since the early studies of workers at the assembly line. We now are faced with entities that override our previous most basic assumptions of the division of labour between humans and machines. Complex sociotechnical systems may thus be understood as the articulation of the profound question of how humans relate to our surrounding world.

It seems that the clear-cut distinction between the living organisms and material objects is at least debatable. A wide range of studies of tool-use in both human and non-human organisms within anthropology, psychology, neurobiology, and zoology propose that material objects have a twilight status – they are on one hand a material part of the world in terms of having physical extension and being subjected to laws of physics. At the same time, they are deeply integrated in the human experience of the world (Ingold 2000; Johnson-Frey 2004; Laeng, Brennen, Johannesen, Holmen and Elvestad 2004; Maravita and Iriki 2004; Lewis 2006). These studies suggest that, in a deep sense, we live with and through objects. It is further indicated that the relationship between an organism and tools is somewhat open-ended, as the use of tools is not just moving physical matter around (e.g. weaving a stick). It seems like tool-use entails some form of integration of the tool into the body schemata of the organism and that it further structures the way the organism relates to the world (e.g. a blind person orienting herself).

However, the emergence of complex sociotechnical systems represents an elaborate form of tool-use, that is, when technology and tools become not just single material objects used by a person, but entire technological contexts in which the organisms (read: workers) experiences the world through. This suggests a deep integration of humans in technology - and vice versa (Ihde 1983; Clark 2003). Here, the capacities of the organism are extended into the immediate objects and interfaces, but the world also changes character through its appearance ‘filtered’ by technology.

The modern complex systems, such as the control rooms and airplanes and offshore installations, represent the construction of technological contexts that removes the operator from the immediate and direct presence in the world into a state of elaborate mediation. The technological context becomes an ‘experiential veil’ between the

human and the world (Ihde 1983; Mitcham 1994). However, the nature of this ‘veil’ is somewhat dual. Norros (2004) argues that work characterised by technological mediation becomes both increasingly physically remote, but at the same time this mediation invites the operator deeper into work in terms of richer information and elaborate abstraction. Hence, technology enters between the operator and the given environment where work takes place, and mediates the relevant features of it by way of formal representations and higher order relationships. For example, traditional radars aboard ships or aircrafts represent the surroundings in simplified 2D graphics. Here, the environment takes the form of a representation in terms of numbers and simplified shapes, thus reducing and removing the operator from the context. Yet, the environment becomes richer in terms of information (for more examples of higher order representations, see Burns and Hajdukiewicz (2004)). Technology opens up the context in new ways as the operator experiences the world through technology.

This ‘heideggerian’ line of reasoning emphasises the active engagement of the organism in the world through tools, where the non-perceivable context becomes perceivable and the perceivable becomes obscured (Fløistad 1993; Ingold 2000; Dreyfus and Wrathall 2005). Technological mediation may here be understood as a form of restructuring of the experience of the environment for the operator - giving rise to a new form of habitat for humans. Complex sociotechnical systems then emerge as novel technological habitats constructed for some specific purpose (e.g. power management, oil production, economic trade)<sup>1</sup>. Researchers within the field of cognitive engineering (CE) may thus be regarded as occupied with the ecology of human–technology systems as they focus on the challenges associated with the introduction of new technology into complex sociotechnical systems (Flach, Hancock, Caird and Vicente 1994; Vicente 1994; Woods and Dekker 2001; Hoff 2004).

Vicente (1994) discusses the consequences of regarding complex sociotechnical system as ecological systems, and argues that one of the main implications is that the unit of analysis in human factors changes from the behaviour and characteristics of single operators to the reciprocally coupled contextual embedded human-technology

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<sup>1</sup> The term ‘habitat’ is here used to label a context description that is closely tied to the intention and structuring of action of the organism. For a further discussion, see Ingold (2000) and his discussion of the term by reference to von Uexküll.

system. Central to the coupling of humans and technology into a functional system is the description of the environment in relevance to system goals. This means asking questions regarding what the features of the surroundings are that bears relevance to the goal at hand for the human-technology system. Here, the concepts of ‘*affordances*’ and ‘*constraints*’<sup>2</sup> are central to establishing the reciprocal coupling (Rasmussen, Pejtersen and Goodstein 1994; Ingold 2000; Albrechtsen, Andersen, Bødker and Pejtersen 2001; Vicente 2003). These concepts emphasise the connection between a controlled process and the human-technology habitat in question. The functional entity of a goal-oriented human-technology system unfolds in correspondence with some external, physical reality (e.g. flow electricity in electrical grids, underground oil pressure during drilling operations, wind and weather during flying, etc). These external (or environmental) constraints exist independent and apart of any belief or preconception of the operators.

Complex sociotechnical systems may thus be regarded as ‘correspondence-driven systems’ as it adapts to an outside process (Vicente 1999). Oppositely, coherence-driven work defines the human-technology dyads that do not have take an external reality into account – for example gaming consoles, driving simulators, board games or computerized word-processors. In closed, coherence-driven systems, the fit between the user and the artefact can be fine tuned in accordance to the cognitive and perceptual characteristics of the user. In correspondence-driven systems, however, there are constant disturbances and variation in system performance. In this case, there are two sets of constraints to respect: the environmental/operational constraints and the cognitive/perceptual constraints of the operators, and the fit between these two are shaping the conditions for performance.

The reason for making the effort to distinguish between the unit of analysis and its relationship to the context is rooted in the need for attributing complexity and origin of patterns correctly. Simon (1981) described a now widely cited example of the problem of tracing the generating mechanism for the movement patterns of an ant walking about on a beach. The example illustrates that a detailed geometrical

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<sup>2</sup> The concepts *affordances* and *constraints* are here used in reference to their use within human factors research as exemplified by Flach (1994) or Albrechtsen et al (2001) or Norros (2004). See references for a full discussion of the definition and contents of the terms.

description of the movement path of the ant yields a highly complex pattern and widespread irregularity. To look for the generating mechanism of this complexity within the ant (the ant brain, preferably) is arguably a faulty attribution of the origin of complexity in which the contextual features (surface and terrain of the beach) are left out.

Beyond this rhetorical example, other researchers have shown this principle empirically. Thelen and Smith (1994) summarise several studies of motor development in children and non-human organisms. The intriguing process of both human and non-human organisms learning to walk left researchers to search for detailed 'motor programmes' located in the host organism, either in form of cognitive schemata (Zelazo 1984), genetic coding (Forssberg 1985) or neural maturation (Konner 1991). Conversely, Thelen and colleagues describes several studies where the change of context conditions changes the motor skill level and granularity of walking movement. For example in human motor learning, babies held torso-deep in water showed stepping movement long before being able to walk and thus forestall their present motor developmental stage. Further, the babies failed to express stepping movement when they were added weight to their lower legs and joints in the same water condition. When held on to a treadmill, the babies showed coordinated walking movements assumingly way ahead of their motor development. In non-human motor learning, studies have shown movements in hatching chickens that are characterized by synchronous thrusting with both legs. When ready hatched, this specific type of movement normally disappears and is not expressed again. However, the hatching movement may be elicited by subjecting the chicken to conditions similar to the hatching situation. Subjugated to a treadmill, 'motor premature' chickens, cats, and frogs all showed proper coordinated locomotive movement.

The interesting implication of the motor studies described by Thelen and colleagues is that movement do not seem to origin from some complex inner structure, but as a result of the dialogue between the biomechanical constitution of the moving organism and the context specifics. The layout of limbs and joints will display advanced coordination 'prematurely' if provided the sufficient conditions. The underlying argument is that behavioural output should not be understood isolated from the behavioural situation in which it occurs.

The link between hatching chickens and operator performance in complex sociotechnical systems may seem somewhat far-fetched. However, Vicente (1999) comments on the similarity between motor control development and performance of complex sociotechnical systems, and writes:

*“... these parallels lead to viewing the control of the human motor system and the control of complex sociotechnical systems as both involving the coordination of many degrees of freedom by a resource-limited agent (or agents)”*

(Vicente 1999).

The emphasis on coordination of degrees of freedom prerequisites some form of description of the context structures and agents involved. So far, I have argued for the change of unit of analysis from the single operator to functional human-technology systems, and pointed to the concepts of affordance and constraints as examples of operative context denotations. The implicit line of reasoning here aims at specifying the ‘limbs and joints’ of complex systems and the relevant context when describing complex and coordinated behaviour in human-technology systems. Here, several authors have launched the issue of the coordination of the degrees of freedom rising from the operation of a complex sociotechnical system in a goal-relevant context as the key feature of human factors research (Rasmussen 1990; Hollnagel 1992; Norros and Savioja 2002; Jagacinski and Flach 2003).

Vicente (1994) imports the argument of Thelen and Smith (1994) into human factors by stating that the pattern-generating mechanisms must be understood only in reference to the contextual layout. He quotes Neisser (1987):

*“If we do not have a good account of the information that perceivers are actually using, our hypothetical models of their information processing are almost sure to be wrong. If we do have such an account, however, such models may turn out to be almost unnecessary”.*

(Neisser 1987)

Still, the explanatory value of perceptual information or field descriptions diminishes to the extent that the organism is faced with unfamiliar and unanticipated situations and/or underspecified perceptual information. Instead, the more cognitive founded

processes come into play. This means that to the extent of information and access to the context is unclear, irregular, and uncertain – performance is not only the perception and action in accordance to a structured context. Uncertainty calls for reflection and understanding as basis for performance. And this seems to exactly be the case for complex sociotechnical systems – operators are constantly subjected to uncertainty, dynamism and complexity (Vicente 1999; Norros 2004; Woods and Hollnagel 2006). So, coordination of multiple degrees also concerns the problem of assessing the ‘number’ of degrees of freedom and the significance of them, in addition to the actual performance under such conditions (Rasmussen 1990).

This brings the theme of how operators manage to stay in control of a dynamic process that is constantly challenged by disturbances and uncertainties to the front stage of human factors research. Further, the description of system behaviour, operator adaptation, and multiple frames of reference for work practice become important areas of interest.

This perspective marks a changing paradigm for understanding human-technology systems. It completes the transition from the ‘single operator’ focus to the Joint Cognitive Systems approach (Hollnagel and Woods 2005).

### ***1.2 Joint Cognitive Systems: Adaptation and Control***

The label Joint Cognitive Systems (JCS) refers to human-technology systems that are characterised by technological mediation of work in a complex and dynamic work process (Woods and Hollnagel 2006). This perspective is semantically equivalent to the term complex sociotechnical systems (Vicente 1999)<sup>3</sup>, but emphasises the nature of coordination, adaptation, control and resilience of goal-oriented human-technology performance in a constantly changing context.

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<sup>3</sup> The terms Joint Cognitive Systems (JCS) and complex sociotechnical systems will be used interchangeably in this thesis. For a nuanced discussion of the two concepts, see Woods and Hollnagel (2006) and Vicente (1999).



JCS is understood as a constellation of humans and technology in which the functional coagency forms a cognitive system that “*modifies its behaviour on the basis of experience so as to achieve specific anti-entropic ends*” (Hollnagel and Woods 2005). The term ‘anti-entropic’ is imported from thermodynamics, and emphasises how JCS are able to resist disturbances and disorder, and sustain task integrity. An anti-entropic system stays intact despite disruptions, meaning that the performance of JCS in question can counteract forces and disturbances that seek to bring it out of stability or chosen state (Swenson 2000). For example, an aircraft can maintain its course despite side winds and/or poor visual conditions.

Human factors researchers focus on JCS in terms of *what* the system does and *how* it is achieved. In line with the formative approach described by Vicente (1999), the JCS perspective focus on how operators find themselves amidst the clash between work demands and the resources available. This is what Woods and Hollnagel (2006) emphasises when they define successful performance in terms of adaptive control where the ability to adapt relies in anticipating variability and thus cope with complexity.

### ***1.3 JCS and Transport: Maritime Domain***

Traditionally, studies of JCS have been oriented towards stationary installations such as control rooms, hospitals, power plants, stock markets, etc. The dynamics that unfolds is tied to the process controlled (nuclear fission, health care, oil drilling, economical fluctuations, etc). Similarly, moving human-technology systems also qualify as JCS (Burns and Hajdukiewicz 2004). Advanced transport systems have high levels of automation, multiple operators, uncertain datasets, distributed systems, and other characteristics central to JCS (Perrow 1999; Vicente 1999). Dynamics in transport systems have been traced to the fact that the system moves across different contexts and through its surroundings – leaving movement itself as the process to be controlled (Petersen and Nielsen 2001). This shapes the challenges encountered by human factors researchers as the dynamics of the controlled process in transport of movement is tied to the interaction between environment and the technological

components serving the motion. This gives rise to a number of novel human factors issues regarding safe and efficient transport.

Beyond aviation, which long have been recognized as full-fledged JCS, other domains of transport have become an interesting field of studies for human factors researchers during the latter years. Examples of complex transport systems are personal vehicles (Cacciabue 2005) and trains (Wilson, Norris, Clarke and Mills 2005).

Lutzhof (2004) argues that the maritime domain is currently experiencing a widespread technological development and rapid change. Aspects tied to ships, traffic control centres, ship crew, and pilots are all subjugated to an ‘upgrade’ and renewal, and central to this change process is the application of new technological artefacts – first and foremost information and communication technology (ICT). There are primarily two trends here. First, traditional systems are being digitalised. For example, paper charts are now available as electronic charts. Mechanical rudder control is replaced by hydraulic systems controlled by a joystick. Secondly, previously separate systems are coupled together in integrated systems, where the same control panels serve several subsystems, such as radar, charts, engine power, and the global positioning system. Here, the control panels of integrated systems basically consist of a computer screen, mouse, joystick and keyboard. The previous physically separate systems are transformed into generic ICT interfaces and generic buttons and sticks.

How does this development affect the nature of maritime operations? Research and theories argue that technological change necessarily also change the nature of the task (Carroll, Kellogg and Rosson 1991; Woods and Dekker 2001). Technological change reverberates into details of work practice, changing the way the practitioners solve their tasks and how they express their skills. It is fair to say that the vast and rapid change within the maritime domain will affect how mariners work and how they maintain, express, and develop their skills

The first reports on the effects of integrated bridges have been published, indicating a number of adverse effects. The studies invoke different explanations for the observed

effects, such as ‘increase in human error’ (Mills 2006), or the increased need to adapt to the new conditions for skill expression set by the new technology (Lutzhof 2004).

This thesis aims to look further into the implications of studying transport systems from the JCS perspective in which maritime transport is chosen as the case study.

#### ***1.4 High-speed Crafts***

High-speed Crafts (HSC) refers to a class of vessels that are characterised by the combination of light ship constructions and the ability to maintain manoeuvre abilities while holding high speed. The formal definition states that a high-speed craft is a craft capable of maximum speed measured in meters per second (m/s), equal to or exceeding  $3.7\sqrt{\nabla}^{0.1667}$  where,  $\nabla$  = Volume of displacement corresponding to the design waterline (m<sup>3</sup>) (Kjerstad 2003). The speed and manoeuvrability makes HSC suitable for operating in in-shore regions in both commercial and military service. This vessel class is operated by two to five crewmembers that are responsible for navigation and manoeuvring the ship. Navigation entails determining position and knowing where to sail, whereas manoeuvring refers to the steering of the ship.

HSC is no exception to the technological push within maritime transport. ICT based integrated systems are being developed across the industry, and are being exported into work practices of mariners in an intriguing tempo where radars, electronic charts, global positioning system, automatic engine control, auto- and trackpilots coagulate on the ship bridge.

#### ***1.5 HSC in military service***

HSC used in the Norwegian Royal Navy is labelled Fast Patrol Boats (FPB) and has during peacetime the formal tasks of upholding national presence along the inshore coastline of Norway and maintain national sovereignty. The FPB also assist civil authorities and participate in search-and-rescue operations. In times of tensions, the FPB is involved in the early stage of the crisis given its high mobility and inshore

operation expertise. The vessel class also participates in multinational military forces, such as UN or NATO operations.



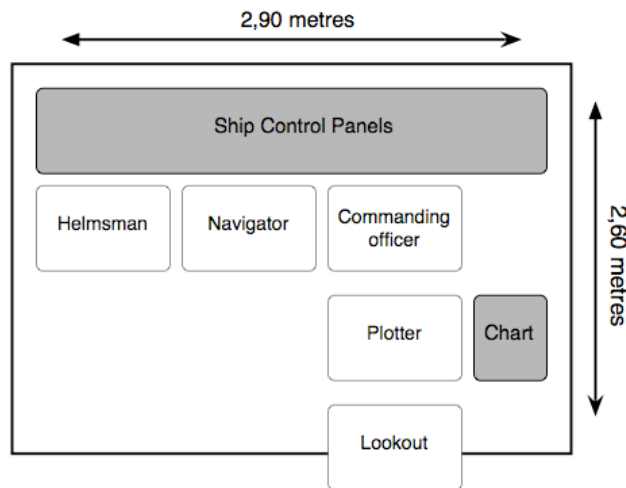
**Figure 1: A fast patrolling boat (FPB) in the Norwegian Royal Navy**

The nature of the formal tasks gives rise to a number of characteristics of ship operation, such as

- variable traffic (remote waters versus port areas)
- confined and open waters (inshore versus open sea/fjords)
- high flexibility demands (often change in plans and ad-hoc tasks)
- uncertain data (incomplete charts, GPS inaccuracies)
- ship automation (engine control)
- long work shifts (10-16 hours)
- diverse weather conditions (blue skies versus heavy snow/fog/or rain)
- little error tolerance (inshore waters and high efficiency demands)

The FPB employed by the Norwegian Royal Navy is referred to as the Hauk-class. A crew of 25 persons operates the ship. Five are involved in navigation and manoeuvring. These are as follows: The commanding officer (CO) has the overall responsibility of operational and strategic tasks of the ship. The navigator has the responsibility of taking the ship to its designated destinations by way of navigation and manoeuvring decisions. The plotter handles the charts and supports the navigator in navigation. The helmsman handles the wheel, and steers the ship on the command

of the navigator. The outlook is positioned outside the ship bridge to visually monitor the surroundings and reports to the navigator. This crew of five persons together serves the navigation and manoeuvring of the Hawk-class vessels.



**Figure 2: Overview of ship bridge with crew positions**

The technical data of the Hawk-class outlines a classical HSC configuration. The ship has a displacement weight of 150 tons, is 36.5 metres long, the beam is 6,5 metres and the height of 14,2 metres. The propulsion systems contain two engines of 3600HP each, giving a total of 7200HP. The ship uses a twin-rudder system regulates steering movement. The top speed is approximately 30 knots given optimal conditions, and is reached from standstill in about 2 minutes. The ship equally spend about 2 minutes from top speed to standstill over 0,8 nautical miles. In emergencies, a standstill can be reached in 32 second over 310 metres, a procedure that severely strains the machinery and is thus very seldom used.

The Hawk-class vessels are arguably understood as JCS based on the details of operational instructions and technical configuration. The issue of modelling navigation and manoeuvring, as well as discussion the effects of technological innovation, are thus suitable for the JCS perspective.

### ***1.6 FBS operation: Navigation and manoeuvring***

To paraphrase Simon (1981) – viewed as a geometrical figure, the trajectory of the FPB is irregular, complex and hard to describe as the ships traverse the inshore coastline and local archipelagos. The movement can on one hand be described as a line defined by lengths and angles. On the other hand, the ship movement has a distinct purpose and inherent qualities – the ship is on its way somewhere specific, and it moves safely and efficiently, in the sense that it seeks to reach the destination in time without hitting land or come in conflict with other objects along the way.

Conceptually, FPB movement consist of navigation and manoeuvring<sup>4</sup>. The navigator always prepare an upcoming journey before departure by planning the detailed track and he or she physically draws the course lines and turn points into the sea chart. After leaving port, the navigator executes the plan by choosing appropriate speed and ordering specific rudder angles for the helmsman to steer. The plotter helps the navigator by verbally reporting details from the map. The navigator continuously strives to combine observations of the surroundings to determine and confirm the ship position, and compares this to the plan in the chart. Sometimes the Commanding Officer intervenes with extra information or correcting commands, or the lookout reports on other vessels approaching, objects floating in the sea, or other events relevant for navigation and manoeuvring.

The neat distinction between navigation and manoeuvring quickly becomes blurred as the ship seldom or never is exactly on track. In demanding periods, the navigator handles the disturbances and deviations in terms of course corrections while coping with uncertainty in position determination. Performance oscillates between doing and thinking, and the planned track is not merely ‘implemented’ into the technical system in the sense that the track is ‘executed’. It is rather a question of adaptation and control in face of disturbances and uncertainty.

Where should we look for the mechanisms generating an adaptive movement of a human-technology artefact of 150 redundant tons doing 32 knots in between sunken rocks and along narrow passages? The Law of Fluency offered by Woods and Hollnagel (2006) states that “ ... *well-adapted work occurs with a facility that belies*

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<sup>4</sup> Navigation refers to the determination, plotting and planning of upcoming ship position. Manoeuvring refers to the steering of the ship, preferably in relation to navigation.

*the difficulty of the demands resolved and dilemmas balanced*". This suggests that we should specify the demands that rise together with the dilemmas occurring when coping with those tasks. This means asking what demands are the ship relating to? What means of action and control are available? What dilemma rise<sup>5</sup>?

On one hand, the detailed layouts of waters they sail represent part of the demands for movement. Depth, sunken reefs, rocks and seamarks are indicators of the specifics of the waters, and are all part of the work domain constraints (Vicente 1999). However, the 'objective' layout of waters does not have equal significance to all ship classes. Dependent upon the ship construction, some waters are sailable while others are not. This means that the work domain constraints specify the *functional waters* for the ships, and thus the demands for where to manoeuvre the ship and not.

On the other hand, parts of the demands originate from the task at hand. FPB operates under the generally formulated instruction of patrolling the coastline and upholding national presence. However, this general task formulation is broken down into concrete operations, where the ship crew approach the formal task and transform it to specific journeys. This means extrapolating concrete tracks to sail. (LePlat 2006) describes this process of task transformation as the transition from the task prescribed to how the task is understood by the operator and further how it is redefined and finally realized.

The demands are thus twofold – first, there are the constraints in the work environment (functional waters), and secondly, there are demands rising from organisational and strategical decisions.

What LePlat labels as the 'task truly realized' may be understood as the pairing of resources with the demands, and echoes the Law of Fluency in that demands often involves dilemmas and lacks a clear-cut solution. The task truly realized is the functioning of the practitioners in the given field of study and how they configure the artefact in order to balance the demands and resources.

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<sup>5</sup> For a more elaborate description and discussion of demands and resources, see (Vicente 1999) and his choice of conceptual distinctions (e.g. p.111).

For the navigator aboard the FPB, this concerns the decision of what parts of the waters that are sailable given the destination, and what margins of safety to maintain during operation as opposed to prioritizing efficiency. The navigator seeks towards being efficient in terms of taking advantage of the sailable waters available (e.g. the shortest way through a region). At the same time, the navigator must maintain safety, that is, being able to avoid conflict with contextual dangers (land, rocks, other vessels, etc). The dilemma is that safety and efficiency entails quite different strategies.

### ***1.7 Previous research on high-speed crafts***

There has been relatively little previous research on the operation of HCS or FPB specifically. The studies related to maritime domain have covered areas such as use of simulator in training and interface evaluation (Hockey, Healy, Crawshaw, Wastell and Sauer 2003; Donderi, Mercer, Hong and Skinner 2004), survey-studies of HSC operation (Kjerstad 2003), use of automation in operation and traffic monitoring (Lozano, Corbera and Xavier Martinez de Oses 2000; Lutzhoft and Dekker 2002; Mills 2005), usability of maritime equipment (Dobbins and Samway 2002; Mills 2006), Cognitive Work Analysis and design in the HSC domain (Erlandsson 2006), egocentric representation of sea charts (Porathe 2006a), and performance shaping factors in FPB accidents and incidents (Gould, Røed, Koefoed, Bridger and Moen 2006).

### ***1.8 Problem formulation***

The central theme in this thesis addresses the issue of technologically aided movement. The thesis asks how technology set the premise for human movement, and more specifically, how technology enables humans to be in control of their movement and thus express functional movement. This issue relates to the use of technology within transport, where the configuration of human-technology interaction assumes a certain staged mobility with designated roles of human agents and technological artefacts.



This thesis investigates the issues of moving JCS and offers a philosophical, theoretical, practical, and methodological discussion. It does so by entering HSC operation in a military setting in situ – that is – getting close up to the actual operation of FPB under real performance. The observation of FPB operation was recorded on video, and accumulated 120 hours of material. The participating observation implied watching the crew and ship during naval exercises and training. The participation is central to the explication of theoretical frameworks for understanding ship operation, in which operation is closely tied to how movement is controlled and anticipated by the mariners. Based on observation and derived theories, a range of design mock-ups are presented. Further, this thesis seeks to contrast close-up observation and design with a philosophical discussion of the nature of the relationship between humans and technology in the creation of movement.

The problem formulation underlying the range of contents in this thesis aims at clarifying our understanding of movement assisted by technology: How can we improve safety and efficiency of movement in transport human-technology systems?

The following section discusses the research perspective for approaching the problem formulation, and is followed by comments on the articles included in the thesis.

## 2 Research Perspective

### 2.1 *Observing JCS: Participation and abstraction*

The purpose of JCS research is to acquire valid and scientific knowledge about the given domain and/or problem area. A central tenet of the study of JCS is the precedence of observation to theorizing (Woods and Hollnagel 2006). This implies that observation forms the basis for the eventual theoretical concepts and systems we wish to apply. Moreover, the JCS perspective emphasises observation *in situ*, that is, at the time and location where the phenomena of interest takes place – in the cockpit during flight, in control rooms during operation, and in actual ship bridges during sailing.

Woods and Hollnagel (2006) notes that *authenticity* is a crucial factor in which the relevance and ‘realness’ of observation is questioned. The observed JCS performance should be as close as (or preferably identical) to how the system performs in everyday operation. This involves shaping the conditions of observation so that the samples acquired are as close as possible to the natural unfolding of JCS dynamics.

Examples of shaping conditions of observation are prolonged time for observation, choice of tools/measures used to observe, and establishing an alliance with the operators (Lutzhof and Koester 2006; Woods and Hollnagel 2006).

Whereas participation serves as gaining insight into the actual JCS performance, the researcher need to avoid being blinded by the details of the system studied. This refers to the principle of observations never being disconnected from some conception of what we are observing. Our concepts and linguistic classifications contribute to how structure what we see, and the activity of participation should be reflecting upon how we develop concepts and rationales for what we observe. This means that as well as participating in the JCS in action, there should be a simultaneous self-reflective activity in which the current understanding is monitored. The balance here relates to how well we manage to observe without imposing structure on the observed

phenomenon versus being able to abstract the patterns underlying the detailed unfolding of work. The complementarity between participation and abstraction remains the centre of the observation in the study of JCS (Woods and Christoffersen 2002).

## **2.2 Demarcation of relevant data in observation**

The observation of JCS performance in terms of participation and observation soon becomes confronted with the need to specify criteria for what situations to observe and what indicators that describes them. This means that the human factors researcher must explicitly state what part and what behaviour of a given system he or she is interested in, and develop a set of classifications to account for the observed events (Dekker 2002; Norros and Savioja 2002; Hollnagel and Woods 2005). The challenge here is that due to the complexity and distributed aspects of JCS, the demarcation of relevant data becomes cumbersome as most part of performance involves a complex web of interactions between of numerous technical components and human agents.

On one hand, failure to specify measures and provide definite description of the measurement undermines observation. Hollnagel and Woods (2005) write that

*“A measurement is an expression (...) of the value of a system parameter or characteristic (...) at a given point in time or for a known duration. That which is measured must obviously be describable by the classification scheme and the definition of the measurement must be based on a model, which describes what the essential aspects of performance are and which therefore constrains what can be measured.”*

(Hollnagel and Woods 2005).

Here, underspecified measures and observation yield flawed data, or at least ‘unconstructive’ data. On the other hand, the difficulty of specifying observation in advance must also be seen in light of what phase the research project is in at the given moment. Robson (2002) argues that observation may have several functions in a study. For example, the *exploratory phase* of a study aims at orienting the research in terms of basic structure and dynamics, and proceeds to suggest that so-called non-obtrusive observation might be an apt choice. Here, the lack of clear-cut definition of

measurement is not critical. As long as the enquiry motivating the observation and study is openly and broadly formulated, the level of precision of measures might be equally open-ended. However, some form of progression towards more focused observation and measures is implicit in this line of reasoning. The Practice-Centred Approach offered by Woods and colleagues seem to concur in the sense that it emphasises iteration between participation and abstraction where the abstractions become increasingly elaborate and detailed. The Real World Research approach by Robson also includes this idea of progression as the process of analytic induction where rough definitions guide observation that then leads to formulation of an initial hypothesis of the phenomenon. Further observation serves to refine either the hypothesis or redefine the phenomenon to exclusion.

The stance in philosophy of science that the researcher applies when entering observation has relevance for the significance of the varying degrees of precision of measurement. (Mjøset, Unpublished work) differentiates between types of theory in social sciences, where the pragmatist approach outlines research that is primarily oriented to cases and to the creation of explanation based knowledge. This implies that the emphasis is on explaining the given case, and intervening to solve the problem motivating the study. The pragmatist approach is generally sceptical towards knowledge that is separated from its case origin (e.g. universal laws across unique contexts). The progression of science is thus regarded as the accumulation of different case explanations and the associated change processes in society or problem domain. The pragmatist perspective is contrasted by the so-called 'standard view' known from the natural sciences such as physics, biology, and chemistry. Here, researchers aims at interpreting the observed by reference to an abstract structure, preferably in logical or mathematical terms. This means that science progresses by completing the system of relations between theoretical entities representing the inherent structure of the observed. It is a form of scientific realism where science gradually and with varying degrees of certainty uncovers the structure and dynamics of an external world (Lund 2005; Mjøset, Unpublished work).

The JCS perspective places itself somewhere in between the pragmatist and standard philosophy of science. On one hand, the observation of JCS clearly is 'theory-begging' (Hollnagel and Woods 2005), in the sense that it does not have pre-specified

classification schemes and explicit models of performance. Part of the literature emphasises the need of holding back one's attributions and preconceptions in order not to impose excess structure on the observed phenomenon. However, there are some assumed general traits in JCS performance as indicated in the formulation of 'Laws of JCS' (Law of Fluency, Law of Demands, Law of Stretched Systems, Law of Requisite Variety). JCS literature also explicitly refers to and applies research from standard science disciplines such as classical physics, cybernetics, and control theory. In this sense the JCS perspective may be said to search for general law-like relationship across cases and regularities.

The literature on human factors and JCS states that it is a discipline concerned with the understanding and support of safe, efficient, productive and health promoting work in human-technology systems (Vicente 1999; Hollnagel, Woods and Leveson 2006). In some sense, JCS research projects do not pursue knowledge for the sake of knowledge itself, but is engaged in the real problems of real JCS and seeks to change or support the particular work practice as it exist. It does so by achieving authenticity and closeness to the system studied, but also by way of generalized concepts and laws to guide observation ('preparing to be surprised' - (Woods and Hollnagel 2006). Rather than classifying human factors and JCS research in terms of philosophy of science – one should perhaps focus to what degree it actually provides change or not in the JCS in question.

### **2.3 *Design Work***

The design process is not subjected to the same criteria as scientific endeavour (Beyer and Holtzblatt 1997). Design may be said to explore how artefacts forms the basis for skills rather than seeking conceptual and theoretical coherence (Woods 1998; Dekker and Nyce 2004). This means that design is somewhat loosely connected to the analytical effort made in the modelling of JCS in the sense that the theoretical conceptions may function as 'design seeds' that can the explored during the design process (Roesler, Woods and Feil 2005). The human factors researcher and the designer meet at the crossroads of systems analysis and design iteration. The artefacts emerge from the countermovement of abstracted understanding and material

articulation of that understanding. The material object thus bears the analytical accumulations of the researcher and the explorative actions of the designer.

To what extent is design valid? Is it reliable? The application of criteria of scientific methodology comes out as rather odd when confronted with design. The link between design and analysis is not a direct, one-to-one relationship – as experienced when shifting from theory-building to design brainstorming. The link between the two is best described as concerning the degrees of freedom defining the exploratory space for materialization of skills and expertise (Ingold 2000; Hyysalo 2002; Dekker and Nyce 2004; Norros and Nuutinen 2005).

However, the challenge is to describe or specify the leap from analysis to design in greater detail. Beyond the quite normative statements of the relationship between the two, there are few concrete rules or heuristics. The first real encounter surfaces as the proposed design is subjected to testing, either through evaluation during prototyping or more elaborate evaluations. Here, analytical effort should be able to provide lucid criteria for what is suitable design and not. Savioja and Norros (2004) states that

*“The quality of artefact is manifested in their ability to promote meaningful and appropriate use in the organisation in which they exist”*

(p.2) (Savioja and Norros 2004).

In order to be scientific models, as opposed to ‘folk models’, the analytical effort should be able to map out appropriate use in terms of distinct performance critical variables that would guide testing of the suitability of designs solutions (Dekker and Hollnagel 2003). The line of reasoning in this thesis is that the leap from analysis to design is not a deductively structured affair, but rather one of providing a sketch of the work practice that the design is intended for. Further, the coupling between analysis and design re-enters the design process during testing in which it should be able to provide some indications of when a design allows appropriate use and not – preferably in terms of clear performance indicators.

## *2.4 Flexible research designs*

This thesis presents a case study of FPB as an instance of human-technology symbiosis specialized for safe and efficient maritime movement. As pointed out in the sections above, the observations aboard the ships were not specified in terms of procedures in advance, no explicit hypothesis were tested or pre-specified elaborate methodologically framework used.

This deliberate choice of to ‘underspecify’ the methods and research questions origins from what Robson (2002) labels ‘real world research’. The study of movement in human-technology systems as expressed in the operation of FPB was initiated from the far end of the continuum between real world and the highly structured experiments. The motivation for doing so was the choice to start out close to the object of study, being prepared to accommodate findings in terms of methodology and theoretical concepts.

In fact, there are very few field studies of the FPB in terms of the specific organisational and operational setting in our study. So, given the scarce accumulated knowledge in this particular domain, the goal was to let the domain appear as ‘real’ as possible in its raw format without the rationalisation of researchers and scientists.

This thesis is based on participatory observation of FPB during operation. However, observation may be articulated in a number of ways, ranging from the unaided observation of the system to the elaborate set of recording artefacts (audio recorder, video, taking notes, taking pictures, drawings, sketches, etc). The implicit idea behind a flexible research approach is the multiple use of aided observation (how to observe) in addition to multiple operationism (what to observe and how to classify it). This means that the observation shifts between various methods and the particular expression of them. Here, the primary modes of observation have been the use of video, taking pictures, and taking notes. This of course yields certain type of data – attuned to the desire to start out ‘underspecified’ and have an exploratory approach. The strength is that it facilitates the generation of hypothesis to explore

systematically at a later point in time, and the researcher is open to aspects to JCS performance that was not expected or foreseen.

### **3 The articles in this thesis**

The following sections will address each of the articles included in this thesis, and shortly comment on their contents and pointing out present and/or future development of the main ideas and findings. The comments on the articles will be followed by a reflection over the unfolding of this thesis.

#### ***3.1 Article I: Technologically Aided Movement***

The article investigates technologically aided movement, and starts out by arguing that transport is a primary structure in modern societies, as the movement of people and goods is extensive and is rapidly growing. The demands of efficiency and safety are likely to be maintained and probably increase as existing margins in capacity are capitalized upon.

Accidents and incidents are often approached with a conceptual apparatus that explicitly or implicitly builds on quite distinct assumptions regarding human thought and behaviour, and the attributions of causes in accidents and incidents is a classical feature in psychology and human factors research. The article cites for example (Hills 1980) stating that approximately 95% of all car accidents are due to ‘human error’ and that ‘perceptual error’ explains 44% of all car accidents.

If taken into human factors, the philosophical ideas discussed in the article have consequences for the concepts often used. Human error is often presented as the major cause of accidents when no other apparent reasons are present. Typically, the intact functionality of technology necessarily (and ‘logically’) implies that the other part of the man-technology equation is flawed. If technology works as planned and designed – accidents are due to human actions. In case of transport accidents, it is assumed that the driver committed a mistake or performed an error as long as the transport medium



had the technical integrity enabling control (Hollnagel 1993). However, the mere presence of functionality and the formal ability to control are not sufficient conditions to master human technology systems. There is now a growing consensus that we have to differ between the mere availability and the actual observability of information (Dekker and Woods 2002; Woods, Patterson and Roth 2002). The fact that system information (and/or functions) is available to the operator is not equal to the observability and functionality of the system. This means that adaptive (and thereby safe and efficient) human-technology performance builds on some higher order feature, where the status of subcomponents does not fully explain the behaviour of the whole. Technical integrity does not secure safe system behaviour alone. This has been exemplified in numerous accidents investigations, for example the report on the TWA800 aircraft accident in 1998, where the aircraft was reconstructed from the wreckage after the accident. The investigation could not pinpoint the component or key event that triggered the explosion (Dekker 2005).

The failure of 'technical' deconstruction to reveal system breakdowns propagates to the feasibility of the analytical separation humans and technology in joint systems. The hierarchical deconstruction of technical systems to trace overall failure builds on the same idea of deconstruction that lies beneath the analytic separation of human and technology in accident investigations (Dekker 2005). The dualism underlying the approach where humans are treated apart from technology in analysis is conditioned by a categorisation where the physical apartness of the two agents is taken literally. However, the physical separation does not necessarily warrant the separation in analysis of the joint system (Hollnagel 2001).

The article addresses the problem of deconstruction and dualism to model human-technology systems has consequences for the perspective on human use of technology. It suggests that the configuration of technology might be anchored not exclusively in terms of 'objective' specifications (e.g. formal technical specifications), but also explicitly in relation to the characteristics of the organism operating the system. In sociotechnical systems, this means that functions are not merely technical capabilities, but also representations of opportunities for action for the operator (Rasmussen 1990). Following this line of reason, design of human-technology

systems must include some notion of psychological and physiological characteristics of the users (Vicente 2003).

However, this raise the question of what characteristics of the human mind designers and engineers applies in relation to the approach to technology. More specifically, how do people maintain control of their movements when engaging in transportation systems? Further, from a Human Factors perspective: How does technically aided transportation affect the ability to control movements with these vehicles? The article points to aspects of unaided motor control in this question, and elaborates on the consequences for human-technology designs in transport. Transport is suggested to represent a constellation of technology and human agents into a multileveled unity, fulfilling a great number of functions and goals.

### ***3.2 Article II: Control Situations***

This article investigates what the relationship between the demands and the resources of ship manoeuvring as it unfolds in the FPB operation. It builds on a theoretical framework for ship manoeuvring by Petersen (2004). On one hand, he argues that we might regard performance as the sufficient positive margins in terms of system critical parameters at any given point in time (e.g. position at Time N or arrival at destination versus planned arrival). On the other hand, operators are not oriented toward the parameters values in isolated moments, but seek to establish safe and efficient performance over time. The article in the thesis discussed this time-scale perspective in terms of the manoeuvring of the ship.

Manoeuvring is defined as the control of speed and course. These systems features are instantiated in physical components effecting the longitudinal and rotational movement. The safety and efficiency of FPB is intrinsically tied to the manoeuvrability of the ship.

The modelling of JCS focus on the ‘field description’ serving as the space of possibilities for the operator (Vicente 1999). However, transport system are characterized by a high rate of disturbances and uncertainties (Petersen and Nielsen

2001; Burns, Hayes, Baxter and Fidge 2005). This feature has relevance for the use of Rasmussens Abstraction Hierarchy (AH) as a field description in a formative analysis of JCS. The problem is that the effect of physical components as effectuators of system behaviour parameters (speed or course) is conditioned by the nature of interaction with the context. More specifically, the effect of propulsion and rudder angles in FPB is highly variable and dependent upon contextual variation such as currents, wind, and depth of waters. This means that operators must in addition to focus on the given system parameter values (e.g. position) manage the capabilities for control in the upcoming timeframes. They must make sure that the ship position concurs to the planned track, but must also make sure that the ship has the control capabilities to be at a planned future point in space and time. Does the ship have the steering capabilities to make the next turn? Can the ship be stopped in time if an obstruction is detected? The tricky aspect is that as the ship increases speed, the navigator has decreasing means of steering as the turn rate (degrees per second) is reduced. High speeds gives low turn rate, slow speeds gives high turn rates. Here, it seems that the issues of safety and efficiency do not pull in the same direction – safety involves *idealising* the space of possibilities in terms of staying as far from the edge of controlled performance as possible. That means going slow, and keeping a high turn of the ship. At the same time, the ship operates under the instruction of going fast (patrolling large regions) – that is, to be efficient. This means increasing speed and decreasing manoeuvrability. Further, speed regulates the pace of events and demands that must be handled. So, the control situation involves the configuration of demands and possibilities at hand for the operator. However, choice of speed may constrain the relationship between the two, but it does not specify how the operator chooses to disperse resources when confronted by demands. The article offers to add the concept of control strategies to the control situation framework in order to accommodate this feature.

### ***3.3 Article III & IV: Activity Theory and Design***

Design is, explicitly or implicitly, an articulation of how users express their skills and solve some problem or task (Woods 1998; Beaudouin-Lafon 2004). In this sense, design is indeed a frontier in human factors as designers lay the basis for skills by the

details of a given artefact. And if so, one should be able to inform in such a way that the artefacts deliberately support some features of user interaction.

The articles III & IV present an Activity Theory (AT) analysis of FPB operation by way of the AT concepts and systems. AT is a framework particularly occupied with the nature of mediation and tool-use, as subjects are thought to never act in isolation, but always with and through some form of tool or artefact (Nardi 1996; Rabardel and Beguin 2005). Article III aims at laying out the conceptual structure for performing conceptual analysis of FPB operation. The central contribution here is the update of AT in terms of including the coupling to the context. This is done by echoing Norros (2004) and her use of ‘outcome features’. Here, the concepts of constraints and affordances are brought in to strengthen the inclusion of contextual factors. Further, the nature of tension across hierarchical and temporal structures of activity is suggested. Tension refers to deviation or conflict between system state and the task of the system (e.g. actual position versus planned track). Article IV describes a design session at Kongsberg Maritime gathering human factors personnel and industrial designers. The aim of the session was to bring analytical understanding to design work – and exemplify how research might yield a different design making a practical difference. As indicated by Savioja and Norros (2004), the proof is in the pudding, meaning that the eventual success of a given design is validated to the extent it enables the user to cope with complexities and fits into the given organisation where it is used. The design session only provided a mock-up for demonstration, and was not taken further into evaluation or subjected real-work settings and thus not been taken into the phase of elaborate testing and evaluation.

Through the presentation a specific mock-up, the article implicitly addresses the issue of the usefulness of theories to guide design. Halverson (2002) discusses the how theories might be useful to the study of human-technology systems<sup>6</sup>, and emphasises the capability of a theory to guide our observations towards salient and important aspects of the phenomenon in question. Further, she argues that theory should enable us to make inferences that are useful in some form of application. Halverson thus

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<sup>6</sup> Halvorsen (2002) originally discusses of computer supported cooperative work (CSCW’s), however, the same line of arguments is arguably valid for the study of human-technology systems.

adapts a pragmatic view on theory, and proceeds to present four attributes for evaluating the pragmatic value of theories.

First, there must be some *descriptive* power, that is, the theory must help the researcher to make sense of the phenomenon studied. Secondly, the theory must have *rhetorical* power that enables the mapping of conceptual structures to real world observations. Further, it should help us to convey our findings to others. Third, there is the *inferential* power where researchers are able to go further than the directly observed and realize important interactions or features of the system studied. Fourth, theories should contribute to *application* of the knowledge and observations gathered. Here, Halverson points to how theories might inform design as an example.

The design articles in this thesis present material relevant for the first three criteria by initial description and further insight into the dynamics of operation of high-speed crafts in military service. What threats are there to the value of this kind of input?

Vicente (1999) comments the issue of validity of the interpretations of the observed data. He argues that the descriptive approach struggles to separate what actions that are motivated by system states (e.g. changes in process to control) and what actions that are forced by the artefacts used to control the process (e.g. characteristics of interfaces). This is equivalent to the notion of the task-artefact cycle where human action is seen as shaped by both the problem to be solved, but also by how the tool is used (Carroll, Kellogg et al. 1991). Descriptive analysis struggles to differentiate between ‘true’ task challenges and tasks originating from the use of the specific tools. Vicente thus criticises descriptive work analysis for being device-dependent, which implies that we inherit the challenges related to the characteristics of the tools currently used rather than designing new tools as such that build on an understanding of the task at hand. Characteristics of technology and tools should be an output, not input, to the design process. The suggested cure is a device-independent work analysis, downplaying issues of current tool use by focusing on the intrinsic work constraints. In the AT articles, we have applied reduced model of AT with focus on how outcome features also structures operator actions. We thus aim to incorporate ideas from the formative approach without leaving the close description of human

activity with its tool-use. The main motivation here is to provide design input that is *formative* in the sense that it describes the foundation for the adaptive functioning of a system, not the specific action per se (full further discussion, see Vicente, 1999).

Threats to the value of theoretical founded analysis as input to design in accordance to Halversons first three criteria involves the formulation of the findings in such a way that it captures more than the merely observed, and that we thus manage to bring forth some underlying dynamic or functioning relevant for the design (or redesign) of new artefacts. This is referred to as rhetorical and inferential aspects of the pragmatic value. This may be compared to the practice-centred perspective of Woods and colleagues previously presented that emphasises how studies of systems are founded in the oscillation between observation and abstraction. This suggests that the observations acquired during participation in actual system performance are formulated as ‘patterns’ or higher order relationships serving as framework of the skill of practitioners. Halversons principles here serve as criteria for the movement from observation to abstraction, suggesting that the abstraction of patterns should have some distinct qualities in order to prove useful for design – the abstractions should sufficiently describe the phenomenon, provide a solid mapping between concepts and observations (rhetorical power), and finally contribute with some surplus value by pointing out features beyond mere descriptions of the system (inferential power). Woods describes how success studies should *spark inventiveness* – a term that may be understood as equivalent to Halversons *pragmatic value*.

In the AT articles, we build on our observation studies to describe how activity levels and phases unfold, and how tensions present challenges to the navigator. The AT analysis in the articles in this thesis offers perspectives of the system studied that goes beyond mere descriptions – and arguably meets the criteria of both Halverson (2002) and Woods and Hollnagel (2006).

### ***3.4 Article V: Using Video in Field Operation: A case study***

Article V presents a discussion of the methodology of observation of work practices. A central tenet of human factors is that it is focused on work as it takes place in its

natural setting. This means that we as human factors researchers seek out the sharp end of work practices and establish an understanding from there. Field observation of JCS means observing work performed by multiple human agents operating numerous technical systems in a work process that is sometimes subtle, irregularly paced, and characterised by uncertainty and dynamism (Casey 1998; Norros and Nuutinen 2005; Woods and Hollnagel 2006).

The practical problem here relates to how the researcher can keep track of everything that happens. The use of video in field observation of JCS is founded in common sense as it allows the researchers to revisit events captured in terms of perceptual, spatial, contextual, and semantic aspects of work practice. Many disciplines have embraced the use of video as a tool of documentation of work practice, such as health care and education, software design, and product design.

However – beyond the common sense of using video, there are a number of issues arise. The article argues that there are primarily two categories of concerns, namely practical challenges and theoretical considerations<sup>7</sup>. The resolution of these is conditions for the observation to yield relevant data of sufficient quality.

The practical issues concern the logistics of cameras and adherent equipment: How to install cameras in the physical context of the work practice of interest? How do you secure the quality of sound and vision of recorded material? The ship bridge is an unforgiving environment with confined physical space, poor and highly variable light conditions, noisy, and constantly vibrating and shaking. The video equipment setup must thus overcome these obstacles

The theoretical challenges concerns the relevance of observation – what should the video cameras capture? Given the distributed and partly subtle character of FPB navigation and manoeuvring, the relevance becomes a theoretically informed choice. By theory and conceptual understanding, the researcher decides what to focus on.

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<sup>7</sup> The article does not discuss the challenges of analysing video, which is clearly a significant problem in terms of establishing classifications and indicators.

The article argues that the practical and theoretical issues are mutually informative, and must be handled in as intertwined. The practical issues reveal something about the work conditions, and the theoretical abstractions inform what practicalities that must be overcome. Moreover, the setup of video equipment should, due to the coupling between theory and practical challenges, be arranged in some form of ‘phased scale-up’. This implies that the video observation starts out in a low key manner, making few theoretical assumptions and using flexible low-cost equipment, in which the gradual attunement and adaptations to the demands unfolding might be more easily accommodated. This is a concretisation of what Robson (2002) labels ‘flexible research’ in which both hypotheses, assumptions, and methodology is gradually fitted to the case at hand.

The article present the study of FPB operation in terms of a chronological stages scale-up, where initial assumptions and technical equipment is fitted in accordance with the experiences during the study.

#### **4 Reflection**

The maritime domain has come a long way from the traditional methods of moving at sea. Sailing by wind and navigating by the stars marks only the historical heritage in modern ships that have undergone a full-fledged transformation to specialized maritime mobility. Today, maritime transport is an intricate web of humans, technology, and organisations, and qualifies for the label complex sociotechnical system in every sense. The current technological push with the maritime domain is expected to increase the complexity in the years to come, and the eventual improvements or extended capacities are likely to be used to push for new demands and new tasks.

Hollnagel and Woods (2005) states that “... *the purpose of science is to produce valid, scientific knowledge about a particular domain or problem area*”. Human factors differs from basic science as it is a discipline that seeks to apply the knowledge to improve human-technology systems by facilitating safety, efficiency, productivity, and promote health. Knowledge should ideally be transformed to



practical consequences for work. Here, I would argue that human factors bears a specific responsibility in terms of engaging in the ongoing emergence of new work practises in the maritime domain. The fast paced development and integration of technology represents a radical restructuring of the conditions of expertise and skills of operators, and the nature of this relationship between performance, artefacts, and humans is crucial to promote functional transport systems at sea.

The subtitle of the Hollnagel (2004) book ‘Barriers and Accident Prevention’ suggests that we should “*improve safety by understanding the nature of accidents rather than finding their causes*”. The phrasing implies that in order to improve human-technology systems, we need to reflect upon the basic assumptions we have on the relationship between human and technology as such. A central theme in this thesis is the recognition of the fact that physical separateness of humans and artefacts does not necessarily entail a equivalent separation in analysis of process and function (Hollnagel 2001; Hollnagel and Woods 2005). To take this argument seriously leads to a revision of the basis for the models humans and technology. Human factors are thus tied to the improvement and understanding of JCS. Historically, the theories offered to do so have been both useful and not that useful. The danger of being focused on the case-based description of the human factor in technology use is that the theories and concepts to do so become watered out. For example, labels of psychological states are offered as explanations to complex outcome. Dekker and Hollnagel (2003) have discussed the use of ‘folk models’ in human factors, addressing how a certain conceptual apparatus of human factors research seems to be counterproductive. Central to ‘folk models’ are the use of descriptive labels as causal explanations, the troubles of confirming/disconfirming explanations, and overly simplified generalisations way beyond the origin situation. In their article, the concepts such as automation complacency, situation awareness, and human error are problematized.

How does this thesis hold up to the criticism of folk models? What explanatory value does the theories and frameworks presented offer?

Article I present a philosophical discussion of humans and technology. The main conclusion is that the issue of control becomes a key parameter in the description of

system performance. The concept of control is then taken into a rather concrete setting of FPB operation, in which the details of control demands and control possibilities are laid out. I would argue that these two articles outline a viable path for further specifying system performance and outcome parameters, in which performance can be operationally defined – For example, the control demands in FPB partly revolves around positioning, and can be defined properly precise in spatiotemporally terms (location at a given point in time). Equally, the control possibilities (speed and steering) can be estimated and compared to control demands. Combined, this would offer a state-space representation of operation that the operator relates to in terms of strategies prioritizing safety and/or efficiency. Other researchers have demonstrated state-space representations in modelling of decision making in complex work (Granlund 2003; Jenvald and Morin 2004).

The use of AT in analysis of JCS have been criticised for being too descriptive in the sense that it does not yield clear data informative of technological change and handling of future events. This thesis includes two articles based on AT, and is subjected to the presented criticism.

The AT articles are linked together. The first contains an elaborate AT analysis of FPB operation. The second reports on a design session implementing these results in a mock-up of an autopilot for HSC<sup>8</sup>. The AT analysis offered contains an inclusion of concepts of constraints and affordances, and seeks to integrate the idea from the formative approach described by Vicente (1999). At the same time, the analysis explicitly aims at capitalizing on the strengths of AT, namely the close-up view on work, as it is expressed. The high level of descriptive character allows for the phenomenon to appear as intact as possible, as opposed to applying a formal set of concepts of abstract character (e.g. algorithms for perceptual coding, etc.). Further, the central concepts in describing performance are ‘tensions’ and the nature of artefact mediation, concepts that that are associated to the ideas of control demands and possibilities. The tensions may be understood as growing control needs, whereas the nature of mediation concerns how control possibilities are made available to the operator.

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<sup>8</sup> The design ideas and FPB setting is currently taken further into student work on the use of haptics in maritime equipment, and will proceed toward early testing in the time to come.

Seen together, the control situation framework and the AT analysis addresses the issue of operational constraints (system-context interaction) and interface constraints (operator-technology interaction).

Article V principally concerns the basis for conducting confirmation or disconfirmation of the explanations and concepts used in modelling as it addresses the issue of gathering relevant data of sufficient quality. Any evaluation of a human-technology system must have some form of criteria for describing the relevant system performance as well as a means of recording it. The video article comments on the iterative process of ensuring these aspects<sup>9</sup>, thereby enabling evaluation.

#### ***4.1 Scope and limitations***

For whom does this thesis have relevance? First of all, the thesis has FPB operation as the case study, and aims to be of value to practitioners and the associated industry. The thesis should be able to enter the education and training of FPB navigators with the emphasis on control situations and hopefully the design mock-up may open up to new design ideas for the creation maritime equipment – both in terms of detailed design as well as the reflective approach to the design process. The input from practitioners is still often left out of the processes leading up to the creation of new technology.

Secondly, the work presented here hopefully of interest and relevance for an audience beyond the practitioners of FPB operation and associated industry. The control situation framework addresses issues basic to all transport system, in which the variability and irregularity of system parameter effectuators is crucial. The moving human-technology systems are characterised by the changing conditions. The framework should therefore bear relevance for trains, and personal vehicles. Yet, the

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<sup>9</sup> The video article is currently taken further into explication of the technical system, in terms of integrating system performance data. The domain in question is train driving. Further, the data acquired during the field studies are now being quantified and will hopefully be published in relation to the issue description of the dynamics of technological mediation in FPB operation.

actual application and further explication of the principles offers will provide more answers to the relevance of the control situation framework.

#### ***4.2 Concluding remarks***

Woods and Hollnagel (2006) argue that the question regarding Joint Cognitive Systems (JCS) is not whether or not they are fallible. They are. Accidents and incidents will happen. Still, we strive to limit the negative consequences of this, and to strengthen the factors important for safety and efficiency, while diminishing the factors undermining resilience. This thesis offers to contribute to the field of human factors by a broad set of distinct contributions.

Most ships do not crash. Most planes and trains leave and arrive as planned. Yet, the equality of the outcome does not necessarily imply the singularity of the process. Hopefully, human factors will continue to evolve by maintaining its variety of methods and theories to improve the relationship between humans and technology.

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**The embodied mind:  
Implications for the understanding of control in technically aided movement**

RUNNING HEAD:  
Control of technical movement

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A reconceptualization of transportation technologies and their impact on human life and experience is presented. It is based on an embodied mind approach, where the human body is perceived as the centre for experience and control of activity. It is argued that humans both can and do merge with objects in a functional sense. This merging alters the basis for experience and control and shape new ways of relating to the world. The present article explores some of the implications of this perspective on the impact of transportation technologies on human experience and life.

*Keywords:* Control; Embodiment; Technically Aided Movement

## 1. Introduction

Human society and our way of life are highly dependent upon the existence and use of technical transportation devices. Goods, animals and humans are transported long distances with the use of large cargo skiffs or by airplane. People commonly use collective or transportation means such as trains, busses or commercial aircrafts for personal transport. Technical transportation vehicles allow for longer and faster movements than would be possible by foot or on horseback. Thus, cars, trains, boats and airplanes entails advantages in efficiency, speed and cargo load that the current western civilization is dependent upon these aids in order to maintain the current standard of living. This striving for efficiency entailed that the western civilization are now based on something that is more efficient than humans itself—it has become a civilization based upon the possibilities given by technology.

The use of transportation technologies is steadily increasing. In Norway, a country with about 4.6 million inhabitants, there was in 1991 about 2.3 million vehicles, a number that increased to 2.8 million in the year 2000. The number of kilometres driven on Norwegian roads increased from 48092 million in 1990 to 54351 millions in 2000, a 13 % increase (Statistisk Sentralbyrå, 2002).

Human death and injuries are now a major problem worldwide. The first traffic accident occurred in 1869, when a young woman was crushed to death under the wheels of a steam-carriage (Fallon & O'Neill, 2005). With the increase in transportation since then, the number of casualties has also increased. A recent report estimates that about 1.2

million people die each year from injuries sustained in traffic accidents worldwide (Peden et al., 2004).

A majority of these accidents have been claimed to be caused by ‘driver failure’. For example, Hills (1980) claimed that up to 95% of all car accidents can be explained by human error and that perceptual error has been shown to be a factor in 44% of all car accidents. High speed was claimed to be a cause of 23% of all accidents. Numerous other surveys and review articles also lay claim to human error as a major cause for accidents and loss of lives (see e.g. Reason, 1990; Vicente, 2004). Human error is often presented as the major cause of accidents when no other apparent reasons are present. As long as the driver had the possibility to actually control the boat/car/train/plane etc. there is assumed that the driver committed a mistake or performed an error (Hollnagel, 1998). However, the mere presence of information and ability to control has shown not to be enough to control technological processes, and there is now a growing consensus that we have to design for the psychological characteristics of the users (Norman, 2002; Vicente, 2004). However, this again raises the question; what are the characteristics of the human mind, and how do people maintain control of their movements? In addition, from a Human Factors perspective; how does technically aided transportation affect the ability to control movements with these vehicles?

In this article we will present an ecologically based account on how humans control their movements both with respect to both unaided bodily movement and technically aided movement. Technically aided movement is only meant to pertain to movement aided by mechanical vehicles, where the body does not constrain the movement per se. Natural unaided movement is therefore related to movement which is



dependent on and constrained by the physical capabilities of the human body. We will describe a model of human functioning based upon a recent trans-disciplinary opposition to the established information-processing perspective<sup>1</sup> on human functioning (see e.g. Reisberg, 2001, for a description of the information-processing approach). The model has been described as the *embodied mind approach* (Varela et al., 1991; Lakoff & Johnson, 1999). The foci of the present article are twofold. First, how are control realized in both unaided bodily movement and technically aided movement? Secondly, how does this model affect our understanding of transportation technologies and their effect on the humans that use them? By reframing the ways that we understand human interaction with technology on both a psychological and philosophical level, we seek to present a trans-disciplinary basis for the further investigation of themes related to how technology affects human movement and mobility.

## **2. The Embodied Mind**

The embodied mind approach argues that human interaction with the world is a reciprocal co-ordination of the actors' mind, body and environment, rather than being guided by internal problem solving or mental internal representations (Varela et al., 1991; Clark, 1997, 1999). The emphasis on internal computational processes has been elaborated by the Information-Processing perspective within cognitive science (see e.g. McDermott, 2001; Reisberg, 2001).

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<sup>1</sup> Knowledge about the information-processing approach in psychology is not needed to read or understand the principles of this article. It is referred to, as it points out a frame of reference for those who have knowledge about psychological theories and the implications of these.

The embodied perspective reformulates the questions of what constitutes and connects human thought and behaviour. It does this by setting aside the traditional reference to the core axiom of formal structuralism where the ‘mind’ is explained by reference to an abstract structure, preferably logical or mathematical in nature. The embodied approach attacks the issue of human thought and behaviour by emphasizing the coordination and control of action in accordance to a continuously changing context. This further implies a denial of the philosophically cumbersome dualisms between ‘mind-body’ and ‘mind-world’ originating from the Cartesian heritage in the classical information processing paradigm (Gibson, 1979; Thelen & Smith, 1994; Lakoff & Johnson, 1999; Ingold, 2000). This reformulation of the nature of human thought and behaviour removes the related separations of issues concerning perception-cognition, perception-action, and action-cognition. The interlocking of these three aspects beyond their separation in the language of scientists, constitutes a founding basis of an embodied approach to human functioning. The synthesis of the three aspects is recognized as expressions of how humans coordinate and control their action in their habitat as they adapt to environmental constraints, biomechanical constraints and task constraints<sup>2</sup>.

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<sup>2</sup> In this paper we will often refer to the term *constraints*. Constraints as a general term will refer to the presence of elements that limit the number of possibilities within a system. Examples of constraints are for example limitations in human working memory or the angular direction of a creek which determines the direction of water flow. The most basic constraint is described by the second law of thermodynamics which states that the distribution of energy in a closed system moves towards equilibrium in an irreversible manner (Atkins, 1984). A system with no constraints would be totally chaotic, prediction of future states would be impossible. Further transformation of energy into work would be impossible (Juarrero, 1999). Constraints direct a system’s behaviour by reducing the possible degrees of freedom inherent in the system, thereby making some options for behaviour unavailable (*ibid*). Constraints also exist in the psychological and bodily spheres. Both perception and movement is limited by the capabilities of the human body, the characteristics of a person’s sensory systems is the physical constraints for what can be perceived. Similarly the state of the muscles, tendons, skeleton and the cardio-vascular system imposes physical constraints on the movements that a person can perform. The physical bodily limitations to perception and action will be subsumed under the term *bodily constraints*.

Three important features will be explicated below, in order to elaborate the perspective of embodied approach. The *first* element is the tight interlocking coupling of perception and action which constitutes the basis for cognition. The *second* aspect is the possibility for a functional extension of the human body. The *third* and last characteristic of the embodied mind is the cognitive extension of the human mind.

### **2.1. Perception-action coupling**

The term ‘perception-action coupling’ is used to denote the cyclical relationship between human perception and movement in the world (Gibson, 1979). The term emphasises how humans perceive in order to move, and how this movement in turn guides and facilitates the further perception of salient characteristics of the environment, which again shapes and guides the further exploration of the environment (Swenson & Turvey, 1991). Action is a way of perceiving and perceiving is a way of acting (Smitsman, 1997; Noë, 2004). This reflects a dual relationship between perception and action. Action is constitutive for perception, since without movement of the body or the environment, there would be no changes in sensory stimulation and neural adaptation would occur. This argument is supported in studies of neural adaptation in ‘fading of visual objects’, when a perceived object held stationary on the retina for more than a few seconds fades from view and is no longer perceived by the individual (Yarbus, 1967; see Martinez-Conde et al., 2004 for a recent review).

On a larger scale, perception is assumed to be similarly constitutive for action, where functional action can only occur in those circumstances in which the body is able

to resonate to the changes in the environment brought forth by movement. If the body cannot perceive meaningful changes following a movement, this movement cannot be controlled in relation to the environment. This means that movement is both enabled and constrained by perception. In other words, perception and action are mutually constraining and constitutive of each other.

The view of perception and action as interlocking capacities of the human body entail that human natural movement is understood to be controlled and coordinated by continuously altering behaviour attuned to constraints related to the task to be performed, as opposed to being controlled by pre-defined motor programs or mental models (Thelen & Smith, 1994; Fajen & Warren, 2003). The embodied mind is thus geared towards controlling action, but it is also based upon physical action (Clark, 1997; Noë, 2004).

## ***2.2. The functional extension of the body***

The second important claim of the embodied mind approach concerns how the boundary of the body is regarded not as fixed, but can extend beyond the skin and may include objects to create a new bodily synthesis. This phenomenon has been approached explicitly from three distinctly different fields of enquiry. The first is case-based research on the phenomenon of phantom limbs. The second is the philosophical endeavour following the phenomenological philosophy of Husserl. The third is neuropsychological research on humans suffering from neurological injuries and macaque monkeys. These three fields related to the nature of the ‘extended body’ will be described below.

**2.2.1. Phantom limbs.** Variations of phantom limbs are widely described in medical literature (Ramachandran & Hirstein, 1998). Primarily, phantom limbs are defined as the vivid impression of a deafferented (amputated) limb still present, and that the limb is still giving rise to various experiences as part of the body (Mitchell, 1871; Ramachandran, 1993; Ramachandran and Hirstein, 1998). The documentation of phantom limbs is primarily gathered from medical science as a form of pathology in patients after deafferentation. The phantom limb is thus an experience of a missing body part that is not present in the person's physiological structure (nerves, muscles, and so forth).

The traditional explanation of this phenomenon has been the malfunctional activity of severed or damaged nerves at the place of deafferentation. However, the existence of phantom limbs is also found in children with congenital missing limbs (La Croix et al, 1992). Children born without some limbs (e.g. arms or hands) had phantom limb experiences and were able to voluntarily move them about. This phenomenon evades the theory of anomalous and abnormal physiological activity after body trauma. Further, it is possible to induce phantom limbs sensations in normal health individuals. The procedure contains the invoking of stimulus contingencies by coordination of the movement and perception of the body of the subject (see; Ramachandran and Hirstein, 1997; Lackner, 1988). Ramachandran and Hirstein (1998) conclude that body image is far from being a permanent and durable state, but it is a transitory state flexible to contextual specifics.

**2.2.2. Phenomenological philosophy.** Similar to Ramachandran and Hirstein (1998) do the phenomenological philosopher Merleau-Ponty (1962) claim that the notion of our

body evades traditional physiological and psychological explanations, and that the experience of our embodiment is in flux. The experiential notion of being embodied is not tied to the naturalistic objective categories of ‘present’ or ‘absent’, where the phantom limb offers the paradox of a ‘presence-not-present’ part of the body. Merleau-Ponty goes beyond medical and psychological explanations to establish a phenomenological language for describing the flux of bodily images or experiences, where the body is the carrier or the instantiation of a being that exists in a context (world). He claims that to ‘hold a body’, is to bring oneself together with a context by practical engagement in terms of perceiving and acting through the body. The body being the medium through which we perceive the world—‘we are our bodies’ (Merleau-Ponty, 1962, 1968). This ‘being-to-the-world’, and its intentional engagement in the context, centre on the encountering of items and objects in praxis. This implies the claim that ‘some form of action precedes or grounds conception’ (Ihde, 1983). For Merleau-Ponty, ‘being’ is first and foremost practical.

This line of thought builds on works of Martin Heidegger’s *Being and Time* (1962), where the practical engagement is the core of human existence. Humans constitute their world through practical engagement. Heidegger refines earlier works of Edmund Husserl. In the analysis of the Cartesian stance, Husserl followed the steps in the reduction of existence to a dualistic perspective by Descartes, yet, concludes somewhat different. Where Descartes find human existence to be isolated from the external world (mind apart from world), Husserl argues that humans are present in the world, and that is this presence that is the founding conditions for existence. Further, the presence in the world is structured, and the nature of this structure is intentionality. It is this line of

thought Heidegger builds his arguments on, where the focus is on how beings find themselves in the world. He goes further than Husserl to specify this and one distinct difference is to the extent Heidegger emphasizes the practical engagement. Beings always find themselves in a situation by comporting themselves to the possibilities by and through everyday concerns and activities. Praxis becomes the ground for establishing a relationship with our world. It is by doing that we find our place in this world.

Given this approach, tools and technology enters the front stage of analysis of human existence, because humans do not act in isolation or alone. Human action is intertwined with tool use, and practical being is thus the expression of a 'body-subject' in a particular situation of praxis. The merging of Merleau-Ponty and Heidegger is done by emphasizing the embodied state of existence ('body-subject') and the practical everyday tool use ('Verfallen'). Our comportment to the world is one of practical involvement. Still, there are several ways of comport oneself in the use of objects. In our primary engagement in the world, we involve ourselves in the world *through* objects ('zuhanden' or 'ready-to-hand'). This means that objects find their meaning through use in a given context of referential totality of all the objects included. For example, a carpenter uses his hammer by using it in the context of building a house and the skills included in this activity. The world of that carpenter appears through the various tools that define the worldness of his being. On the other hand, objects may be experienced as detached from its referential and practical context. Objects apart from its use is experienced as objects in themselves, they appear present-at-hand ('Vorhanden'). By actively using objects which are present-at-hand, these objects become ready-at-hand, they become appendices that shape the ways that the body can perceive and act (Heidegger, 1962, 1977). Through

active use, tools can become functional extensions of the body's action capabilities (Hirose & Nishio, 2001; Hirose, 2002). It effectively alters the body's ability to act upon its environment (Hancock & Chignell, 1995; Smitsman, 1997).

**2.2.3. Neuropsychological research.** The possibility of a functional extension of the body through tools has been corroborated by several independent lines of neurological research. One line of research on the extension of the body through tools is present in indirect single-case research on patients with hemispheric neglect<sup>3</sup>. The results indicate that there are differences in the degree of neglect between the 'near' space (the area within manual reach) and the 'far' space (area outside the person's manual reach) of the contralesional side (Vuilleumier et al., 1998; Berti & Frassinetti, 2000; Laeng et al., 2002). In the Berti and Frassinetti (2000) study, action within the 'near' part of the contralesional side was more affected by neglect than the 'far' part. However, when the subject used a stick to perform the test task in the 'far' part (extending the 'near' space) the degree of neglect was approximately equivalent to the 'near' part. This has been taken to indicate that artificial appendices, e.g. tools, can alter the representations of the body to also include the tool (Berti & Frassinetti, 2000).

Other indications of the extension of the body come from neuropsychological research on macaque monkeys. These studies have shown that the 'near' and 'far' spaces are associated with activation of different areas in the brain (see Maravita & Iriki, 2004, for a recent review). Another study showed that following the use of a rake to extend

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<sup>3</sup> Hemispheric neglect is a pathological neurological condition where the person is often alienated towards one of the body hemispheres. This body side or parts of it is often reported as not being owned by the person. Persons with hemispheric neglect often do not shave or dress the affected body part, although the body part can be used during daily activities such as walking, eating or dressing (Gallagher & Cole, 1995).



manual reach, receptive areas in the brain related to the area within manual reach expanded to cover the area covered with the rake (Iriki et al., 1996). Also of importance is that this process depends on the active use of the tool, passive wielding is not enough to for the tool to be embodied (Maravita et al., 2002). This dynamic alteration of neural activation patterns following active tool use is believed to be a possible neurological basis for the embodiment of tools and objects (Maravita & Iriki, 2004).

### ***2.3. The Extension of cognition into the environment***

The third aspect of embodiment is the notion that cognition may also extend into the environment. This line of reasoning somehow follows from the argument of the functional extension of the body, in the sense that the context not only offers possibilities for action and movement, but for what psychologist label ‘complex problem solving’. Within psychology, the observation of chimpanzees struggling to acquire object outside their reach offered the first suggestions that cognition were tied to the context beyond the mere sensory registration (Köhler, 1917: Koffka, 1935). For Köhler, the chimpanzees ‘saw’ the solution in the context rather than generating adequate mental algorithms. As pointed out by Gibson (1979), perception is a mode of action, implying that what we perceive is a function of how we act. In philosophy, Merleau-Ponty (1962) discusses the presence of ‘body-subject’ in the world may be considered as different from the description of mere objects (e.g. rocks, water, dirt). The body-subject differs in that its presence is situational rather than positional. This means that the body occupies space not just as mass distributed in a three dimensional space (positions of points of mass), but as

a body-subject gestalt of possible actions (situational tasks and activities). Perception is thus practical, not only in terms of functional movement and bodily extension, but also in terms of ways of relating ourselves to the world. The context offers ('affords') ways of doing, that is, it offers solutions to problems. It opens for the idea of the extension of cognitive abilities beyond the skull and skin of organisms. The situational presence is aimed at doing and at the active use of the body, not merely at thinking and problem solving.

Perceived environmental structures do not only offer opportunities for movement, but also for cognition. The *cognitive extension* hypothesis involve a radical departure from classical cognitive psychology by stating that human cognition is not solely dependent upon intracranial cognitive processes, but rather permeates out into the environment through the actor's (re)structuring of the environment (Clark, 1997, 1999, 2005; Clark & Chalmers, 1998). The notion of internal representations guiding action also becomes theoretically redundant when we accept that "the world is its own best model" (Brooks, 1997, p. 417). There are considerable advantages in relating to the external world rather than to an 'internal mental model' with respect to real-time decisions. One can decide what to do faster and with more precision when using the 'external world' than when using an internal computational program to guide one's actions (Clark, 1997).

Real-life examples of the extension of cognitive structures beyond the skull of the human being is the use of maps during planning and execution of a sea voyage, and the use of a pencil to structure a text to ease further reading are (see e.g. Hutchins, 1995;

Clark, 1997). Cognition is in this way perceived as being distributed across body, activity, and environment (Lave, 1988; Ingold, 2000).

#### ***2.4. Summary of the embodied mind's key features***

In the sections above, the embodied mind approach is explicated in terms of key features, where the postulate of a close interdependency between perception, action and cognition is put forth. The claim is that the borders of the body are fluent and adaptable, as observed during experienced tool use. Another central claim is that cognition is distributed across body, activity and environmental artefacts. These features imply that humans are not distanced observers separated from the environment, but rather that the environment in which humans is embedded is a vital and indistinguishable part of human cognition and action. This theoretical approach is taken as a basis for the availability for

### **3. Natural unaided human movement**

Natural, unaided human movement, consisting of only the body and the ground supporting movement impose natural constraints on the speed, height, length, duration and effect of human movements. Human movement capabilities are widely different across individuals, but the best estimate of the absolute boundaries for unaided human movement is probably those of the current world record holders within athletics. The current (ultimo August 2005) world records in athletics and weight lifting are presented in Table 1.

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Insert Table 1 about here  
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The records presented in table 1 indicate the top performance a person can achieve through bodily training. For example, the maximum speed obtainable by a human, calculated from the 100 meter sprint, is approximately 41 km per hour, while the maximum speeds sustainable over longer distances (10.000 meter) are approximately 22-23 km per hour.

These achievements not only demand excellent strength, stamina and cardiovascular performance, but also the coordinated dexterity between limbs and between the body and the environment the athlete moves through (Latash & Turvey, 1996). For example, to achieve a successful long-jump a person must [1] come as close as possible to the take-off board without stepping over, [2] have a body posture at the last step that enables the correct amount of force to be directed both downwards and forwards in order to get the optimal jump trajectory, and [3] have as high controllable running speed as possible (Berg et al., 1994).

To attain objective 1 the long-jumper must coordinate the step length to fit the visually perceived distance to the take-off board. This claim has been corroborated in several studies (Berg et al., 1994; Lee et al., 1982). This means that the athletes must engage in active perception-action coupling in order to achieve an optimal distance to the take-off board during the jump. Thus, long-jumpers cannot pre-train a stereotyped step pattern (motor program) and then implement this at the long-jump arena, but must adapt

to the relation between environmental circumstances (e.g. the distance to the take-off board) and bodily movements that occurs during each single long-jump.

In order to attain objective 2 and 3, the athlete must be able to perceive the position and movement of the limbs (proprioception). This is a sensory modality which most humans take for granted and are not aware of. However, without proprioception the control of one's own movements become almost impossible, as the case of Ian Wasserman (IW) has shown (Cole, 1995; Gallagher, 2005). IW suffers from of a type of neural neuropathy where large neural fibers below the neck were damaged by infectious mononucleosis, leading to the total loss of proprioception and touch below the neck. The immediate effect of this was that IW lost control of all bodily movements, and only after a couple of years of retraining could he control his movements and then only when he actually could see his movements<sup>4</sup>. Today, IW can control his movements with a dexterity similar to normal people, although he has to concentrate on his body's position and use his sight in order to maintain a movement (Gallagher, 2005). This implies that humans without disabilities like IW (unconsciously) employ the wealth of bodily information arising from their own body to control their movement—movements which again give rise to a particular set of sensory changes.

To sum up, during natural unaided bodily movement there is a continuous dynamical interrelationship between the movements performed by a person and the perception of the altered body posture and the environmental changes brought forth by the movement. This implies that perception of both the environment and the body is a part of the ways that humans control their movement. In short, a person must be able to

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<sup>4</sup> See Gallagher (2005) or Cole (1995) for a comprehensive description of IW's case. The description used here is taken from Gallagher (2005) and used only to exemplify the importance of proprioception in the control of movements.

perceive changes in the environment and in their bodies, and they must adapt to these changes by altering movement to fit the current situational and biomechanical constraints (Turvey, 1990; Thelen & Smith, 1994). However, this entails the question, “how are people able to perceive the changes in the environment that signifies movement or change of movement”? This is the question we now will attempt to answer.

### ***3.1. Relation between environmental changes and movement.***

As the long-jumper runs towards the take-off board, movement-dependent changes in the athlete’s sensory systems (vision, hearing, touch, etc.) occurs. For example, the take-off board takes up more space in the person’s visual field (it comes nearer) and the angle at which it can be seen alters as the person approaches the board. This interrelationship between the movements of an observer (or athlete) and the sensory changes of the environment is within ecological psychology seen as complementary to the interrelationship between perception and action (Gibson, 1979; see also above).

These interrelationships have led ecological psychologists to present the term *lawful transformations*. A term that comes from the understanding that specific movements are being followed by equally specific changes in the sensory information presented to an observer. Take the case of vision, where light rays are emitted from light sources (the sun, lamps etc.) and are reflected from the surfaces of objects. Reflected light thereby ‘fills’ the environment in which humans live—light rays will converge from all possible angles at all possible points of observation. This is the physical basis for human visual perception and has been called the ‘*ambient optic array*’ (Gibson, 1979).

The ambient optic array can be described as rays of light which are reflected from the surfaces of objects in the visual field of the observer (Johansson, 1991). These rays will penetrate the lens and the cornea of the human eye and hit the retina in the back of the eye which contains nerve cells that react to light. Any movement of the observer's eyes or head will move the rays of light over the retina, creating an *optic flow*. The optic flow over the retina (also called *retinal flow*) can then give information about the movement of one self and of objects in the world (Gibson, 1979; see Lappe, Bremmer & van den Berg, 1999 for a recent review).

Changes in the origination of optic flow towards or optic flow out from will indicate a change in the heading of movement (Cutting & Readinger, 2002). The transformations in optic flow during forward, backwards or sideways movement are *invariant* during a given mode of movement; e.g. forward movement entails the same changes in optic flow (flow out from the point of heading) in all cases of this type of movement. This applies to backwards and sideways movement, as well as in changes in heading (Cutting & Readinger, 2002). Invariant relationships exist in other sensory modalities such as rotational inertia (Pagano & Turvey, 1995) and static torque (Kingma, et al., 2004) and in dynamic touch (Turvey, 1996). The multitude of sensory systems engaged in natural bodily movement show how the human perceptual systems capitalize on *redundancy* and *variability* in the sensory changes following movements, factors which are important for the ability to detect movements and control movements (Waddington & Adams, 2003; Davids et al., 2004). The state of overall redundancy in the sensory systems is the rule rather than the exception.

Since there is an invariant relationship between movement and sensory changes it is possible to say that *movement is specified* by the invariant changes in the environmental stimulation. Thus, the environmental stimulation can act as a substitute for the movement, as is confirmed in the case of visual kinaesthetics where people who were standing still while being presented with visual information that specified backwards or forwards movement swayed or fell even though the floor they stood upon was perfectly still (Lee & Aronson, 1974; Lee & Lishman, 1975). Similarly, Johansson (1977) found that people experienced themselves to move up or down when a film of moving dots in was presented to the periphery of their vision.

The specification of movements by invariant changes in the ambient energy array enables humans to also perceive the velocity and direction of their movement. A person can then see which way s/he moves relative to the environment by observing/enacting changes in the ambient energy array. The invariant specification of movement by multiple sensory systems is what makes on-line control of movement possible, —by allowing the perceptual system to directly detect the higher-order characteristics of self-movement (Gibson, 1979; Fajen & Warren, 2003). Given this account of human natural unaided movement, then the means to control movement are directly present in the combined perceptual-motor capabilities of the agent. However, as we shall see, technologically aided mobility seriously alters the perceptual and experiential basis for control of self-movement.



### ***3.2 The bodily basis for control of natural unaided movement***

We are at this stage ready to describe the central features of how people control their activities and movements. The central features of the human mind as described in the embodied mind approach have as a common component the mutual interlocking relationship between an observer/actor and the environment. The body can be extended to include external objects (Hirose, 2002). Cognition is understood as also including the environment external to the skull in problem solving (Clark, 2005). Both these processes depend upon activity and movement and are guided by the interlocking activities of perception and action which both constrain and constitute the basis for each other (Overgard & Hoff, 2005). This interlocking relation is exemplified by the presence of invariant transformations in the ambient energy arrays that surround the person, and indicate that what constitutes the human mind is distributed in the interplay between body and world (Ingold, 2000).

These features show that humans are actively immersed in their environment, and that the control of activities is directly present in the joint body-environment system. The boundaries for control of unaided movement are realized in the interdependent system of bodily and environmental *constraints* on perception and action. Since the constraints for action is inherent in the body-environment system, the areas of safe, efficient, and informative movement is readily realized by the human body (Overgard, 2005; Overgard & Hoff, 2005). When the constraints for human activity are present in the body-environment system a person is able to maintain control the activities performed.

However, this interlocking relationship between body and environment undergoes changes when technology enters the loop. This is the focus of the next section.

#### **4. Technically aided human movement: Exceeding bodily constraints**

The majority of transportation vehicles have in common that they are operated by a human, either in the form of a driver situated inside the vehicles or as a control-room operator who monitors the movement of whole systems of trains or airplanes. However, living and moving with technical implements that exceeds the human bodily constraints entails problems of its own. These problems, as they pertain to the human ability to control the movement of the technical transportation vehicle will be presented.

**4.1.1. Exceeding human bodily capabilities.** Technical transportation devices increase our ability to move. We can move faster and longer than before. Technical transportation aids may increase our movement capabilities without also increasing our ability to perceive and control this movement. This means that, technologies and technical vehicles may impose a *discrepancy* between the normally interlocking action-capabilities and perceptual capabilities. Cars allows people to move in speeds that greatly exceed the human bodily limitations, but does not allow people to see further or to effectively adapt to these speeds. The limited field of view that comes from moving in high speeds is one direct effect of movement speed. In the worst case scenario, the person may be totally alienated to the movement as such, not knowing the direction and speed of the

movement, as may be exemplified the following quote of a helicopter-pilot trying to land in dense fog:

'The pilot took a waveoff as he attempted to land the helicopter on a spot lighted probably by four flashlights. Because of the extreme denseness of the fog he was unable to find the spot. As he circled to attempt a second landing apparently he became completely disoriented. While he was in vertiginous state, he circled to the right but thought he was turning to the left. Although he was on instruments he does not remember altitude or airspeed. As he crashed he stated he became a passenger and rode it in. "

(Clark & Graybiel, 1955; cf. Holly & McCollum, 1996a, p. 461).

Even though the instruments in the cockpit gave the pilot opportunities to supervise the helicopter's movements, it was not enough to avoid a crash. The mere presence of these instruments was not enough to inform the pilot of the helicopter's speed and direction. The increased ability to move about often leads to a discrepancy between the possibilities for action and the possibilities for perception, as is show in the quote above. The ability to move in 100 km/h by car does not lead to an increased ability to react to unexpected dangers, nor does it lead to an increased perceptual skill. In other words, technology allows us to increase our move in ways that do not allow us to use our bodily given perceptual capabilities to distinguish the qualities of a movement from other possible movements. During some modes of technologically aided mobility, the movement is guided almost exclusively by technological instruments, as in sea or air navigation at night, in dense fog or in shallow waters (Bjørkli, Røed, Overgard, & Hoff, in preparation).

The quote from Clark and Graybiel (1955) shows that some transportation technologies allow for movements that are only possible through the use of this particular vehicle. The helicopter allows for a range of movements, some of which is equivalent to the human vestibular system (Holly & McCollum, 1996a, 1996b). When movements are not distinguishable by the vestibular or proprioceptive sensory systems other sensory modalities are needed to know the direction, speed and rotation of the movement. For example: Visual invariants (such as those described above) give direct information about the direction and speed of this movement (Gibson, 1979; Larish & Flach, 1990). Invariant changes in the ambient energy array may then function as a natural externalization of these movements—it reduces the need for internal problem solving and also increases the redundancy in the sensory changes following the movement. The redundancy present in the combination of multiple sensory systems allows humans to directly perceive movement direction and speed. However, when redundancy is reduced, as it is in a simulator, during technically aided movement or when dense fog hinders visual perception humans often have problems controlling their movements. Some reasons for this might be presented. The first is that technical implements impose a discrepancy of perception and action. Another is that the technology takes humans into a new realm of movement and action, thus creating an environment where the forces of movements creates a different set of sensory changes than during unaided bodily movement.

**4.1.2. Perception of movement speed: Perception-action discrepancies.** The boundaries for the human perceptual range are larger than the range of human movements (Hancock & Chignell, 1995). However, technologically aided mobility does

not allow for the same type of perceptual feedback as natural movement. Technological devices that do not demand physical exertion of the driver (e.g. car, motorized boat, airplane, motor bike, train) lead to a *perceptually different* mode of moving (it is a difference that makes a difference) when compared with walking, running etc.

Technically aided movement has been found to affect human perception of speed and direction. Some examples taken from automobile driving may exemplify the effect of a technically based engagement with the world. When moving by car (or other technological transportation vehicles which surround the driver), the most feasible way for a driver to perceive the speed and direction of movement are by the use of vision as the optical flow pattern give information about the movements as such. However, the body is to a smaller extent involved in the movements of the car and the driver is supported by the car seat and belted fast in the car seat. This mode of movement reduces the sensory feedback from the internal sensory systems (e.g. the proprioceptive and vestibular), leading to a different experiential and physical basis for movement—a basis that may not be well fitted to the characteristics of the human embodied mind.

Research on the perception of speed while driving have indicated that this perceptually poor way of perceiving self-motion (related to natural bipedal movement) has led to a tendency to underestimate driving speed. This tendency is present during both the active production of speed and the passive estimation of speed and both in experimental and real settings (Evans, 1970; Recarte & Nunes, 1996; Conchillo et al., 1999; Conchillo et al., 2000). However, the estimation of speed is found to be more accurate when speeds increased, a result that probably was caused by increased noise from the car and road (Recarte & Nunes, 1996).

These studies may be compared with the study of Konczak (1994) where humans moved through a tunnel with movable walls. These walls enabled the researchers to manipulate the visual information about the speed of movement by altering the visual flow speed. It was found that the walking speeds of the participants were only to a small degree affected by the manipulation of visual information of movement speeds, a result that is understandable, as the subjects own movements created stimulation, which could help regulating the speed of walking (Bruce et al., 1996). The results indicate that humans usually are erroneous when they evaluate their driving speed. Compared to the results from Konczak (1994), this might indicate that the nature of car driving, e.g. the lack of bodily movement and sensory stimulation related to moving by car, leads to a discrepancy between actual and perceived movement speed.

Technically aided movement also has the possibilities to exceed the boundaries for the human sensory systems. A case describing this aspect is motion parallax which reflects the fact that visual objects close to the observer seem to move faster than objects further away (Rogers & Graham, 1979). When moving in an environment, objects in the visual field will seem to cross over each other, the nearby objects will seem to 'glide over' objects further away from the observer. The visual patterns moving over each other, nearby patterns occasionally occluding some parts of more distant visual patterns is one type of invariant transformation of optical flow (Gibson, 1979). Motion parallax plays an important part in the perception and experience of self-movement (Johansson, 1977), and the perception of speed in technological aided movement (Larish & Flach, 1990).

Given an observer moving in a stationary environment, the retinal flow speed of a given object will depend on two factors: The velocity of the observer's movement

relative to the environment and the distance of the object from the observer (Bruce et al., 1996). This relationship is related to the optical-geometric characteristics of the environment. Retinal flow speed from an object will increase as the observer's movement relative to the object increases, and it will decrease as the distance to the object increases, as is seen in formula 1.

$$\text{Retinal flow} = \text{Velocity}_{[\text{observer}]} / \text{Object distance}_{[\text{lateral \& angular}]} \quad [1]$$

However, even though the optical and geometrical aspects of retinal flow are deterministic, the effective psychological use of motion parallax is dependent on the human perceptual systems. By travelling at speeds that greatly exceeds the human bodily capabilities, visual invariants related to the mode of movement might be imperceptible as the optical flow field close to the driver does not contain any differentiable structures, but rather, becomes a *blur*. The optical flow over the retina from objects will become non-differentiable for the observer with respect to identifying structures in the environment at some critical speed. This will have the consequence that, at a critical value, motion parallax no longer aids the human observer in discerning the speed of the movement. Given the presence of a critical boundary marking when motion parallax is informative for action and when it is not, formula 1 show that as speeds increase, perceptible motion parallax will be composed of objects further away from the driver, thus entailing to a lack of visual information close to the driver. This problem is especially important when driving in tunnels, as the visual information about movement is presented only in one plane, -at the wall of the tunnel (Sagberg, 2002).

#### 4.2. *Movement mediated by technology*

As humans move naturally in the world, their own body and its action and perceptual capabilities is an inherent part of the action-possibilities laid out for the body. This bodily based relation towards the world is fundamentally altered when one uses technical aids in order to attain some goal. Technologically aided mobility differs from natural human movement and tool use by sometimes demanding that people *act in order to move*.

Hence, the operator has to perform actions—other than those related to bodily movement in order to be able to move. The operator interacts with the technology to be able to control and perform actions, rather than *moving to move* as in natural unaided human movement. Technology as such interferes with the ways that humans normally control action, by becoming a *medium* which mediates the operator's actions towards the environment while also altering their ability to perceive changes in the environment. Thus, by becoming an artificial link between human action and the world they move in, technology help humans to move faster, longer and more efficiently. This effect is the purpose of technology, to extend human perceptual and action capabilities to realms outside the human bodily constraints (Hancock & Chignell, 1995).

This capability-extending effect of technology shifts the constraints on activity out from the body and into the technology-environment system, thereby altering the basis for control of the technological system's activity (Overgard & Hoff, 2005). The forces of production are externalized; they are no longer directly related to human bodily activities (Ingold, 2000). This entail that the human operator is alienated towards the qualities of movement, the body is no longer the basis for the control of activities. This shift in the



basis for control entails that the operator must work with the technology in order to control the processes, however, the design of the interface further constrain the modes an operator can control this process. There is now not only the operational constraint of the technology-environment system (operational constraints), but also the constraints on operations and system representations (e.g. usability, meaningfulness of representations) in the body-technology system. These two layers of constraints divide the body-technology-environment system into two parallel systems which may not be directly bound together; the body does not act directly on the environment (through the technology) but must operate the technology *in order* to act on the environment. This has led researchers to ask that the operational constraints of the system are represented in the interface (Vicente, 1999).

However, the constraints and possibilities for action present in a technical context are artificial as there is nothing which constrains the relation between the represented and the representations in the technological interface (Hoff, 2004). This implies that a technological transportation vehicles can be controlled in any way made feasible by existing technologies. Hence, the constraining factor in technologically aided mobility is the technology and its possible applications, and not the body as such. In this sense there are in every technical context both a set of bodily human constraints and a set of technical constraints. It is the combination of these sets of joint constrains that demarcate the borders for safe movement of this system.

However, it is not enough that the moving agent is given means of controlling the activity of moving about in a technological vehicle—the way that this control is *used*, *executed* and *implemented* by the agent must be related to the characteristics of the

embodied mind and its relation to the physical movement. The transportation technology must be designed in a way that allows the operator to act *directly* on the task of moving about, rather than having to act on a technological interface which is between the operator and the task (Overgard, 2005).

#### ***4.3. Technology enables new Experiences of Movement***

The reasons for the design and use of technology are to extend or even exceed the human bodily capabilities (Hancock & Chignell, 1995). This aim of technologies is especially clear when we look at transportation technologies where we, by technical means, are able to move further, faster and in new terrains than before, a mode of movement which our current culture is based upon. However, on a personal or existential plane, this exceeding of human bodily movement capabilities also removes the body from the act of moving, an act which previously was both constrained and performed by the body. As technology alter the modes of movement is also brings forth new ways to experience movement. The new set of possibilities and settings for human movement also changes the basis for the experience of movement. These new experiences are based on sensorimotor relations only made possible by technology (Ihde, 1993, 2002). By making the technology the constraining factor for movement, the body loses its natural modes of controlling the movement (Overgard, 2005). However, the body is still able to control its behaviour *within* the transportation device; it is the movements *with* the transportation device which now are a problem for the body. A by-effect of technical transportation devices is to introduce in the human life-world an existential mode of being based upon and

constrained by technology (Heidegger, 1977; Ihde, 2002). The world is experienced through technology, and this experience is constrained and structured by the possibilities brought forth by the technology.

Given this view, it is possible to say that not only do technical transportation devices extend or exceed human movement capabilities, but its effect is deeper and more enveloped with human life than merely as capability-extending artefacts. Technology are (implicitly) intended to *reveal* an experience and a possibility for action, rather than just allowing the human body to control a given process through the technical device (Heidegger, 1977; Ingold, 2000). Transportation technologies thus shape the modes of human movement, and they shape it through their design and the possibilities and limitations engendered by their design. Transportation technologies, as they are implemented in the human life-world, give direction to how humans move about. This ‘shaping’, ‘enframing’ or ‘direction’ given by technologies is not value-free as it furthers some types of movement and constrains others. The claim of the value-laden nature of transportation technologies is not singular to transportation, but is extendable to all types of technologies (Ihde, 2002). Technologies take a part in shaping the ways that humans perform actions, and it even allows for some actions that would not be possible (as when riding a helicopter, see above). This structuring of human experience and life enacted by technology carries with it a type of *agency* that alters the modes of human thought and action. Technology carries with it a techno-existential mode of being, where our being-in-the-world is technically based and our actions are technically mediated (Heidegger, 1977; Ingold, 2000; see also Kronlid, submitted). In this view, technologies are not merely

objects in the world that are used, but are *lived*, and their enactment in the human life-world actively shapes our life-world.

## **5. Conclusion**

Technology extend the user's capabilities as have been note by previous researchers (Hancock & Chingell, 1995; Smitsman, 1997) but is also *invades* the human on several levels, *first* by altering the forces inherent in the use of tools/technology to a magnitude outside our bodily capacities, so that we become dependent upon technology to be able to sustain our current standard of life. *Secondly*, the design and functionality of the transportation device also alters and constrain the ways that we move and how we perceive movement to be performed. Our actions in a technical medium are based on the (technical) premises given by this technology. *Thirdly*, our understanding of transportation is to some extent based on the existing technical modes of movement made possible by technical transportation devices. This understanding is again reproduced when a designer uses this (sometimes implicit) understanding during the process of designing future transportation technologies. This shows that transportation technology is not merely 'things' that can be controlled, but that the technology also engenders ways that we look upon ourselves and upon our civilisation (Ingold, 2000; Kronlid, submitted).

As humans interact with their environment and with nature, they alter their *relations* towards the world, they enter new ways of body-world couplings which are not necessarily easily classified when it is agreed upon that the human experiential and existential basis for this coupling is the human body. This line of argument points to the

importance of investigating how technologies affect the human life-world. Technologies are no longer viewed as separate objects which are there to allow control, but as objects with which humans merge in the performance of goal-driven activities.

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## Tables

**Table 1: World records in athletics**

Sport discipline	Results	
	Women records	Men records
100 m Sprint	10,49 seconds	9,77 seconds
400 m Sprint	47,60 seconds	43,18 seconds
10.000 m running	29:31,78 minutes	26:20,31 minutes
Length Jump	7,52 meters	8,95 meters
Height Jump	2,09 meters	2,45 meters
Weight lift (heavy weight)	137,5 kg <sup>1</sup> / 182,5 kg <sup>2</sup>	213 kg <sup>1</sup> / 263,5 kg <sup>2</sup>
Javelin	71,70 meters	98,48 meters

**Table 1:** Current world records in sports, showing the limits of human bodily capacities for specific types of movement and action.

<sup>1</sup>Snatch

<sup>2</sup>Clean & Jerk

Paper II is not included due to copyright.

## **An Activity Theory Analysis of High Speed Craft Operation**

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### **Abstract**

This article presents an activity theory (AT) analysis of the operation of high speed crafts in military service. Today, there exist a significant technological push within the maritime domain where the design and innovation of new equipment is primarily understood as a technical enterprise. Alternatively, design and innovation could be founded in actual studies of the domains in question in order to bring forth important, but neglected aspects of performance if complex systems were studied as primarily technical systems. The AT analysis in this article first outline of relevant AT concepts and perspectives that downplays long term developmental features as culture and history, and where as the detailed description situated action is emphasised. Second, the AT concepts are used for analysing the domain studied, where critical aspects of system performance is made explicit. The AT analysis is discussed in terms of providing an alternative to a technical understanding of complex systems, and to what extent it may be applied in design processes.

Keywords: Activity theory, situated action, high speed craft, product design, mediation, tools.

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# 1 Introduction

The latter years have shown an intensified ‘technological push’ within the maritime transport domain characterized by the ‘digitalization’ of traditional navigational tools. Examples are the development of electronic sea charts replacing traditional paper charts, and integrated bridges converging previously separated technologies such as radar, satellite navigation systems, electronic charts, autopilots, and so forth (Lutzhof, 2004). However, the approach to the development of new and modernized navigational tools has so far been the technical perspective as such, as opposed to actual studies of navigation (Røed, 2005).

The main problem with technically driven design and development is the notion of human-technology systems as primarily technical, that is, there is a focus on the technical functionalities apart from their actual use by the practitioners (Vicente, 1999). The design and development of tools then becomes a rational problem solving process, where the designers merely map technical functions with operation tasks based on pre-specified task requirements (Hyysalo, 2002: p.60). This type of perspective on human-technology interaction builds on the conception of stringent work sequences that bridge technical functions and the human operator during performance.

Several researchers have criticized this type of normative approach to human-technology interaction, arguing that the context of the human-technology interaction is not sufficiently included. For a full discussion, see Nardi (1996), Vicente (1999), or Hollnagel and Woods (2005).

The main challenge has been to approach complex human-technology systems beyond their technical features, that is, to investigate the hybridization of humans and technology into a holistic functional unit. This means that these systems are not understood as primarily technical, but also in terms of their social complexity. An implication of this is that the unit of analysis in human-technology systems is broadened to include more than the ‘mental apparatus’ of singular operators and/or

specific technical solutions and possibilities. Rather, the aim is to investigate humans and their embedded use of tools, and apply this to support design of technological artefacts constituting the human-technology system in question.

From this perspective, performance is based in the history and present status of the joint performance of operators and technology as it involves the coordinate action of several crewmembers that is mediated and assisted by technology. Hence, an alternative frame of reference is needed within the field of analysis and design of integrated navigation technology to counteract a mere technologically driven product development.

The historical and contextual frame of reference in activity theory particularly takes the dyad of humans and tools into consideration (Nardi, 1996). The aim of this article is to map these concepts onto the domain of high speed craft (HSC) navigation in order to arrive at a descriptive analysis that can act as a basis for improved safety onboard, increased effectiveness, and better health among crew members.

The development of such a mapping is to some extent a theoretical endeavour, but first and foremost an empirical one. This article is based on ethnographic field studies of three naval exercises in the Norwegian Royal Navy in the period between 2003 to late 2005 where data was gathered by way of video recordings, interviews and participatory observation.

## **2 Concepts of Activity Theory**

The use of concepts in activity theory (AT) is somewhat unusual, compared with other theories of human-computer interaction. In addition, some of these concepts need to be refined to the application of HSC. Hence, we aim to describe some of the central concept of AT, and its relation to this particular domain.

AT emphasises how human behaviour may be understood in terms of *practice*, that is, the everyday actions of humans as embedded in a matrix of culture, history and

artefacts. Consciousness and behaviour is not understood as discrete disembodied features, but as constituted in a cultural-historical anchored and artefact-assisted practice (Nardi, 1996; Leontev, 1974).

This article presents observations and analysis of navigation in high speed centered on the particular interaction between tool and subjects in their effort to transform the object into outcome. With this perspective, the article shift focus away from the wide scope of the cultural historical timeframes, and suggest to emphasise AT concepts describing the *situated action* of navigation, hence postponing any analysis of the development over longer timeframes (aspects related to tradition, culture, and history).

By concentrating our observations on situated action, we are in the danger of parting the work praxis in our study from the culture it arises from, and we are in risk of not capturing the cultural influence that are present in the activity (e.g. Perrow, 1986). The same problem applies to the historical aspect, where we are at risk of missing the significance of historical development if we don't keep in mind the reciprocal relationship between history and activity.

## **2.1 The Reduced Model of Activity Structure**

Norros (2004) presents a reduced activity structure model that includes the subject, object, and the mediating media of tools that we will apply in order to focus on lower levels of activity in behaviour description. The model is shown in figure 1 below:

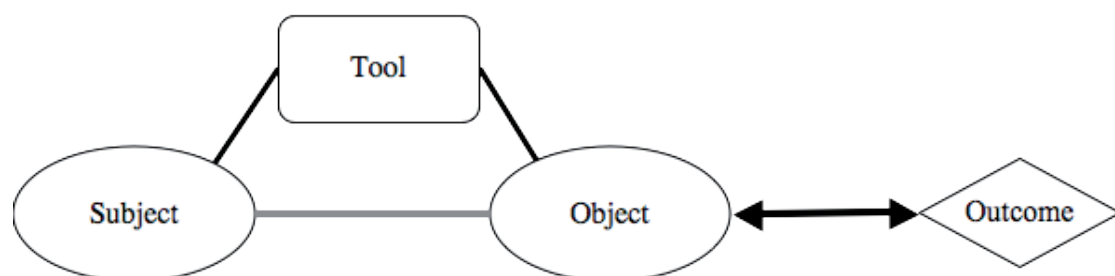


Figure 1: A reduced model of activity as the structure of situated actions by Norros (2004)

The reduced model emphasises how the subject<sup>1</sup> uses his or her tools in order to transform the object<sup>2</sup> into relevant outcome. The model further integrates the reciprocal relationship between object and outcome as indicated by the double arrow connecting the two boxes in the model. This suggests that the object is not exclusively regulated by the subjects, but also adjusted to certain ‘outcome features’ that refer to characteristics of the environment relevant for the activity.

The notion of ‘outcome features’ highlights the embeddedness of the subject in the context where the transformation of object into outcome is understood more as an *integration* or *adaptation* to the given environment. The object is then not some abstract formulation of a ‘static end-state’ to be achieved, but a desired state to be established and upheld through continuous activity in face of contextual variance and disturbances.

Norros (2004) points to Gibson (1979) and his concept of ‘constraints’ to explicate how outcome features may be understood as functional characteristics of the environment that are observer-dependent. In our application of the concept of outcome features, we suggest that there exist constraints that are equally ‘system-dependent’ so that different systems (e.g. different vessel classes) adapt and exploit different constraints in the environment. The specificity of such constraints corresponds to the features of the system capabilities and dynamics.

For further discussion of constraints, see Gibson (1978), Vicente (1999), Flach (2001) or Norros (2004). For an exemplification of system-dependent constraints, see Bjørkli et al (in press).

## **2.2 Mediation and media**

The reduced model of activity structure (fig.1 above) anchors practice in the relationship between subject, object, tools and outcome. Here, the subject and object are not related to each other directly, but connected through the process of mediation.

This implies that the activity elements of subject and object are connected through some medium, and further invites the specification of the media that connects the activity elements.

Hyysalo (2002) have discussed how motives of activity are transformed into outcome by the use of material objects or tools. A tool can be anything used in this transformation process, including external material tools (e.g. a hammer) and internal tool for thinking (e.g. a plan). Mediation then refers to the use of *tools*, that is, any artefact or material objects that enables the subject to achieve his or hers goal.

Rabardel & Beguin (2005) elaborates on the concept of mediation, and discusses *instrumentally mediated activity*. Tools are seen as composite entities based on the 'tool structure' and the subject's 'scheme'. The notion of 'tool structure' refers to the structural and formal aspects of the artefact. The notion of the subject's 'scheme' refers to how the subject organises his or her behaviour, that is, the internal structured set of action features that can be generalised and applied in different settings by the subject. The tool and the subject's scheme thus mediate activity together in some form of synthesis.

In mediation, two aspects may be identified. First, there is the *psychological mediation* that refers to how tools are used to support thinking about the object-oriented actions, for example the use of internal tools such as plans, concepts or heuristics (Kaptelinin, 1996). Second, there is the *communicative mediation* that refers to the use of tools to enable communication between persons involved in the actions.

### **2.3 Activity Levels**

The concept of practice is founded in the reduced model of activity structure where activity elements (subject and object) are connected by mediation through tools. In addition to this structural feature, activity can be articulated as having several layers

of detail granularity and correspondence in the description of subject behaviour. For example, Kuutti (1996) suggest that activity has a hierarchical structure (see figure 2).

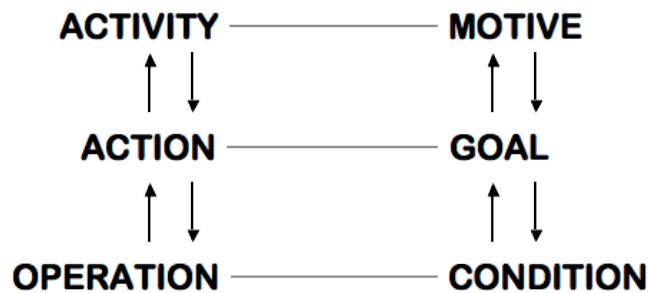


Figure 2 Hierarchical layers of activity

At the top of the hierarchy is *activity*, which is directed towards a widely defined and longer term motives. Subordinated to activities are *actions*. Actions are directed towards specific goals that are structured by a mental representation of the result to be achieved. Goals are reached by sequences of actions and are realized through concrete *operations* that correlate with the conditions of the activity unfolding. An activity system is regarded as functional and adaptive to the degree the behaviour levels and context is in correspondence, that is, behaviour is attuned to the relevant environment.

The concept of ‘tensions’<sup>3</sup> refers to the divergence between the formal object and the means for achieving it. Tensions then describe the disparity that occurs across and within the hierarchical levels of activity as the activity system fails to cope with the context.

## **2.4 Aim of this article**

This study presents a case study of navigation in HSC’s in military service within the descriptive framework of AT. We have outlined concepts and models from AT that will form the basis for the description of HSC operation. The concepts we choose to emphasise were the reduced model of activity structure, mediation and media, and finally the levels in activity. By offering an alternative description of HSC, we aim to make explicit features of practice that are directly relevant for design.

## **3 Method**

### ***3.1 Observation***

The basis for our study is the participation and observation on different navigation teams during three naval exercises in the Norwegian Royal Navy in the period between 2003 to late 2005. Data has been gathered by using video recordings, interviews, observation, and participation on courses for crewmembers. In total 120 hours of video was gathered.

## **4 Results**

### ***4.1 Vessel Class Features***

The Hauk-class fast patrol boat has a length of 36,5 meters, a beam of 6,5 meters, a displacement of 150 tonnes and capable of operation speeds of approximately 30 knots (17 meters per second or 60 km/hour). The ships were specifically designed for high speed navigation in very narrow in-shore waters (22<sup>nd</sup> FPB, 2004).



Figure 3: Fast patrol boat of Hawk-class during exercises in November 2004. Photo by the author

## ***4.2 Formal Instructions***

The Hawk-class is employed by the Norwegian Royal Navy with the formal task of patrolling in an efficient and safe manner and upholding national presence along the coastline of Norway. This implies the ability to operate in a wide variety of maritime environments, ranging from open to very confined waters, and during any time of day/night and any weather conditions. Efficiency refers to the ability to patrol large areas, and this feature is balanced by the need for safe operation, which refers to the responsibility of maintaining functional integrity of the ship by ensuring that the ship is able to sail and stay operative.

## ***4.3 Crew Organisation***

Five persons of the total crew aboard are directly involved in the navigation.

The kingpin in the navigation team is the *navigator* that bears responsibility of safe and efficient operation of the ship. The navigator plans the navigation before departure and executes this plan during sailing.



The *plotter* handles the chart during sailing and cooperates with the navigator to integrate observations from the surroundings in order to determine the ship's position. The plotter communicates information about the navigation plan to the navigator. The plotter has the navigation chart directly in front of him at the chart desk that is placed behind the navigator.

The *helmsman* steers the ship by using a wheel. The specific course to steer is ordered by the navigator. The helmsman has a gyro compass display in front of him where he reads the ship course and the angle of the current rudder position.

The fourth person involved in the navigation is the *lookout* that is situated outside the ship bridge and reports to the navigator what he visually observes. According to procedure, the lookout reports what is deemed important for navigation safety.

The *commanding officer* of the ship has the overall responsibility for the safety of the ship. He is also responsible for solving the military and strategic tasks carried out. The commanding officer usually supervises the navigator when involved in the navigation.

The individuals on the navigation team have their assigned workplace on the bridge as indicated in figure 4:

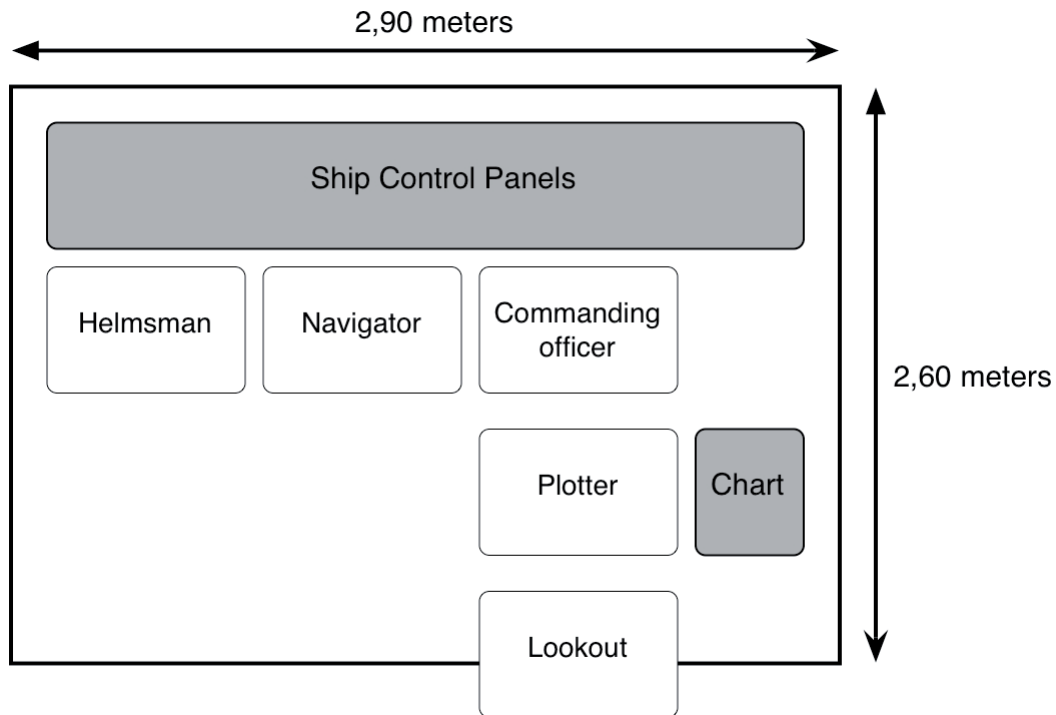


Figure 4: Left: Overview of the bridge. The ship's bow is up. The navigator is placed in the centre of the bridge with the commanding officer to the right. The helmsman is placed to the left, whereas the plotter is positioned behind to the right of the navigator. The lookout is outside the bridge.

## 5 Activity Theory Analysis

In this section, we will here map details from HSC operation to the central concepts from AT that we have chosen to focus on in this study.

### 5.1 The subjects

The operation of HSC concerns how the ship moves. On one hand, it involves the knowledge of the position of the boat represented by longitudinal and horizontal coordinates in relation to the planned track as drawn in the chart. On the other hand, navigation refers to the actual manoeuvring of the ship in terms of regulation of speed and heading. This is done by applying engine power and using the rudder.

Several crewmembers are involved in navigation and manoeuvring. Both the navigator and the plotter do the calculation of position. The navigator observes bearings and communicates the values and positions to the plotter. It is the navigator that plans the track before departure, but it is the plotter that handles the chart during sailing. When it comes to the manoeuvring, the navigator handles the throttles regulating engine power and thus speed. The heading is regulated by the rudder that is controlled by the helmsman, but on specific orders from the navigator.

We will here focus on the navigator as the primary subject in navigation, as he has the formal responsibility of the controlled proceeding of the ship, as well as being the prime agent in both the processes of regulation of speed and heading. The plotter and helmsman will be understood as secondary subjects in terms of their role as support to the navigator.

## ***5.2 The object and outcome***

Safety and efficiency are the main objects, and are manifested in the particular planned route plotted by the navigator in the chart before departure. This means that the main objectives are concretized to keeping the vessel on the plotted course. The outcome is regarded as the position of the boat over time during sailing, or more precisely, the particular trajectory of movement through the given waters the vessel moves through. This implies that position and movement of the ship must correspond to the formal instruction of maintaining safety and efficiency. Given the primacy of movement as the central system parameters, safety may be regarded as upholding minimum distance to dangers that might harm the ship and efficiency may be seen as patrolling large areas. Efficiency will here be to hold high speed to cover large coastline areas and make use of the sailable waters available.

The outcome is effectuated in the decisions of the navigator of where to sail, in detail, the particular decisions of what speed to hold and what course to steer. The subject thus relates to both the overall objective (formal instruction) and concretized objective (route plotted in the chart in terms of track and time spent), and then constantly strives

towards transforming safety and efficiency into particular ship movement in terms of the position, speed and heading.

### **5.3 Tools and artefacts**

The navigation tools used by the navigation team concerns the operations of calculating distance on course, take bearings and calculate the ship's position.

Calculating the distance on the course is performed in three ways. First, the plotter operates a *log* that measures the distance the ship has travelled through water. The distance travelled on the course is subtracted from the planned distance that is marked in the navigation plan written in the chart. The result of this subtraction is the distance to the point where to alter course that is communicated to the navigator. Second, the navigator also has a log that is used for controlling the plotter's calculations. Third, the navigator knows the total distance to travel on a given course line by use of a *stopwatch*.

Determination of position is achieved by combination of bearings. Taking bearings is done visually by optical means or by radar, both operated by the navigator. An *optical bearing device* is used to take detailed bearings where the navigator points this device toward an object and reads the compass bearing display indicating the relative heading between the ship and the object. In low visibility conditions, the radar is used for taking bearings and measure distances to objects that are optically unavailable. The radar provides a bird's eye view over the surroundings of the ship.

The chart is used for combining the bearings into a position, and keeps record of the travelled distance. The navigator communicates bearings to the plotter, and the plotter draws lines in the chart representing the bearings, and the intersection between bearings represent the ships position. The chart also represents land and navigation marks. The chart is hence the representation of the ship's proceeding in the world, as well as the representation of the plan to proceed.

The tools for manoeuvring the ship are fewer, and concern the regulation of speed and of rotational movement.

The helmsman operates the steering wheel that regulates the rudder angle and thereby the rotational movement of the ship that enables course change and maintenance. The helmsman follows the orders given by the navigator in form of specific rudder angles to steer or courses to hold.

The speed of the ship is controlled by the navigator with a throttle stick in the control panel in front of him. The throttle stick controls engine power and thus propeller speed. The navigator usually places and leaves the stick at the preferred level specifying a given speed level and then concentrates on the courses to steer. The throttle sticks are placed neutral position in order to stop the ship.

## **5.4 Mediation**

We will in the following section discuss psychological and communicational mediation found in relation to observation of the operation of HSC and the adhering use of tools.

### **5.4.1 Psychological mediation**

The psychological mediation refers to the synthesis of subject and artefact serving some cognitive function. This means that the tool somehow ‘carries with it’ or extends cognitive functions of the user into the actual tool-use. An example of this was observed in the use of the sea chart and the optical bearing device.

The process of navigation starts before the vessel leaves harbour. Here, the process of internalisation-externalisation is central (Vygotsky 1960; Valsiner, 1997). An internal navigation plan is externalised when the navigator draws lines in the chart that marks the track to sail defined by courses to steer and distances on each course. Further, additional information are added, such as areas with shallow waters, passing distance

to dangers and land along the route, as well as additional information deemed relevant (currents, tides water, especially difficult sections). The navigator externalises his plan in the chart according to his personal sense of what information will be important at what point in time. The chart is thus *enriched* in the sense that information is added and integrated to support the navigator and the plotter in their forthcoming cooperation.

The chart enrichment may be seen as merely ‘holding information’ of forthcoming courses to steer for the navigator (memory). Moreover, the enriched chart also anticipates the particular operations of calculating position and tracking travelled distance at specific parts of the journey to come. The additional information helps both the navigator and the plotter to guide their attention to salient features of the environment and attune their effort to control the ship movement. An enriched chart may outline where and when to take positions (e.g. salient navigational objects), special circumstances in certain areas (e.g. traffic, other naval activity), relevant navigational heuristics (e.g. context-sensitive and convenient methods of position determination), and so forth.

The enriched chart does not only refer to the movement-to-come of the ship, but also to the operations-to-come of the subjects. It forecasts the movement and a possible range of actions of the crewmembers.

The operation of the optical bearing device exemplified psychological mediation where the device is not only for taking bearings to navigational objects in the surroundings (e.g. sea marks), but also used for offloading memory. The plotter informs the navigator of the next upcoming course to steer as the journey unfolds through the movement along course lines and the transitions between them. Here, the navigator may direct the optical bearing device in the same compass direction as the next course. This means that instead of remembering the next course as a three-digit number, he let the tools support him. First, he could get a general notion of the next course by perceiving the approximate angle of the optical bearing device. The information of the next course is not just externalised from the short term memory, but also given a figurative representation as the actual position of the pointing device.

Second, he could read the exact course by viewing the course display. Just as the chart, the optical bearing device serves the offloading of memory of detailed information, but also carries with it a forecast of activities to come.

The chart forecasts in longer timeframes (i.e. the whole journey), whereas the optical bearing device foresees in shorter timeframes. (i.e. next course or next navigation object to be used).

#### **5.4.2 Communicative mediation**

The enriched chart represents a 'journey-dependent' interpretation of safe and efficient movement of the ship where the controlled proceeding of the ship in accordance to the planned track demands the coordinated actions of navigator, plotter, and helmsman. Here, the navigator uses the chart for verbal and physical communicative gestures in the interaction with the plotter. The navigator makes himself understood and elaborates his decisions to the plotter by physically pointing in the chart as well as verbally referring to features of the formal and enriched information. For example, if uncertainties regarding the identity of navigational objects occur (e.g. the identification of a particular sea mark), the navigator may turn over to the plotter and the chart, and point out spatial relationships and verbally elaborate his understanding that the plotter responds to.

The discussion of navigational operations is heavily based in the joint perception and understanding of the chart. Further, the anticipation of the upcoming courses is also based in communication over the chart. The navigator asks for 'the next course', where the plotter replies on basis of the enriched chart. This allows an economized and efficient dialogue. Further, discussions of navigation issues between navigator and commanding officer during supervision also relies on the chart as the common medium.

Considering the resolution of uncertainties as well as the routine navigational actions and supervision, the joint effort was clearly centralized around the chart and the enriched features.

## 5.5 Preliminary summary

The sections above discussed the dynamics of mediation as the subject relates to the object through the instrumental mediation of navigational tools. From this perspective, we have argued that the qualities of the tools guide and coordinate the behaviour patterns of the subjects.

We have exemplified several features, ranging from relatively simple offloading features (e.g. memory) to more complex features as forecasting and anticipation of actions and the communicative aspects of navigation work.

## 5.6 Activity Levels in High Speed Craft Operation

HSC operation is achieved through the coordinated operations within and between crewmembers during sailing. Further, HSC operation also includes considerable preparations, where the systematic planning of courses to sail precedes each journey. Going further in describing the temporal structure of HSC operation, we have outlined three distinct phases, namely pre-sailing, navigation and manoeuvring.

We will here present the phases of the activity in relation to the hierarchical levels in AT.

<b>Planning</b>	<b>Navigation</b>	<b>Manoeuvring</b>
Activity: Planning Motive: Safety & Efficiency	Activity: Navigation Motive: Safety & Efficiency	Activity: Manoeuvring Motive: Safety & Efficiency
Action: Enrich the chart Goal: Plan particular track	Action: Determine position and time Goal: Follow the planned track	Action: Controlled proceeding Goal: Follow track & Avoid dangers
Operation: Enrich the chart by adding information and courses Condition: Knowledge & Time	Operation: Observing of navig.obj. and keeping track of travelled distance Condition: Visibility & Time	Operation: Regulating rudder angles and operation of engine throttles. Condition: Sailable Track & Time

**Table 1 : Overview of activity levels across activity phases in HSC operation**



First, there is a planning phase where the navigator works out the track to sail and enriches the chart with course line and relevant info. There always exist a formalized plan before the ship leaves port. As soon as the ship departs, the crewmembers engage in navigation and manoeuvring.

In the navigation phase, we refer here to the actions of the crew to execute the plan by determining actual position of the ship and evaluate to what extent it deviates from the position indicated in the chart. Further, the crew anticipates where and how the ship is going to be in the immediate future.

The manoeuvring phase occurs simultaneously as navigation where the crew evaluates their position in accordance to the plan, but also in relation to where the ship is positioned in the context. The navigator manoeuvres in accordance to both the navigation plan and the contextual demands by primary regulating rudder angles and secondly adjusting engine power.

The phases follow chronologically, where planning takes place before the ship leaves port. However, the navigation and manoeuvring phases are deeply entwined. In some situations, even planning is performed during sailing, serving to further blur the boundaries between the activity phases.

## ***5.7 Outcome features***

The outcome of the activity system must make sense in relation to the actual situation the system finds itself within. It is, after all, how the system finds itself in the world that decides whether the object is obtained or not.

The state of the surroundings challenge the subject in their maintenance of the activity system within the boundaries set by the object (e.g. safe and efficient sailing). The surrounding world is constantly changing and offers disturbances and variance that

must be handled, for example strong winds, currents, tidewaters, and other naval traffic.

The crew relates to basic constraints when they effectuate navigation by use of their tools during operation. In this article, we comment upon two major constraints in the work domain for navigation.

### **5.7.1 Functional Space**

Maintaining safety and functional integrity implies that the ship must not contact with other solid objects, for example land or rocks. Solid objects can be the terrain above the sea surface, but it can also be shallow waters, sunken rocks, or reefs. Shallow waters for a fast patrol boat means water depth less than three meters, and is practically equivalent to land – it is not sailable.

In addition to the static objects as such (land, rocks, reefs, etc), there is the issue of moving objects. Other boats also represent restrictions in terms of where to sail, hence areas with much traffic are also considered functionally confined, but this feature will not be commented upon in this article.

Functional space thus relates to the extent navigation and manoeuvring takes place in open or confined waters. Open waters are characterized by the absence of contextual dangers (rocks, land, shallow water), whereas confined waters are highly constrained by such contextual dangers. In open waters, the ship moves in a non-constrained functional space. The absence of conflicting objects offers the possibility to sail in any chosen direction and with abundant time to operate. Oppositely, confined waters are highly constrained by the presence of land, rocks, vessels and/or shallow water. The ship has restricted options of which directions to sail, and a significant time pressure for operation and higher demands for precision.

The presence of dangers varies along the coastline suggesting that the distinction between open and confined waters is thus not categorical, but a difference in degrees.

Functional space serves more as a continuum describing the demand for controlling the position of the ship. This refers to the fact that the ship never moves along the *exact* course line, but navigators struggle to be as close as possible to it, and with the explicit knowledge of to what extent the ship deviates from the planned course.

Open waters allow deviation from planned course lines without risking the functional integrity of the ship. The navigator is still obliged to know the exact deviation, but may postpone the correction without any consequences. Oppositely, the demands for precision is considerable in confined waters. Any deviation from the planned course must be corrected immediately, and there is little or no error tolerance in the positioning of the ship. In open waters, deviations of position have mostly relevance for navigation and concern the formal constraints of following the planned course. In confined waters, position deviation has relevance for both navigation and manoeuvring. Position now also bears relevance to the physical surroundings in a more direct way, as contextual dangers directly threaten the functional integrity of the ship.

The ship always operates with small disturbances and variance in its performance, that is, the controlled movement of the ship is always subject to variance.

Disturbances originate from the effects from and interaction between context factors (sea currents, wind, water depth, and so forth) and activity system factors (crew performance, functioning technical systems). So, functional space emphasise that the potential cost of deviations drastically increases as the ship goes from open to confined waters.

The ship is then always off track in some sense. The change in functional space during a journey is thus a highly salient feature of the relationship in the object-outcome transformation, and will determine the significance and possible consequence of variance.

### **5.7.2 Visibility**

The navigator determines the ship position in a two-dimensional geometrical space of longitude and latitude by at least two ship relative measurements of heading to external objects. The term ‘optical navigation’ points to the visual basis of the observation of the relationship between the ship and the surroundings.

Optical navigation in HSC operation in the military setting applies three different navigation modes *(a) navigation by using optical bearings provided by vision, (b) optical bearings by vision supported by radar or (c) by radar alone* (Øi, 1985). These three modes of navigation are tied to the level of visibility: good visibility suggests using ‘unaided’ visual inspection of optical bearings (a) (eyes and binoculars), whereas poor visibility suggests an aided visual inspection with radar as support (b) or by radar alone (c).

The existence of different observation modes suggests that the functionality of the tools is context-bound to the quality of visibility conditions. The navigator adapts the absolute demands of position determination (minimum two observations) to the conditions at hand, where the range of tools available must cover the range of possible states under which observation is made. Here, the quality of navigation and manoeuvring cannot be better than the quality of the measurements made. Uncertain or misleading measurement will give uncertain and misleading position estimates. Further, if observation and measurement is not possible due to visibility conditions or inadequate equipment, the navigator cannot decide the ship position and thus fail operate the ship in accordance to motives of safety and navigation.

The nature of HSC operation in the military setting results in very high demands to precision and timing of determination of ship position, thus making visibility conditions a central outcome feature.

### **5.7.3 Matrix of Outcome Features**

Viewing the joint influence of the two outlines constraints provides a description of the context that activity takes place within. By combining the outcome features, we

see that navigation in confined waters with low visibility is most constrained, while navigation in open waters in good visibility is not significantly constrained.

Operation of HSC always finds itself in some form of matrix of outcome features, where functional space and visibility is of significance for navigation and manoeuvring underlying safety and efficiency.

## ***5.8 Activity System Tensions***

Activity systems revolve around the transformation of the object into outcome, and in this process there are certain tensions to be resolved. Tensions refer to the discrepancy between the object and the means for achieving it, and are here used to describe the gaps that occur across and within the hierarchical levels of activity. As noted when introducing the hierarchical levels of activity, activity have its reference to motives, actions to goals, and operation to conditions. The description of tensions on activity levels will refer to the same detail granularity.

*Tension propagation* is a key feature of the description of the dynamics of tensions where tensions at a given level spreads and develops within and across the activity phases. On one hand, unresolved tensions at the operation level may develop into tensions at the activity level (e.g. threatening safety and/or efficiency). On the other hand, tensions that are coped with are regarded as functional skills of the activity system.

We will now proceed to describe the tensions, where tension propagation will be traced from operation levels to activity levels within activity phases (planning, navigation, or manoeuvring), as well as their propagation across phases.

### **5.8.1 Tensions in Planning: Time and Knowledge**

The basis for the planning phase is the knowledge of navigational principles and how to employ these in order to enrich the chart so that it may serve as a tool that mediates

both psychological and communicational features. This is seen when the navigator prepares for the journey by marking off the route to be sailed and other information in the chart.

The central tool in this phase is the paper chart, pencils, rulers, and supplementary documentation such as tide water tables, additional charts, and so forth. The navigator performs this task alone.

In addition to knowledge, time serves as a key factor as it sets limits on how much information the navigator manages to enrich the chart with. The military context of high speed craft operation often challenges the navigator to change their plans in very short time frames, or perhaps even during sailing. Planning with less time available forces the navigator to prioritize what information to add to the chart. The course lines are absolute demands, but additional information might be left out, for example particularities along the track, distances to other objects such as landmarks and so forth.

Tensions may propagate upwards within activity levels in the planning phase, that is, from operations through actions to activity. Here, the lack of knowledge and/or time may result in a poorly enriched chart that fails to serve the psychological and communication mediation, resulting in the possibility of jeopardizing the overall goal of safe and efficient operation of the ship.

Further, unresolved tensions in the planning phase may propagate into the execution phase of navigation and manoeuvring by affecting how the crew performs in the transformation of object into outcome. More specifically, it fails to forecast specific operations, and suffers the communicative mediation of navigation.

### **5.8.2 Tensions in Navigation: Time and Visibility**

The ship departs and starts its journey when the planning is deemed sufficient. The navigator then follows the navigational plan by taking the ship along the course lines marked in the chart.

For a more detailed description of the tools used during navigation, see Røed et al (2005).

Despite the efforts to control ship movement by closely monitoring travelled distance and position, the ship will never exactly follow the course due to contextual variance (weather, sea currents, and so forth) and crew performance variance (inaccuracies in use of log and stopwatch). Variance is the source of constant disturbances in the activity, and the crewmembers constantly double-check position in parallel in order to control and to adapt to disturbances.

Through the constant handling of variance, the coordination of the keeping of travelled distance is tied in the observation of known external objects through the use of unaided vision, with binoculars, and/or radar. For example, there may be deviance in what the log of the navigator and the plotter is indicating due to inaccuracies in their coordination of resetting the log relative to the ship position at a given moment or situation (e.g. passing of a navigational mark or context characteristic). Further, there can be deviations in what the stopwatch is indicating compared to the log. Tensions are then expressed as indications of deviation between media in estimations of travelled distance (log, stopwatch, etc). However, it is by observation of external objects that the exact position is determined, and that any tensions regarding travelled distance is annulled by a new synchronization or resetting.

So, navigation builds on the knowledge of two aspects, namely travelled distances and position, and they are mutually connected. The unfolding of tensions ties the use of different categories of tools together, where combinations of bearings are the basis of the estimation of travelled distance.

Time is fundamental for navigation during sailing. Relative to speed, each planned course line also indicates the limits for the time available to verify position and prepare the transition to the next course line. Here, the time available for the actions of determining position paces the actions of the navigator as well as being a central feature of navigation itself as measure of travelled distance.

Visibility conditions are also an important constraint for navigation and position determination. When visibility conditions deteriorate, so does the access to visual inspection of the surroundings, and the navigator switches tools to compensate for this (from binoculars to radar). The operations for determination of position changes as well as the means for synchronizing estimation of travelled distance with the context.

In sum, the tensions related to navigation seem to revolve around the time scale and the determination of position. Tension originating from time constraints and visibility may be regarded as characteristic to high speed crafts as the operation in confined waters emphasises the need for timely and correct determination of position as critical for maintaining safety and efficiency. The tensions that may rise from time constraints and visibility conditions propagate both internal to the activity phase of navigation and across to the phase of manoeuvring.

### **5.8.3 Tensions in Manoeuvring: Time and Functional Space**

Manoeuvring refers to the controlled proceeding of the ship by regulation of speed and heading. The tools for manoeuvring are the steering wheel controlling the rudder angle and the throttle that controls the engine power and thereby rotation of propellers. The steering wheel and engine throttle has dedicated displays showing their status at any time. The navigator controls the throttles by hand, and gives verbal orders to the helmsman to execute specific rudder angles.

Controlled proceeding here has two frames of reference. First, it refers to navigational decisions where the navigator executes the planned track to sail. Secondly, it must correspond with the actual surroundings, in the sense that the ship must avoid contextual dangers such as rocks, land, perches, other ships, and so forth.

For manoeuvring, speed is directly linked to time constraints. The use of rudders and engine must be timely applied in order to steer the ship safely and efficient, so the choice of speed regulates the pace and timing of the manoeuvring actions of the navigator. High speed gives less time to manoeuvring, and lower speed gives more



time to control the movement of the ship. Time constrains manoeuvring, and time pressure becomes relative to the choice of speed.

Spatial structures also constrains manoeuvring. High speed craft operation in confined waters here offers a special challenge, as confined waters are characterised by the high number of forced course transitions in short distances (e.g. the Norwegian in-shore archipelago). The sailable track is very narrowly defined in confined waters and manoeuvring is thus tied to the precise and timely use of rudders and engines to accommodate the actual ship movement within this functional space. Further, there is the challenge of keeping the ship close the planned track marked in the chart.

Tensions on the operations level propagates upwards within the activity phase as the navigator fails to control the ship and take it along the planned track and within the sailable track. The untimely initiation lead to the trouble of obtaining situational goals (e.g. execute a specific turn), that is likely to lead to the threatening of the overall motive of safe and efficient operation as the ship is brought to a conflict with the surroundings.

#### **5.8.4 Preliminary summary of tensions**

The description of tensions is based in how the outcome features come into play in the different activity phases and the adhering activity levels. Tensions regarding planning concerns the time available and the use of navigational knowledge, the navigation phase is tied to time and visibility, and last, there is the manoeuvring phase tied to time and sailable track/functional space.

Based on our observation, we argue that the propagation and resolution of tensions within activity phases is not random, but reflects the inherent structure and performance patterns of the system analysed. The nature of the structures and patterns in tension resolution are both immaterial (historical, cultural practice) and material (technical structures). The activity system carries with it traditional and cultural ways of combining humans and technology to the given task, and thereby a way of resolving the challenges that it encounters in its transformation of objects to outcome.

It is in some sense, the long-term cultural and historical developmental traits that have laid the basis for these specific human-technology constructs, but the actual unfolding in situation is also part of the reflected action of the particular crew and ship. The description of tensions emphasizes how complex human-technology systems will reflect its complexity and multilayered composition.

## **5.9 *Tension connectedness***

We have described the actions and operations carried out by the navigation team according to the reduced model of activity systems. On basis of this, the discussion of tensions has indicated how tensions propagate within and across activity phases of planning, navigation and manoeuvring in accordance to outcome features. The propagation patterns suggest an underlying structure and the interconnectedness of activity system elements, and it is by tracking the particular developmental path of tensions during actual performance in situ that the activity system reveals its dynamic. Different types of navigation correspond to specific constraints and tensions where the main struggle for the operator is maintaining a suitable outcome in the ongoing transformation of object.

We have during observation seen particular episodes with tension propagation and will here present two examples of this process. First, we will describe what happened when the calculation of the distance to turn broke down, recalling that this calculation is an important operation for navigation. This example will show how tensions are not a categorical feature in terms of being ‘right’ or ‘wrong’ system performance, but a gradual drift away from desired system status. The operation of high speed craft always operates under degrees of uncertainty, where tensions affect the operation to a higher or lower degree. Second, an example of tension propagation in the subject-object relationship is presented, with emphasis on the physical properties of the mediating artefact as a source tension regulation. By restructuring the artefact, the artefact is differently integrated in the activity system.

### 5.9.1 Tension propagation in the object-outcome transformation

This particular episode took place during sailing in poor visibility due to little natural light and bad weather (heavy snow during night time sailing). The waters had a moderate presence of contextual dangers and are considered moderately confined by expert navigators. The ship was moving at top speed (approximately 30 knots).

In the incident observed, the navigator and the plotter independently calculated the distance to the next course by determining the position of the ship at a given moment. The optical bearing device was pointed in the direction of the forthcoming course, anticipating the bearing of a lighted perch that indicated the exact initiation of the turn to the next course. However, the navigator did not determine the ship's position accurately, but decided that the position was 'good enough' for continuing the navigation without a new position determination, and planned for an accurate updated position determination at the next course transition timed by the anticipated observation of the lighted perch.

In the next five minutes, this led to the propagation of tension in the navigation phase, originating at the 'action level' – the action of position determination was inaccurate and thus failing to support the goal of following the planned track.

The tensions escalated as the ship reached the assumed end of the current course line and prepared the transition to the following one. When the log indicated that the ship had reached the point where it should alter course, the navigator could not see the lighted perch that was anticipated according to the chart and forecasted by the optical bearing device. This suggested that the assumed position was different from the actual, and that the correspondence between navigation activity and context was low.

This tension posed questions to the navigator such as 'how inaccurate is the log'? 'How far can I proceed on this course'? 'How much uncertainty and course deviation can the system tolerate before jeopardising safety'?

The tensions threatened both the navigation and manoeuvring activity phases. The navigator was not certain of the actual ship position and therefore not sure of when and where to manoeuvre the ship. Further, there were clear time constraints present as the navigator was in the risk of overshooting the planned distance constrained by contextual dangers. Further, visibility was low, thus making additional observation for reducing uncertainty difficult.

In this incident, the navigator had planned to use the next perched light to determine the ship's position. However, when the light could not be seen, he trusted he could continue a few more seconds on the present course without heading into danger. The navigator believed the inaccuracy in position meant that he had not yet reached the position the log indicated. The inaccuracy was thus deemed to be in terms of time, not heading.

The navigators eventually choose to reduce speed to reduce time constraints, and prepared for an emergency stop. The lighted perch indicated the course transition turned up eventually, but the last thirty seconds before changing the course involved intensive communication between the navigator and the plotter. The navigator repeatedly wanted the plotter to confirm the next planned course as well as the distance on the present course, and to forecast eventual dangers in the immediate context according to the map.

The tensions imposed on the operations meant that the navigator had to realise his goal (position determination) by other operations. The basic repertoire of operations was expanded as tensions grew and propagated. For example, visual inspection of the environment to find navigational objects increased, where both the helmsman and plotter participated in the visual inspection of the surroundings. Further, the tools used in navigation changed as the use of optical bearings now included use of radar and GPS for determining the position.

### **5.9.2 Tension Propagation in subject-object mediation**

This example describes how tension may rise in the subject-object relationship where tools serve the mediation. Referring to the work of Beguin and Rabardel, the instrumental mediation is described by two dimensions; *instrumentalization*, which is artefact oriented; and *instrumentation*, which is subject oriented.

Our observed example illustrates instrumentalization (artefact oriented) where an artefact is enriched to facilitate the subject-object mediation. Here, the physical properties of a tool are changed to improve its use value. We will describe how the optical bearing device was enriched.

The optical bearing device contains a physical interface that may be rotated in the horizontal plane and an adherent display showing the bearing of the direction that the interface is pointed towards. A common subtask when using the optical bearing device is to take bearings 45 degrees relative to the ship's course. The bearing of objects 45 degrees relative to the ship bearing is central in a frequently used heuristic for calculation of ship position.

There are basically three ways of aligning the optical bearing device to take bearings 45 degrees relative to the ship's course: (1) Take the ship course and add or subtract 45 degrees and then align the bearing device to the calculated direction. While aligning, it is necessary to monitor the display to read the device's direction. (2) The device is also marked with a small scale with absolute bearing that can be used for alignment where zero degrees mark the direction straight ahead. This requires the navigator to lean forward for getting a close look. At night a torch must be used to perceive this scale during decreased light conditions. (3) Recently, navigators invented an ingenious design where the bearing devices were added small pins screwed into the body of the device. One pin is mounted on the moving top of the device at zero degrees, and the other pins are mounted non-moving base at 45 degrees. The navigator can be informed in relative bearings without the need for visual inspection and mental calculation by merely aligning the pin at zero degrees and the pin at 45 degrees.



Figure 5: The optical bearing device. The three alignment pins and the scale can be seen on the close up picture to the left. Photo by the author.

From observation one particular fast patrol boat, we saw that the optical bearing device was not equipped with pins. The navigator could not use the ‘haptic approach’ by aligning the pins when taking 45 degrees relative bearings, and this forced him to use mental calculations of bearings instead. When asked, he reported that the lack of pins made the operation difficult and more time consuming. Further, all artificial light aboard the bridge is shut down during navigation night in order to facilitate sensitivity to natural light conditions at night. This means optical bearing devices without the pins attached demands becomes cumbersome and time consuming to use, as only visual inspection of bearings is possible.

## 6 Discussion

The activity of navigation carried out onboard the bridge of fast patrol boats has been described by using the reduced model of activity systems. The reduced model emphasise the situated action by downplaying the cultural aspect that affects the activity over a longer time span.

The reduced model focuses on the activity elements of subject, object, and outcome. The elements are connected by way of mediation, where the subject relates to the object through tools in terms of psychological and communicational features of use. The object is the formal task that the system operates under which the subjects turn into suitable outcome during performance.

For high speed crafts in military service, the object is to operate and patrol the coast line of Norway in a safe and efficient manner. This object must be turned into concrete movement trajectories in and through particular coast regions. The activity system relates to this process on various activity levels that specifies the detail granularity of actions. The detail granularity of action corresponds with an according level of reference, where descriptions at the higher order activity level correspond with overall motives, actions correspond with goals, and concrete operations correspond with particular conditions.

In addition to this hierarchical structure of activity levels, we introduced a chronological structure in terms of activity phases. Three main phases was here introduced. First, planning the journey revolves around the enrichment of the chart, where the track to be sailed is marked down and supplied with additional information such as course bearings, distance to objects along the track, and so forth. Second, during sailing navigation becomes a key feature and this concerns the determination of ship position in relation to planned track and sailable track. Third, navigation is paired with manoeuvring by the initiation of technical systems to control the movement of the ship.

The notion of activity system performance includes both hierarchical layers and chronological phases. The object is transformed into outcome by upholding correspondence between layers and phases. Here, the notion of the transformation of

object into suitable outcome is highlighted as a reciprocal relationship, where outcome features play an important role in guiding actions. The status of the surroundings and outcome itself serves as conditions and motivation of activity together with the formal object. Examples of outcome features are functional space ('sailable water') and visibility conditions.

In the discussion of tensions, we illustrated the interconnectedness of activity system elements as well as the surroundings. Tensions build up and must be solved to the degree there is a gap between action and its reference at any level of the activity. For example there can be tension between activity and motive, action and goal, and finally between operation and condition.

Tensions manifest themselves in accordance to hierarchical layers and chronological phases, and will propagate accordingly, ranging from activity to operations, and from planning through navigation to manoeuvring. Two examples related to tension were provided.

Given that a tension builds up and propagates freely, it will bring the activity system in a state where it cannot fulfil the overall object of safety and efficiency. Damage to crew, material, or ship is considered a breach of these motives, and represent failure to handle tensions.

## ***6.1 The technological push***

The latter decade has shown a significant technological push within the maritime domain (Lutzhoft, 2004). Traditional tools, such as radar, charts, and steering systems, have been digitalized and this paves the way for integrated bridges where previous separate and tangible tools is operated by a single interface. The perspective for this approach is primarily a technical rationale (see Vicente, 1999). We argue that a primarily technical understanding of the HSC fails to recognize features of use that are essential to the development and innovation of artefacts within the maritime domain.



This article offers a theoretical foundation of systems performance that might provide an alternative to the purely technical approach. More concretely it questions the suitability of integrated systems and suggest an extended set of design considerations to be taken into account.

The suitability of integrated bridges is questioned by reference to the nature of tool mediation between the subject and object. We have shown in this article how subjects act through tools to turn the object into goal, and that mediation has both psychological and communicative features. First, integrated bridges, materialized as interfaces containing mouse pointers and computer screens, fail to support the enrichment of charts in the planning phase where the navigator supplies additional information by use of pencil, drawing directly onto the map. This low-tech instantiation of skill is highly adaptive to the time pressure and multiple formats of information in the enrichment process (courses as numbers, text, figures). The departure from this set of low-tech tools will make the communicational features of mediation to suffer. Integrated bridges restrict the joint communication by its placing and size, where the use of gestures becomes less efficient.

The theoretical input to design processes focusing on navigation equipment opens up the possibilities for artefact structuring and it suggests several design considerations to pay attention to.

## **6.2 From observations to design**

How can case studies be transformed to actual changes in the development of equipment for use in complex systems?

Woods and Hollnagel (2006) state that studies of so-called ‘joint cognitive systems’ are founded in the oscillation between *observation* and *abstraction*. This suggests that the observations acquired during participation in actual system performance are formulated as ‘patterns’ or higher order relationships serving as framework of the

expression of the skills of practitioners. The intention here is to move between observation to abstraction, suggesting that the abstraction of patterns should have some distinct qualities in order to prove useful for design – the abstractions should sufficiently describe the phenomenon, provide a solid mapping between concepts and observations and finally contribute with some surplus value by pointing out features beyond mere, descriptions of the system. Further, Woods and Hollnagel (2006) describe how studies should *spark inventiveness* – opening up for the experimentation with prototypes that builds on the abstracted patterns.

In this article, we build on our observation studies to describe how activity levels and phases unfold, and how tensions present challenges to the navigator. This analysis offers perspectives of the system studied that goes beyond mere descriptions – and arguably meets the criteria of Woods and Hollnagel (2006). For prototypes originating from the present AT analysis, see Røed et al (in press).

### **6.3 Critical Reflections**

This article present material based on AT that extends the description and provides further insight into the dynamics of operation of high speed crafts in military service. What threats are there to the validity of input? This concerns the issue of validity of the interpretations of the observed data.

In his book *Cognitive Work Analysis* (1999), Vicente criticizes descriptive approaches to design. He argues that the descriptive approach struggles to separate what actions that are motivated by system states (e.g. changes in process to control) and what actions that are forced by the artefacts used to control the process (e.g. characteristics of interfaces). This is equivalent to the notion of the task-artefact cycle where human action is seen as shaped by both the problem to be solved, but also by how the tool is used (Carroll et al, 1991). Descriptive analysis struggles to differentiate between ‘true’ task challenges and tasks originating from the use of the specific tools. Vicente thus criticises descriptive work analysis for being device-dependent, which implies that we inherit the challenges related to the characteristics

of the tools currently used rather than designing new tools as such that build on an understanding of the task at hand. Characteristics of technology and tools should be an output, not input, to the design process. The suggested cure is a device-independent work analysis, downplaying issues of current tool use by focusing on the intrinsic work constraints. In our paper, we have applied reduced model of AT with focus on how outcome features also structures operator actions. We thus aim to incorporate ideas from the formative approach without leaving the close description of human activity with its tool-use. The main motivation here is to provide design input that is *formative* in the sense that it describes the foundation for the adaptive functioning of a system, not the specific action per se (full further discussion, see Vicente, 1999).

## 7 Conclusion

This study has provided a description of what is going on at the bridge of a fast patrol boat. To proceed from a description of the domain to concrete design solutions will be the next step in order to use an activity theoretical approach in design. Future studies should aim to implement activity theoretical description in design process, and further evaluate if an activity theoretical based design improves the performance of navigation teams.

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<sup>1</sup> The 'subject' is a person or may also be defined as a group involved in a joint goal oriented activity. The specific study at hand decides whether the subject is defined as singular individuals or a group. See Halverson (2002) and Nardi (2002) for discussion of defining subjects in AT analysis.

<sup>2</sup> Activity is often founded in the reference to a coordinating 'task' or 'object'<sup>2</sup>, which denotes the goal to be achieved under given circumstances (LePlat, 2001). The concept of 'object': The word has several connotations in common use. In discussion of AT, 'object' have at least two meanings: On one hand, it may be understood as a name for material things serving some purpose in a given activity (e.g. a hammer for a carpenter). On the other hand, it might be used as referring to a goal or motive (e.g. the

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goal of building a house). We will in this article use ‘object’ in the latter sense, that is, as referring to shared motives for action or the common defined goal for a given activity system. Objects as material things will be labelled tools or artefacts.

<sup>3</sup> ‘Tensions’ resembles other terms launched to address the issue of malfunctioning activity systems. For example Nardi (1996) has used the terms ‘contradictions’, and ‘breakdown’ to outline the lack of correspondence in activity. See Nardi (1996) for discussion.

# Activity theory as a supportive framework in design of navigation equipment

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## ABSTRACT

This study reports on the use of Activity Theory as a supportive framework in a design process. Crews on Fast Patrol Boats in the Royal Norwegian Navy were observed during high-speed navigation in coastal waters. The unit of analysis was the navigation team of five persons in their work. Activity was regarded as situated actions shaped by tools, objects and constraints. The framework of Activity Theory was used to form a design language that encompassed the aspects relevant to design and navigation. Based on the findings, a prototype of a automated steering system was built. We suggest that in design process, Activity Theory moves the focus from the technical qualities of artefacts towards how artefacts are used as tools to mediate activity.

## KEYWORDS

Activity theory, design, ships, navigation

## 1.- Introduction

A team working on the ship's bridge navigates the ship by cooperation and operation of advanced equipment in order to proceed safely. A ship is here considered a dynamic system as it is heavily influenced by environmental factors such as weather, wind, and visibility conditions.

During the last 10 years automated systems has largely been utilized in operations of ships. Despite the complexity of modern ships, the design of the bridge layout and navigation artefacts is traditionally not subject to any explicit design process. Safe operations are established through the fulfilment of technical and functional demands stated by classification societies and international organizations.

Technology driven design narrows the designers' focus to technical features of the single artefact, rather than focusing on its actual use. By using Activity Theory (AT), we wanted to expand focus to describe how artefacts have more than technical and formal qualities. This study will investigate how such an approach can shape design.

Design approaches commonly emphasize the need to understand the context in which products are to be used. However, these approaches are primarily ways to identify and organize steps in a design process, rather than research-based theoretical frameworks that guide in how to describe context of use. Support from AT may augment design approaches by providing tools for understanding the meaning and implication of the context.

In a design process, AT intends to bridge the gap between descriptions of work and the design of artefacts. This is a large step that can be taken as two smaller steps. First, AT can be used to give a description of work. Second, AT can contribute to a *design language*, which represent those aspects of work that matter to design (Beyer, & Holzblatt, 1998). This paper primarily concerns the latter aspect, but the forming of a design language is based on a more comprehensive AT study of navigation



(Bjørkli, Roed, & Hoff, 2006). In the following, the framework of AT is described, but limited to the aspects of the framework that were used for design purposes.

## 1.1.-Activity Theory

The underlying model of activity is based on Engeström's complex model of an activity system (Engeström, 1999). Originally Engeström emphasizes the cultural and historical influence on activity. To model behaviour generating mechanisms in maritime navigation, we regard activity as *situated actions* taking place over shorter periods of time. The situated actions model of activity also includes *constraints* as adopted from Norros (Norros, 2004). The model is shown in figure 1. By this approach, we have deemphasized factors of longer-term influence such cultural aspects and development of habits.

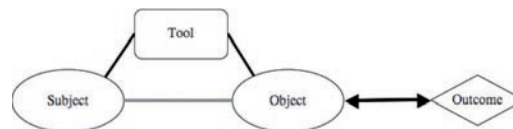


Figure 1: Representation of situated actions

The *subject* is a person or group in the activity. The *Object* is what directs the activity. The subject does not directly relate to the object, but relates indirectly through the use of *tools*.

The tools are used to *mediate* activity towards the object. This study emphasizes two forms of mediation (Rabardel, & Béguin, 2005):

*Reflexive mediation* refers to creating relations between the tools and the subject, and how the subject uses tools for support. Examples are how people use colour codes in software applications to memorize the state of ongoing processes.

*Inter-personal mediation* concerns mediated relationships to others. Examples are computer programmes where people elaborate on other persons' previous work.

The object is transformed into some form of *outcome*. The model has a two-way arrow between the object and the outcome, where the outcome also influences the object. This mutual relationship is shaped by *constraints*. Constraints are system-dependent functional characteristics of the environment. Subjects in different systems (e.g. different vessel classes) operate under different constraints (Bjørkli, Roed, & Hoff).

In the real world, change and development are distinct features of the activity. The term *tensions* are used to describe the misfit or conflict in relation to other activities or within the development of a single activity. In this sense, activity systems unfold through the resolution of tensions.

The last point made here is about the hierarchical structure of activity (Ruutti, 1996). At the top of the hierarchy is *activity*, which is always directed towards a *motive*. Subordinate to activities are *actions*. Actions are directed towards conscious *goals*, where a goal is structured by a mental representation of the result to be achieved (Leontev, 1974). Goals are reached by sequences of actions, and are realized through *operations* that correlate with the actual *conditions* of the activity.

## 2.- Methods

In order to gather knowledge on activity of navigators and the use of navigation equipment, a case study was conducted on board Norwegian Fast Patrol Boats (FPB). Two crews were studied during naval exercises in 2003 and 2004. Direct and indirect observation was conducted, in total 120 hours of video was gathered. Semi structured interviews with navigators were carried out.

### 3.- Results

The Hawk-class FPB is 36.5 meters long, 6.2 meters wide, and reaches a speed exceeding 30 knots (15.4 meters/second) (RNoN, 2006). The ship is designed and built for high-speed navigation in confined waters. The main tasks of the vessel is patrolling and upholding national presence in inshore waters. The FPBs are navigated by a team of five persons, working on the bridge of the ship.

The tasks of the ship require several activities to be conducted simultaneously. In our study, we will limit the focus to the activity of navigation, which is the unit of analysis.

The subject of our study is the navigation team consisting of five persons; the lookout, the helmsman, the plotter, the commanding officer, and the navigator. An overview of their workspace is shown on figure 2.

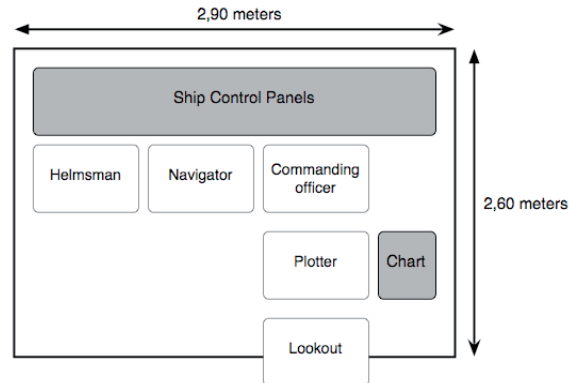


Figure 2: Overview of the crew's workplace.

The *navigator* is the kingpin of the team. He is responsible for planning and executing the voyage. When planning, the navigator draws lines in the paper charts representing the track to be followed. When navigating, the navigator aims to follow the planned track, and the navigator is assisted by the *plotter*. The plotter communicates information from the paper chart. The *lookout* is situated outside the bridge house and reports issues that the navigator should be aware of, such as lighthouses and other vessels. The *helmsman* steers the ship according to direct commands from the navigator. The *commanding officer* has the overall responsibility of the ship. When present on the bridge, he usually supervises and controls the performance of the team.

Navigation encompasses both *position fixing* and *manoeuvring*. Position fixing is about knowing the position of the ship. The navigator and the plotter cooperate in order to have continuous knowledge of the ship's position. Manoeuvring is about directing the movement of the ship in terms of speed and heading. The navigator regulates the speed, and gives verbal orders to the helmsman of what specific rudder angles or heading to steer.

The object of the team can be explained by reference to the hierarchal structure of activity. The motive of the activity is to follow the planned track. Subordinated to the motive are the actions. The most prominent actions are to direct the heading of the ship, control the speed, take positions, and plot the vessels progression. The persons on the navigation team carry out these actions individually. The actions are carried out by operations, which are done through the use of artefacts.

The most used artefacts are the wheel and compass, used by the helmsman for steering. Further, the navigator controls the speed by regulating the engines, using throttle levers. The navigator also operates the optical bearing device for fixing the ships position. The plotter works with the paper chart using pencils and rulers. The CO's most prominent tool is the radar situated in front of his work place.

The navigation team direct their work to transform the object of safe and efficient travel into the outcome of specific movement of the ship.

### 3.1.-Dynamics of navigation

Navigation is a dynamic activity, and there are always tensions present. These tensions can have a small or large impact on the activity. Before we describe tensions' influence on the activity, the dynamics of navigation will be commented upon.

The planning of the navigation is conducted when the ship is secured at port. From the moment the ship leaves harbour, the navigation plan is effectuated. Meeting other vessels can hardly be planned beforehand, but must be included in the navigators execution of the plan. For the navigator to achieve and hold an internal representation of the plan, it is continuously communicated with the plotter and the lookout.

The navigation plan, externalized in the chart, is a tool used for inter-personal mediation, where the plotter elaborates on the previous work of the navigator. The course and distance to sail is constantly communicated between the navigator and the plotter. At regular intervals, the plotter calculates the position of the ship in the chart, and estimates the future positions. When the navigator has received and understood the information given to him, he acknowledges. If the navigator is in doubt about the meaning of the information, he asks the plotter to repeat or verify. When the navigator and the plotter discuss upcoming parts of the voyage, the chart serves as a common frame of reference.

A particular way of reflexive mediation is the navigator's use of the optical bearing device. In navigation, upcoming courses are often cued by characteristics in the environment. For example, a specific heading of a lighthouse in relation to the ship may cue an upcoming course transition. The navigator may then in advance direct the bearing device so that it points to where the lighthouse will become visible in accordance to the navigation plan. This forecasting of the direction where an environmental characteristic will appear is used to effectively find and identify the course transition cue. An advantage is that the navigator does not have to hold the next course in his working memory as he could just read the course on the bearing device's display. Further, he could let the tool figuratively represent the direction instead of remembering the next course as a three-digit number. First, he could get a general notion of the next course by roughly estimating the angle of the optical bearing device. Secondly, he could read the exact course by viewing the display. The information of the next course is not just externalised from the short time memory, but also given a figurative and spatial representation by the actual position of the pointing device.

Just as the chart, the bearing device offloads memory of detailed information. In addition, they also carry with them a forecast of activities to come. The chart forecasts in longer timeframes (e.g. the whole journey), whereas the optical bearing device forecasts in shorter timeframes. (e.g. next course or next navigation object to be used).

### 3.2.-Serious tensions

The activity can become entangled in a sequence where the activity is "going sour" when faced with serious tensions. This means that minor and unproblematic tensions come together and form a breakdown (Woods, & Sarter, 2000). We will in the following describe a situation where several tensions surfaced and threatened the activity.

The factors described corresponds to how the navigation team interacted with different types of tensions; environmental constraints, external and internal tensions.

Environmental constraints, such as daylight, influence the activity. This is demonstrated by the following example. Reference points for position fixing were not visible due to darkness and snowy weather. This led to uncertainty about the ship's position. The navigator realised this, but decided that the ship's position was accurate enough for continuing the navigation. In the next five minutes, this led to an activity breakdown. The ship's position was not able to be determined, and the situation became more and more uncertain. Eventually the navigator prepared to stop.

The sequence was made even more complex because a meeting ship had to be cleared, and this forced the navigator to deviate from the planned track. A third internal tension was connected to the technical status of the ship, as a critical alarm was sounded on the bridge.

All tensions occurred simultaneously, and their total impact on the activity can be described by the hierarchical structure of activity.

When minor tensions were present, the activity was carried out as operations. When tensions came into play, the activity took the form as actions directed towards conscious goals. As an example, when the ship's position were uncertain the navigator took the radar into use and estimated the ship's position based on radar measurements. During this work it was necessary to work consciously on the radar. Communication between navigator and plotter became more ad-hoc based, rather than procedural. The team also shed certain tasks, such as communication with persons outside the team. Equipment were re-configured, the engine controls were put to manual operations since this would allow the ship stop in a shorter distance.

At the peak of the episode the navigator had to deviate from the planned track, which meant that the activity could not longer be directed towards the motive. The navigator then established a new motive, and directed the activity towards keeping the ship in safe waters for a time long enough to get a position fix. The object was to avoid a basic constraint, solid land. After the ship's position was found, the activity again was directed towards the planned track.

The description of navigation has focused on the dynamic aspects of the activity, and how artefacts fill their mediating role. Tensions are always present and shape the activity, and thereby also the persons' use of artefacts. In the following, the description of the activity will form a basis for design of an artefact for supporting the navigation team.

## 4.- Design

AT was used to support design of an automated steering system. This kind of steering system is frequently used on modern high-speed craft, and will be taken into use on the next generation FPBs. Here, a course- and track pilot will replace the helmsman. This system can steer the ship on a given course, like a helmsman, or the system can make the ship follow a planned track, combining Global Position System (GPS) data with steering data. These two modes are called course mode and track mode.

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When proceeding from the description of navigation and to design of specific artefacts, AT contributed to a design language reflecting what mattered in FPB navigation and what mattered in design.

### The Slider

The design result was *The Slider*, as seen on figure 3.

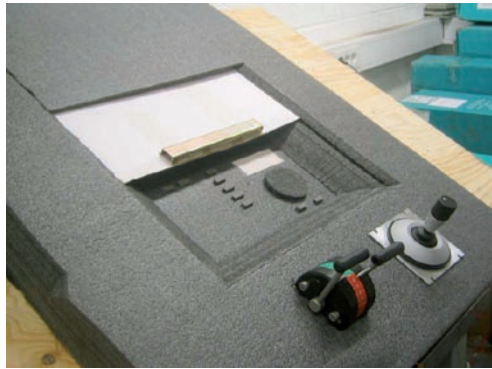


Figure 3: The Slider, course- and track pilot

A sliding curtain regulates the access to the functions and interface of the course- and track pilot. The pilot can be operated in three modes; in fully manual mode the curtain is all down, hiding all functions of the autopilot. The functions then visible are the least automated controls, the throttle for controlling the engine, and the joystick for controlling the heading of the ship. When the curtain is raised to half open, as on the figure, the interface of the course pilot is revealed. The curtain must be fully opened to reveal the track pilot interface. Changing the position of the curtain automatically switches mode.

The course- and track pilot is a tool for mediate steering of the ship. The pilot should be easy to operate in order to support its mediating role. The structure in which information is embedded should be easily available by avoiding menus and submenus.

The Slider clearly communicates its status as there is a distinct representation of the three different modes. In order to change mode, one physically operates the artefact. The levels of automation are clearly represented to enable communication about the given automation level. Change of automation level is as well clearly represented.

A course- and track pilot has a highly automated function enabling the ship to follow a planned route. This opens for tensions connected to technical issues. The pilot should therefore have different levels of automation, and the least automated level should correspond to the basic constraints of the activity. For a ship, that is to avoid solid land by controlling engine thrust and steering heading.

## 5.- Discussion

In this study AT provided a framework that coherently described the persons involved in FPB navigation, their use of tools, and what directed their behaviour. Further, AT provided a basis for a design language that was used in design of a course- and track pilot. The AT framework argues that an artefact encompass qualities beyond formal technical attributes.

AT are described as an attempt to integrate three perspectives; the objective, the ecological, and the sociocultural (Kaptelinin, 1996). In our study the latter perspective is downplayed. Literature (Perrow, 1984; Norros, 2004) has described that longer-term formations influence navigation safety. We recognize that longer-term formations are highly relevant, however they are outside the scope of this design study.

AT is a highly descriptive framework, and descriptive methods in design work have some weak points. A new design will influence the activity, which again will demand a new design. This is called the task-artefact cycle (Carroll, Kellogg, & Rosson, 1991). One way of overcoming the task-artefact cycle is to describe the structures of the activity rather than the particular and artefact specific tasks that are carried out (Vicente, 1999). For this reason the design language should have the power to make inferences (Halverson, 2002).

This study argues that using AT can bring important inputs to a design process. However, there is no 1:1 mapping between the theoretical descriptions of the domain and the design solutions. Descriptions provide a solution space including several possible design solutions. Proceeding from description to design involves a “magic step” where one or more solutions are chosen.

Because theoretical findings do not directly imply a specific design, one could argue that other approaches could lead to the same design. Several design guidelines such as Norman’s seven principles (Norman, 1988) and Nielsen’s design heuristics (Nielsen, 1993) embed several of the qualities that the Slider represents. However, this study claims that there are issues that are specific to the activity. Design guidelines and heuristics are general. To capture specific issues, there is a need for a framework that focuses the important structures of the activity in question. However, AT should not be an isolated tool, but should be regarded as one way of improving a design process.

The Slider has not been user-tested or evaluated in other ways. The purpose of our design was to suggest improvements to a system. The design of the slider can in this sense be regarded as a hypothesis of how a course- and track pilot can be designed. Further work on the design of the course- and track pilot should iterate between evaluation and design.

## 6.- Conclusion

This study argues that AT findings can contribute to design of navigation equipment. AT provides a framework that can be used to capture specific issues of the domain in study. The unit of analysis directs the focus to how artefacts are used as tools, and provides a framework for describing how artefacts have qualities beyond the formal technical attributes. Terms from AT can contribute to a design language, in order to support design.

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#### RÉSUMÉ

Cette étude rend compte de l'utilisation de la théorie de l'activité comme support à un processus de conception. Des équipages de vedettes rapides de la marine royale norvégienne ont été observés au cours de navigation à grande vitesse en eaux côtières. L'unité de l'analyse était un équipage de cinq personnes pendant leur travail. L'activité a été considérée en tant qu'actions situées, déterminée par des outils, des objets et des contraintes. Le cadre de la théorie de l'activité a été utilisé pour élaborer un langage de conception englobant les questions concernant la conception et la navigation. À partir des résultats obtenus, un prototype d'une commande de pilotage automatisée a été réalisé. Nous suggérons que la théorie de l'activité change la centration du processus de conception : des propriétés techniques des artefacts vers la manière dont ils sont utilisés comme outils médiateurs de l'activité.

#### MOTS-CLÉ

Théorie de l'activité, conception, bateaux, navigation.

#### RESUMEN

**La teoría de la actividad como soporte para el diseño de equipos de navegación.** Este estudio da cuenta de la utilización de la teoría de la actividad como soporte para un proceso de diseño. Se han realizado observaciones de tripulaciones de lanchas rápidas de la real marina noruega, en el transcurso de navegación a gran velocidad en aguas territoriales. La unidad de análisis fue una tripulación de cinco personas durante su trabajo. La actividad fue considerada en tanto que acciones situadas, determinadas por las herramientas, los objetos y las dificultades. Para poder elaborar un lenguaje de diseño que englobe las cuestiones referidas al diseño y a la navegación, se ha utilizado el enfoque de la teoría de la actividad. A partir de los resultados obtenidos, se ha realizado un prototipo de dispositivo de pilotaje automático. Concluimos señalando que, durante el proceso de diseño, la teoría de la actividad desplaza el foco de atención. Mientras que el diseño tradicionalmente se centra en la calidad técnica de los artefactos,

la teoría de la actividad hace foco en la manera en que los artefactos son utilizados como herramientas mediadoras de la actividad.

**PALABRAS-CLAVE**

Teoría de la actividad, diseño, embarcaciones, navegación.





# Using video in field observation: A case study

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## Abstract

This article presents a case study that focuses on the use of video in a field observation study of the operation of High Speed Craft (HSC) in military service. The article describes the use of video in relation to ‘joint cognitive systems’ (JCSs), a human–technology systems perspective that considers system performance to be grounded in the distributed and coordinated actions of operators and technology. In this perspective, human factors research should start with the observation of work practice, as instantiated between and across operators and artefacts in the system in question. Video supports observation and enables a parallel view of a range of central system agents. However, the integration of video is not straightforward. The field observation involves the explication of the theoretical understanding of the JCSs at hand, and the resolution of practical problems encountered. This article presents a structured scale-up of the video tool set-up. The various stages of the integration and enhancement of the technical set-up are described. Finally, the relationship between theory and methods in integration of video in field observation are discussed with emphasis on the interaction between theoretical explication and practical challenges.

## 1 Background

The study of joint cognitive systems (JCSs) is based on observations of the interactions of people and technology during goal-oriented performance. Thus, the

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unit of analysis is people and their artefacts as they cope with the dynamics and complexities of the system they control. The prime subject of observation is *work practice*—the adaptive skills of JCSs as they unfold in a given context (Norros 2004). Field studies need to observe work in its natural habitat, which is constituted by the subjects and the goals they strive to achieve. Here, observation serves as the basis of the study by facilitating hypothesis generation and the discovery of domain specifics (Roth, Christian, Gustafson, Sheridan, Dwyer, Gandhi, Zinner and Dierks 2004).

JCSs are approached through observation by shifting between participation in work practice and the abstraction of patterns constraining work. The complementarity between the involvement in the observed work practice and the analysis of the system studied seeks to establish *authenticity* of abstracted patterns in analytic descriptions. Authenticity here relies on the correspondence between the theoretical abstractions derived and the practice observed (Woods and Hollnagel 2006). However, not only theories and patterns are derived from field studies. Researchers are also faced with the challenge of applying methods of data collection to the specific circumstances of the given field study. Here, methods and the associated techniques or procedures are primarily generally or formally defined; for example, interviews can be defined as formal conversations between two persons with the intent of evaluating or sharing information. Observation can be defined as the recording or description of the action of the study subject (Faulkner 2000; Robson 2002). However, the general definition must somehow be translated to the conditions of the particular study at hand. Here, one considers methods as not merely being executed during studies (as if there were strict procedures to simply apply). The application of any method suggests the adaptation of general principles to particular circumstances. The use of methods and techniques implies the invention of practical ways of collecting data whilst preserving the principles central to the respective method (Robson 2002). Hence, it is through some form of particular methodological expression that observation is established and thus enables theory construction.

### ***1.1 Use of video technology***

The use of video is a fairly new enterprise in observational research, and has emerged in human factors research in the last two decades (Dowrick and Biggs 1983; Xiao and Mackenzie 2004). Development of affordable and flexible video technology has made its impact on the study of JCSs, and high-risk settings as video tools provide a viable mode of observation of operator and/or system performance. Despite the relative short history of use, video technology has been accepted within a range of research domains, such as software design (Mackay, Ratzer and Janecek 2000), product design (Buur and Soendergaard 2000), training of medical personnel (Guerlain, Turrentine, Adams and Forrest Calland 2004), and design of maritime navigation equipment (Bjørkli, Røed, Bjelland, Gould and Hoff 2007).

There are several advantages of video technology in field studies. Video data may capture perceptual, spatial, contextual, and semantic aspects of work practice, and these are regarded as fundamental to the understanding of JCSs. Further, it enables time-shifted analysis so that researchers can ‘revisit’ the events captured and repeatedly explore the patterns and constraints expressed (McNeese 2004).

However, the introduction of video observation tools brings forth new challenges in terms of methodological, theoretical, and practical issues (for a discussion, see (Xiao and Mackenzie 2004). Few articles have touched upon the practical and theoretical challenges associated with the integration of video in observational studies, with the exception of some research groups working in the medical domain (Mackenzie, Xiao and Group 1999).

The potential advantages of video are determined by the relevance of the recorded events to the given study. The relevance of video data depends on what the cameras actually capture, and this is determined by what the researcher chooses to include in the picture frames. On one hand, this is a practical issue, as the researcher must find a practical solution to the problem of where to position the cameras and how to arrange the logistics of the video equipment set-up (Guerlain, Turrentine et al. 2004; Lutzhoft and Koester 2006). On the other hand, video data should have some theoretical foundation. Here, theory provides the basis for what aspects and details of the system to focus on (Strauss and Corbin 1998). The outcome should optimally be a practical

viable observation that yields relevant recordings of operators and artefacts in action during system performance. The challenge of using video is thus the resolution of theoretical considerations and practical challenges.

## ***1.2 Practical challenges and theoretical considerations***

There are several practical challenges associated with video observation. The context in which observation takes place may have unforgiving physical attributes such as poor light conditions, vibrations, confined space, and noise. The implementation of video in observation means that the cameras must be attached in such a manner that they capture *relevant data of sufficient quality*. Relevance is related to what the cameras capture within the picture frame (operators, artefacts, etc), and quality concerns how the physical attributes of the environment are handled (light, vibrations, noise, etc). Further, the recording of data must use a format that complements the amount of data to be recorded and the intended use.

The theoretical challenge of video observation is tied to the nature of the system studied. JCSs feature characteristics that emphasise the complexity and dynamics of human–technology coordination (Woods and Hollnagel 2006). JCSs thus have attributes that challenge observation, such as coordination of behaviour of several operators, subtle use of artefacts that are spread out across physical space, multiple threads of work, subtle communication lines, and so forth. The theoretical understanding must somehow correspond to the practical implementation of video as an observational tool. Our understanding of the system guides our focus, suggesting that the content of what the video captures must somehow correspond to our theoretically founded unit of analysis.

Robson (2002) discusses *fixed* and *flexible* designs in social sciences, where the primary difference is to what extent these research designs are pre-specified before they are executed. In *fixed* designs, researchers know which methods to use, how to administer them, what data to collect, and have clearly formulated hypotheses to confirm or reject. The scientific ideal is to isolate effects or patterns through ‘control’

of the data collection situation. The research design is largely outlined in advance, before it is actually performed. In *flexible* designs, researchers cannot sufficiently pre-specify the interesting features of the study objects and thus cannot pre-specify the details of data collection. Rather, methods and theories are attuned through exploration of the domain in question.

This article argues that field studies of JCSs primarily belong in flexible research designs, and that the use of video exemplifies the explorative and iterative nature of observation. This implies that not only must the choice of method be adjusted to the ongoing field observation, but also the particular expression of the chosen method.

### ***1.3 Application area for this study***

This article is based on an observational study of navigation and manoeuvring in High Speed Craft (HSC) in military service. The aim of the article is to describe the experience gained, and the lessons learned, about the use of video as a research tool.

The field observation was conducted aboard Hauk Class naval ships in the Norwegian Royal Navy, and focused on the analysis of JCSs performance during ship operation. The observation was primarily exploratory as it aimed to uncover and document the interactions of operators, artefacts, and technology. A multidisciplinary team of researchers and domain experts conducted the observation and collected over 100 hours of recorded video, covering a range of operational contexts, crews, and ships.

For a description of the scientific results of the field study, see Bjørkli, Øvergård, Røed and Hoff (In press). The study also facilitated the innovation and design of artefacts in use on the bridge, as presented in Bjørkli, Røed et al. (2007).

Central to this article is the development and adaptation of video observation to support the study of work practice and JCSs performance. The implementation of video technology is described across stages of integration and gradual refinement where both practical and theoretical issues were resolved.

## **2 The study of high-speed craft**

Hauk class vessels refer to a class of HSC used by the Norwegian Royal Navy. This ship class is used for patrolling and upholding a national presence in inshore waters along the coastline of Norway, as well as contributing to international operations. These tasks imply the ability to manoeuvre in a wide variety of maritime environments, ranging from open to very confined waters, and under all weather conditions. Vessels also operate at any time of the day and night, exposing them to various visibility conditions. The crew aboard must also be able to plan and execute a new course and route if given orders to do so.

The Hauk class of the Norwegian Royal Navy is instructed to operate efficiently and safely in their designated coastline areas. Efficiency refers to the ability to patrol large areas, that is, to maintain high speed whenever possible. This feature is balanced by the need for safe operation, which refers to the responsibility of maintaining the functional integrity of the ship.

### ***2.1 Hauk ship and crew***

Hauk vessels have a displacement weight of 150 tons and measure 36.5 metres in length. The beam is 6.5 metres and the height is 14.5 metres. Propulsion is provided by two diesel engines of 3600 hp each (total of 7200 hp). The top speed is over 30 knots under optimal conditions, and is reached in approximately two minutes from standstill. A picture of a Hauk class ship is presented in Figure 1.



Figure 1 shows a Hawk class vessel during operation (photo by the author)

Thirty crewmembers are active during the operation of the ship, five of whom are directly involved in the navigation and manoeuvring activity on the bridge.

The *navigator* is the main person in the navigation crew, and is responsible for taking the ship to its destination in a safe and efficient manner. The navigator plans the track to sail before departure and executes this plan during sailing. The *plotter* is responsible for handling the map during sailing. He plots out the ship's position and calculates the ship's position based on communication with the navigator. Further, he serves the navigator with information derived from the map that the navigator prepared before departure. The *helmsman* steers the ship on the direct command of the navigator. The commands are given verbally, and the helmsman executes and verbally confirms them. The *lookout* is placed on the outside bridge to visually monitor the environment. The lookout reports to the navigator when observing relevant features or events. The *commanding officer* holds the overall responsibility for the safety and efficiency of the ship. He also serves as a supervisor to the navigator, as well as being in charge of strategic decisions in military operations.

The five crewmembers involved in navigation and manoeuvring are situated at designated workplaces on the ship bridge. Figure 2 indicates their positioning.



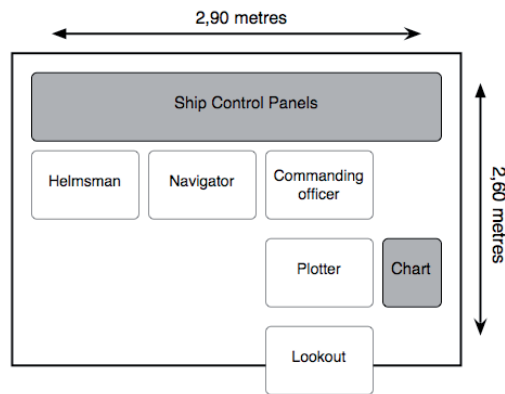


Figure 2 shows a schematic overview of the Hauk class ship bridge

## ***2.2 Complexity of the HSC operation***

This article presents experiences from a field study of HSC in military service. The ship operates within a strict organisational and technical context that underlies the functional coordination of operators and technology in the face of natural forces in the maritime domain. The operation of military HSC is characterised by classical features of complex sociotechnical systems and JCSs (Gould, Røed, Koefoed, Bridger and Moen 2006; Bjørkli, Øvergård et al. In press). The features defining HSC operation include a high level of automation, tasks distributed across multiple operators and artefacts, a high level of hazard, uncertainty in datasets, mediated interactions, and constant disturbances to system states.

The latter decades have shown a trend towards integration of information and communication technology aboard ships in order to increase safety and efficiency (Lutzhof 2004). However, the integration of new technology has been only moderately successful. This is due to the fact that new artefacts have been understood as primarily ‘technical objects’ (Vicente 1999). An alternative to the purely technical orientation is found in field observations that analyse artefacts as integrated agents within an established work practice (Bjørkli, Røed et al. 2007). This suggests that artefact design may be aided by studies that are grounded in actual system performance such as the contextualised interaction between operators and artefacts suggested by the term ‘work practice’ (Norros 2004). The need for field studies makes

the use of video relevant in observation, and actualises the challenges connected to this.

### **3 Video tool migration path**

Researchers seldom have the final set-up ready at hand when initialising a field study. Rather, they apply some form of phased approach to ‘scale-up’ the video equipment where different possible set-ups and solutions are tested during data collection (Mackenzie and Xiao 2003). However, there are no strict rules to guide this ‘phased scale-up’; rather, it seems to be constrained by the balancing of practical and theoretical issues within the project resources available.

The following sections present the video tool developed for the ongoing study of HSC, where the video tool was gradually enhanced over five stages. The stages will be described and discussed in the following sections.

#### ***3.1 Stage 1: Domain orientation and initial analysis***

The first stage of the research project was to approximate the domain in terms of getting the general overview of ship class functioning and tasks. This early phase aimed at discovering system behaviour and basic patterns in performance with emphasis on describing the nature of the system complexity.

The core activity in this stage was participatory observation during ship operation and docking time. The focus was on ship performance and was approached through several methods, such as formal interviews with crewmembers using cognitive- and expert walkthroughs and semi-structured interviews, and documentation of the bridge interface and physical layout by photography of ship bridge details and physical measurements (decibel, light conditions, and physical size). In addition, members of the research team engaged in navigation training, including studies of navigation

literature, training in the use of sea charts, and in situ navigation and manoeuvring training.



Figure 3 shows details from the cognitive- and expert walkthrough of the Hawk class ship bridge

The aim of the domain orientation was to uncover the basic constraints of HSC navigation and manoeuvring by explicating the system performance in relation to the JCSs theoretical framework. The outcome of this theoretical grounding of the field study was to provide an answer to the seemingly simple question ‘who and what should we film?’ Early testing of camera angles included taking pictures from several suggested camera positions that captured various combinations of central operators and artefacts.

The domain orientation served as preparation for the practical implementation of video observation. The challenge was how to fit the cameras into the physically confined ship bridge in such a way that it enabled us to record the performance of central agents in the system. Besides the challenge of a rather confined physical space, there was the question of how to overcome the unforgiving environment. Ship bridges on HSC are constantly moving as the ship moves through and with the water, and our subjects were thus embedded in an environment that was very noisy, and was constantly vibrating and shaking. Further, the lighting conditions are often poor and changeable as the ship operates day and night in very diverse weather conditions, ranging from fog, snow, rain, to blistering sunshine.

The initial domain orientation revealed a highly complex cognitive structure where system performance emerged from the distributed activities of operators and

technology. The HSC were found to have many of the classical characteristics of complex sociotechnical systems that suggested the recording of multiple system agents. Further, it became evident that we were faced with practical challenges of how to overcome the unforgiving physicality of the joint cognitive structure of our study. The noise and movement competed with the audio and visual data of our interest, and there was little space available to mount cameras. This early domain orientation stage resulted in a prototype set-up of video observation equipment for field observation.

### **3.2 Stage 2: Sketching and prototyping**

The first video recording was conducted in the second stage of an international military exercise over three days in November 2003. The ship and crew performed at peak limits, giving a very real impression of system performance and conditions of observation.

The set-up included one fixed camera and one handheld camera operated by the observing researcher. Off-the-shelf Sony MiniDV Handicam cameras were used. The recording medium was regular DV-tapes with one-hour recording capacity. Figures 4 and 5 indicate the position of the fixed camera.

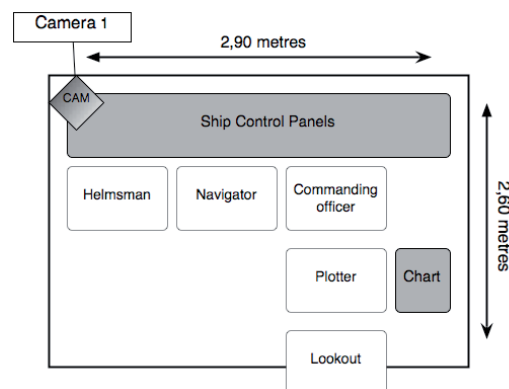


Figure 4 shows the position of the fixed camera in the sketching stage



Figure 5 shows the position of the fixed camera and the researcher replacing the DV tape

The fixed camera was placed right in front of the helmsman and captured the actions of the navigator, some actions of the commanding officer, and occasional actions of the plotter. The handheld camera was operated without any clear procedural instruction. The aim was to follow the assumed chain of actions perceived in situ, as well as in accordance with the navigation knowledge acquired during the training in HSC navigation and manoeuvring in the first stage of domain orientation.

The sketching stage represented the first step towards integrating the theoretical understanding of the HSC operation with the practical challenges of using video observation. The fixed camera explored the overlap between the theoretically interesting and the practically viable. The contents captured in the picture frame may be regarded as a hypothesis that specifies the key agent (navigator) and artefacts (optical bearing device and control panels) that are central to system performance, and represent a practical solution to the problem of fitting the camera in a confined physical space. Given the coordination of multiple agents and artefacts, as well as the confined space, the position of the fixed camera became a compromise of theory and practicality.

The handheld camera may be considered an exploratory activity of the assumed and perceived system dynamics and complexity. Whereas the fixed camera focused on one operator (navigator), the handheld camera aimed to follow the flow of information during critical tasks (e.g., when determining position or manoeuvring in confined waters). For example, the camera could film the plotter using the sea chart in order to retrieve information that was verbally given to the navigator, who used this information to change ship course. The handheld camera focused on the sea chart, the

plotter, the navigator, the helmsman, and the wheel controlling the rudder, in accordance with the chronological unfolding of the coordinated sequence.

This first externalisation of theoretical understanding and practical solutions in terms of the particular video set-up generated some rather unsystematic and poor data. The angle of the fixed camera excluded some parts of the interface, and the sound was of barely sufficient quality. The handheld camera swivelled from place to place and explored the various activities of operators and artefacts in a more or less random fashion.

The sketching stage proved valuable in relation to the development of the video observation. Our initial definition of the ship as a JCS was partly confirmed as we saw the distribution of agents and activities during performance and the variance in contextual demands. The handheld camera identified patterns of work practice that were in line with our assumptions, but also identified patterns that were surprising. For example, the roles of crewmembers were sometimes unclear, and equipment was used in opportunistic and unexpected ways. Further, the detailed documentation of the navigation and manoeuvring was difficult without knowledge of the process being controlled. In this case, the process is the movement of the ship through the environment. The events and context outside the ship relate to ship movement and should therefore be represented in the video data.

The sketching stage also made the practical challenges clearer. More specifically, this concerned how to attach cameras, as well as how to improve the audio. The physical environment of the ship bridge, with all its shaking, heeling and high levels of noise, required attention. The light conditions were also problematic, as the integrated infrared (IR) lighting of the fixed MiniDV camera was covered by an attached mechanism. The process of strapping the cameras was also made difficult by the fact that ship bridges on Hawk class vessels are not identical in physical layout. This made a generic attaching procedure across different ships in the squadron impossible. The fixed camera was strapped to ventilation pipes above the helmsman, and the angles and placement of these pipes are subject to variations between ships in the Hawk class. In addition, the need for a mobile video tool solution was emphasised as the context

of military exercises left very little time to mount and dismount cameras. The set-up and removal of cameras had to be completed within very short time frames (approximately 30 minutes) due to the ongoing military exercise and the role of our ship and crew.

### ***3.3 Stage 3: Consolidation of observation experiences***

The third stage consolidated the experiences from the sketching phase in terms of theoretical abstraction and practical implementation. The collection of data in this stage took place in an international military exercise during February 2004. The ship and crew were pushed to the limits of their capacity and performed at peak levels.

A 'fisheye' lens (Mutagon 0.6x) was added to the fixed camera in order to capture more of the ship bridge and to eliminate negative effects on the camera angle due to variation in ship bridge layout. The position of the fixed camera was the same as for the sketching stage, where the navigator remained in the centre of the picture. The attached mechanisms were refined, and included pre-cut padding (polyethylene foam) of various sizes to support the camera and absorb vibration. The flexibility of the foam was manipulated by applying heavy-duty gaffer tape to compress the padding. The camera was secured to the padding and ventilation pipes with nylon strips. The solution with pre-cut padding and nylon strips enabled quick and robust set-up of the video cameras.

The handheld camera was still used to follow the chronological and spatial unfolding of tasks during sailing. There was still no extensive definition of what to film, but several ideas, such as information exchange, use of specific artefacts, and detail of work with the sea chart, were tried. In particular, the work performed by the plotter and the coordination with the navigator were increasingly documented, and sequences of the outside environment were filmed. For example, a 30-minute sequence of the view forward from the outside bridge during passage through a particularly challenging inshore archipelago was recorded with the handheld camera. The picture frame included the bow of the ship and the view further ahead. The documentation of

the outside environment also included filming sea marks and context specifics (e.g., perches, terrain characteristics, and other ships) used in the navigation task and observed from inside the bridge by the navigator.

The consolidation stage built on the previous stage by elaborating on the abstracted theoretical patterns that were found and by going further in implementing solutions to the practical challenges that occurred. The theoretical patterns explicated concerned how the crew and artefacts were organised into a JCS, where the maintenance of safety and efficiency were tied to the collaboration between the various agents. However, the navigator remained a pivotal point in this joint effort as he coordinated the multiple threads of work and events into a functional and efficient work practice of ship and crew. The nature of this integrative work was situated around the work place of the navigator, but propagated along the communication of information among the crew and tasks across operators and artefacts. These events showed high levels of interaction between crew members, and the delegation of tasks, particularly in relation to coordination.

A concrete outcome from the anchoring stage was the production of a DVD that showed the occurrence of a critical incident observed during ship operation. The DVD production used Final Cut Pro software. The DVD showed a split screen with two video sources, one with the navigator (fixed camera) and the other showing the handheld camera view with the perceived flow of information during the incident (switching between helmsman, navigator, plotter, and artefacts). Norwegian subtext was added to the DVD, to show the crew dialogue during the incident. The DVD also contained an interview with the navigator during the planning of the route on which the incident later occurred. Here, a close-up of the navigator working with the chart was also filmed. In addition, the DVD contained an improvised interview with the navigator immediately after the ship entered the docks regarding the incident and how the navigator experienced it. The figures below show screenshots from the DVD.



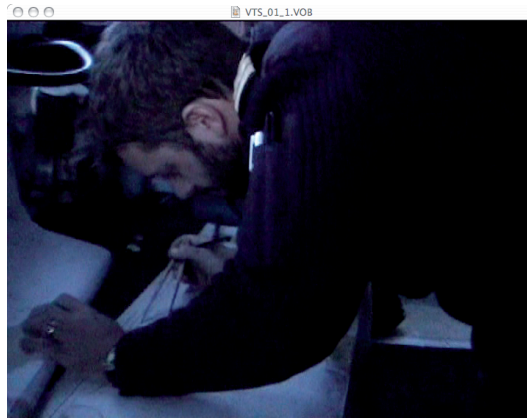


Figure 6 shows a screenshot from the documentation/interview during the planning phase

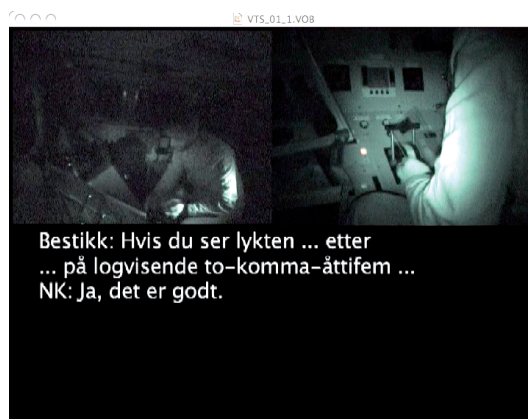


Figure 7 shows a screenshot from the DVD during the critical incident



Figure 8 shows a screenshot from the interview after the incident

The incident recorded on the DVD concerned the uncertainty of the ship's position at a critical moment when the ship was entering a challenging region with sunken rocks and shallow waters under poor weather conditions. Briefly summarised, uncertainty of position is highly critical for the operation of HSC, and must be handled immediately as it entails the possibility of a ship grounding. In addition to uncertain ship position,

several alarms concerning the propulsion systems went off. This caused a highly pressured situation that challenged the crew to act under very short time constraints and high risk.

The DVD demonstrated that the operation of HSC is highly event driven, and occurs at an abrupt and uneven pace. Further, it elaborated on the early domain orientation by providing insight into key aspects of HSC operation (route planning) and the subjective perspective of the navigator in reflection over critical incidents.

### ***3.4 Stage 4: Synthesis of findings***

The synthesis stage of the field observation focused on the reflection of the data collected in the previous stages. Excerpts from the various video data were discussed with the research team present. The research team consisted of a trained psychologist, an industrial designer, a naval officer, and two human factors specialists.

The focus of the research team was to reflect upon the authenticity of the data in terms of the extent to which it provided relevant information about the domain and case study in question. This explicitly concerned how well our theoretical abstractions of the work practice of navigation and manoeuvring corresponded with the experience of work practice of the naval personnel. The joint presence of practitioners and researchers formed the basis for this reflection. The dynamics of the JCSs were outlined in relation to how the system performance is driven forward by events and incidents. The system performance of the HSC was characterised by the integration of events over different timescales and criticality. Some events happened within short timeframes (making a specific turn), other events unfolded over longer periods of time (meeting another ship or passing through a challenging region). Some events were important and directly related to the safe and efficient operation of the ship (determining position or status of technical systems); others were more trivial (information on docking at arrival, organising mealtimes, etc). The crew operated the ship through the flow of multiple events.

The practical challenges were also a specific theme in the research team discussion. This concerned whether the current procedure for video tool set-up was functional in terms of providing content in line with our theoretical abstractions. In addition, the practical feasibility of using pads and nylon strips was discussed in terms of usefulness. Here, the most important constraints were time available (very little time to set up the cameras) and the physical environment of the bridge (vibration, lighting conditions, and noise). The use of MiniDV tapes was also problematic. The tapes contained one hour of recording capacity, and the ships often sailed continuously for 12–18 hours. This meant the number of MiniDV tapes was considerable and offered a logistic exercise that was very time consuming. Another problem was that accessing the cameras to replace MiniDV tapes every hour meant interrupting the crew as the researcher had to lean over the helmsman to retrieve the camera. It became obvious that in the long run, MiniDV tapes were not a practical solution to extensive data collection of video data aboard this vessel class.

There were several outcomes of the synthesis stage. First, our conceptual understanding of navigation and manoeuvring of HSC in military service was further attuned. Some assumptions were confirmed, whereas others were refined or reformulated. For example, the navigator remained the key operator in the JCSs, and the coordination between navigator and the plotter was emphasised. However, the role of the commanding officer was also given more attention. Our data at this point did not sufficiently capture the interaction between supervisor and navigator, and it seemed that this relationship had more influence than we first assumed. As a result, the research team called for more data of their interactions. The video excerpts from the outside bridge were increased to understand the relationship between structure in work practice and ship movement.

A ‘DVD prototype’ was produced, based on the video material collected. The DVD production used Final Cut Pro software. The prototype consisted of edited video excerpts that were combined into a mock-up of a full-scale video system to show what the combination of four cameras would look like. The DVD featured a split screen with four windows that recorded the navigator, the plotter, the commanding officer, and the context in parallel.

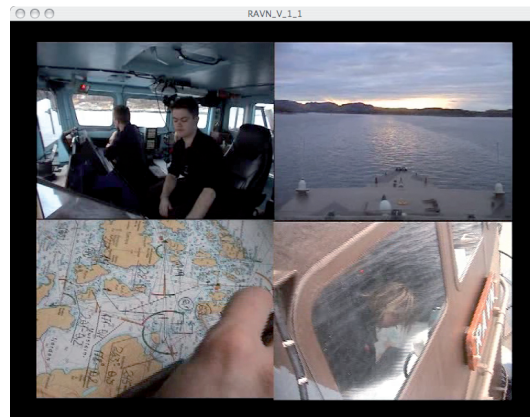


Figure 9 shows a screenshot from the DVD with video material

The DVD offered a 30-minute section that showed the passage through a particularly challenging region characterised by a number of sunken reefs, shallow water, and narrow, sailable tracks. The video material used on the DVD was collected by passing the same region at different times during the military exercise, and was filmed with two cameras. Parts of the DVD reveal some obvious inconsistencies across the four screens (e.g., one person being in two places at the same time), and some parts show fewer than four video sources. Despite the contradictions and ‘logical breaches’, the DVD represents, in principle, the typical dynamics of HSC in these waters. It depicts the rough structure of HSC operation, despite the lack of formal correspondence within the situations in which the video material was actually recorded. The representation of navigation and manoeuvring in HSC is synthesised from the raw video material in accordance with the theoretical patterns and practical solutions. The DVD also features chapters that mark specific events, incidents, and actions relevant for ship operation. For example, the use of chapters provides access to key actions in position determination, use of charts, verbal commands, or external events that stretch crew performance. The chapter system suggests that HSC operation is event-oriented.

### ***3.5 Stage 5: Articulation of observation experience***

The articulation stage took the field observation one step further, by using the previous experiences to form the basis for the use of video. The data collection took place during February 2005, in an international military exercise.

The MiniDV cameras were replaced by a fully digital video recording system that consisted of four USB 2.0 cameras with fisheye lenses (0.4x) and a central hard disk recorder. Three fixed cameras were placed inside the ship bridge and focused on the navigator, the commanding officer, and the plotter. The bridge cameras were attached with steel brackets and nylon strips. The fourth camera was placed outside on the top bridge and showed the bow of the ship and the view ahead. The external camera was attached with nuts and bolts, and placed inside a closed steel container with a window for the lens to protect it from seawater and rough weather conditions. The recording system also included an external IR lamp, an external microphone attached to the roof immediately above the navigator and commanding officer, and a switch for adding chapters in real time to the recorded video stream. The PC controlling the recording equipment was placed in the ship control centre beneath deck with a single screen interface operating on a Windows platform. The software used recorded footage from all four cameras simultaneously into a four-way split screen, and external hard disks served as a storage medium that allowed 14–16 hours of recorded material in each session.

The figures below show the schematic overview of the video tool, the placement of cameras, and the screens of the four cameras combined (quad-split).

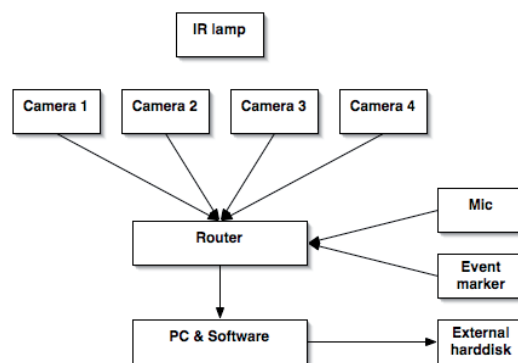


Figure 10 shows the schematic set-up of equipment

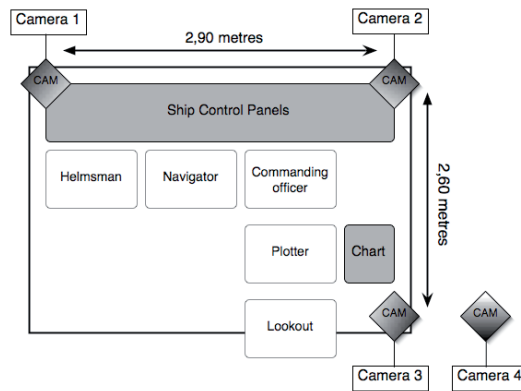


Figure 11 shows the positions of the fixed cameras



Figure 12 shows the quad-split screen in the video feed

The video tool in this early beta version demonstrated the experiences from previous stages that revolved around theoretical and practical issues.

## 4 Video observation and stages of integration

The field observation described in this article used video to observe the coordination between operators and artefacts in a JCS during navigation and manoeuvring in a HSC in military service. Mere participation and ‘unaided observation’ was not deemed sufficient due to the distribution and subtleness of the coordinated process regarding central to system performance. The decision was made to include video as the primary research tool, and the integration of the video technology in accordance with both theoretical understanding and practical issues began.

The process of developing the video observation is described here in relatively clearly marked stages, and the physical scale-up was gradually refined after examination of each video recording. In this sense, the method of video observation was not merely ‘executed’ in terms of just setting the cameras up and starting to record. Rather, the adaptation of methods was related to how the researchers understood the system and to the practical challenges that surfaced during observation.

There was also ‘direction’ in this process in that an explicit choice was made to start out ‘low tech’ (off-the-shelf handheld cameras) and gradually expand (digital recording and professional lenses) as the demands were recognised. This general movement from low complexity to high complexity in terms of video technology ensures that costs are kept low and that efficiency of the field study is constantly in focus. It further induced a high level of flexibility in the initial phases of our understanding of the system so that changes in observation could be easily implemented.

The physical scale-up described in this article spanned five stages (domain orientation, sketching, consolidation, synthesis, and articulation). The labels of and demarcation between the stages are somewhat arbitrary. We did not apply any strict rules or formal criteria of when and how to proceed from one stage to the next. However, the stages are not random. Rather, the process of integrating video is explicitly motivated by process models of products design (e.g., ISO 13407 or User Centred Design). Here, the process of enhancing the product specifications is guided by an explicit reflection in an iterative cycle. This means that each stage transition is motivated by the explicit reflection of lessons learned in the previous stage.

## **5 Discussion**

### ***5.1 Particular expressions of the method***

McNeese (2004) discusses the choice of methods in Cognitive Systems Engineering (CSE) and argues that once a given approach to a study is chosen, certain interpretations and understandings become instantiated for use. Some methods are incorporated into the context of the study, while others are left out. However, we wish to add to that argument by pointing out that not only are specific methods chosen, but also the *particular expression of the chosen methods* becomes instantiated. Some ways of implementing the chosen method are realised, whereas others are left out. Methods are defined principally and formally (e.g., as defined in text books), but must always be transformed into practical solutions to meet the context and the specifics of a study object or domain. This perspective on methods is thus related to what Robson (2002) describes as the '*return to real world*', suggesting that science may in contrast to controlled laboratory settings be oriented towards searching for practical and substantive relationships in contexts of actual, real use. The shift in attitude when going from laboratories to real world settings grows beyond the general discussions of validity and reliability, and becomes a question of how to adapt scientific ideas and methods to the peculiarities of the phenomenon at hand. The authors of this article thus present the development of the video tool as a case study of how to establish a contextual viable tool that conjoins our theoretical approach to CSE/JCSs while remaining practically oriented.

## ***5.2 Authenticity and abstraction***

Woods and Hollnagel (2006) state that CSE is based on the observation of *work in context*, thus emphasising that the field study is tied to 'where and how' we observe the system. The methods shape the conditions of observation, and this guides the reflection regarding the nature of work. This article suggests that methods are not adjusted merely to formal 'rules of application' or purely theoretical considerations, but also in accordance to the context specifics of the system studied. The practical challenges of applying a method therefore have two aspects: it concerns the practical application of methods, but is at the same time informative of the work practice studied. Methods thus become both the input and output to the observation. The particular integration of video observation presented in this article carries with it an understanding of the system in a theoretical and practical sense. Theories guided the



focus of what to capture on video, whereas practical problems revealed system characteristics that formed theories. Methods shaped observation, but observation may have also shaped methods. For example, the challenge of limited physical space was central to the working conditions of the operators, as well as being a challenge to our integration of video. Further, the work of the crew was characterised by irregular time schedules and sudden changes of plans, and this also heavily constrained the procedure of attaching the cameras quickly and securely. The physical environment of the ship bridge in terms of noise and light conditions was fundamental to the task of navigation as it made visual observation and verbal communication difficult—it also made it challenging to capture these crucial aspects of system dynamics on video.

### ***5.3 Next stage?***

This field observation study had five stages, ranging from early domain orientation to an articulation of the accumulated experiences with theoretical elaboration and practical challenges. The last version of video set-up included a solution that allowed visual and audio representation of the main agents on the ship bridge (navigator, plotter, and commanding officer). It also showed the view and movement of the ship ahead. The decentralised control interface for the equipment allowed the observer to operate the recording equipment from below deck, and thus avoid intruding on the crewmembers' performances. The hard disk recorder enabled extensive recording of longer sessions of sailing (14–16 hours). The research team that worked on this project did not have any further observations planned. Given that more data was needed, what would be the 'next stage'?

The continued development of the video observation tool should still be motivated by reflections on the type of data that is needed, as well as by the combinations of data types. A possible next stage in this case study could go further in representing the data from the technical systems that the crewmembers operate. Potentially, data such as heading, rudder angle, speed, engine RPM, and GPS position in electronic charts could be added graphically to the video stream. This would further enable researchers to evaluate the correspondence between agent actions and the controlled process.

Similar addition of technical data is seen in observations of medical procedures (Mackenzie and Xiao 2003) and car simulator studies (Bjørkli, Jenssen, Moen and Vaa 2003).

## **5.4 Concluding remarks**

In summary, the observation of ship and crew revealed characteristics that had theoretical and practical implications for the integration of the method of video observation. The consequence was that the theoretical could not be isolated from the practical. This is in line with what Woods and Hollnagel (2006) describe as the oscillation between participation and abstraction. The balance between these activities should be considered a key issue. Our field study unfolded by oscillating between emphasising participation and abstraction. Sometimes, theoretical issues came to the fore and practical issues receded to the background, and *vice versa*. We regard the balancing activities to be separated only in terms of serving as a premise for each other, thus arguing that the separation is *inclusive* rather than *exclusive*. This suggests that theory and method complement each other in the study of real world phenomena. This article and the experiences with the presented field observation study clearly recognise this as one of the basic activities in a real world research project.

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