THESIS FOR THE DEGREE OF LICENTIATE OF PHILOSOPHY

Navigation Methodology and Teamwork in High Tempo Operations

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Abstract

Maritime navigation of small vessels at high speed can be very hazardous. Vessels are becoming more potent with greater speed capabilities. The demand of deliverance is also manifesting itself within organizations and there are fewer possibilities for slowing down the overall pace. The methodology to cope with the new challenges the speed imposes is not keeping up. Accidents occur due to this situation and their consequences are potentially fatal.

The topic of high speed navigation has been elucidated from different perspectives in five papers. The papers present an understanding of high speed navigation looking at the contemporary literature as well as the author's own experiences. The theories used to describe navigation are coming mostly from the Human Factors domain. The results from the papers I-V that are presented in this thesis are reinterpreted from a new theoretical standpoint than the one introduced in the original papers.

Navigation at high speed is a team effort that requires effective collective actions. The navigation methodology studied, Dynamic navigation (DYNAV) is mainly constructed of four phases used to coordinate activities within the crew in relation to a mission objective or a goal. Five pieces of key information have been identified and constitute the backbone of the communication between crew members. Mechanisms are incorporated in the navigation methodology to catch unwanted variability in the collective understanding of the situation.

It is suggested from the concepts of complexity, variability and epistemic actions that DYNAV is a methodology to choreograph joint activities, that re-planning is an essential part of effective teamwork and driven partly from the need of aiding understanding of the situation.

Keywords: High Speed Navigation, DYNAV, SAR, Joint Cognitive Systems, Joint Activity, Epistemic actions, maritime, adaption, replanning

List of Publications

Paper I — Dobbins, T. Harris, D. Smoker, A. Hill, J. Forsman, F. Brand, Tyler. Dahlman, J. and Stark, J. (2010). *High Speed Craft Command & Control: a Model of Navigation and Crew Interaction to Enhance Performance and Safety in the Harsh Shock and Vibration Maritime Environment.* Conference Proceedings; NAV-10, Royal Institute of Navigation, 2010, London, UK.

Paper II — Forsman, F. Dahlman, J. and Dobbins, T. (2011). *Developing a Standard Methodology for Dynamic Navigation in the Littoral Environment.* Paper presented at Royal Institute of Naval Architects, International Conference, Human Factors in Ship Design and operation, 2011, London, UK.

Paper III — Forsman, F. Dobbins, T. Hill, J. Brand and T. MacKinnon, S. (2012). *Exploiting Simulation to Enhance Operational Effectiveness and Interoperability in Littoral Maritime Operations.* Paper presented at the STO Modelling and Simulation Group Conference held in Stockholm, Sweden from 18 to 19 October 2012.

Paper IV — Dobbins, T. Forsman, F. Hill, J. Brand, T. Dahlman, J. Harris, D. Smoker, A. Stark, J. and MacKinnon, S. (2013). *Information Architecture for Fast Response Craft – Command & Control & Human Systems Integration.* Paper presented at SURV 8 - Surveillance, Search and Rescue Craft, 20-21 March 2013, Poole.

Paper V — Hill, J. Forsman, F. Brand, T. and Dobbins, T. (2014) *Risk, Competence, Interoperability and Qualifications for Fast Craft Operations.* Paper presented at Royal Institute of Naval Architects, International Conference, Human Factors in Ship Design & Operation, 26-27 February 2014, London, UK.

Distribution of work:

Fredrik Forsman, under supervision of Joakim Dahlman and Scott MacKinnon, considers the domain of maritime high speed navigation in five papers. All five papers have been written jointly with the co-authors in an iterative and developing process. In paper I Forsman has contributed with the fundaments to the High Speed Craft Command and Control model and provided the training perspectives. In paper II and III Forsman is the main author. In paper IV and V Forsman has contributed with the detailed model and perspectives of DYNAV that serves as a foundation for further argument and conclusions made in the papers.

About the author

Fredrik Forsman has been working with and developed the training of High Speed Navigators for the Swedish Combat Boat 90 (CB90) in the Amphibious Corps for a period of more than ten years. Forsman was responsible for the training of the CB90 crews, the development of the methodology and pedagogy at the Fourth Amphibious Regiment (Amf 4).

Forsman was the first officer in the reserve in the Amphibious Corps that was allowed to cross over to become a regular officer without undertaking the mandatory two years of studying. This was possible thanks to his merits and skills in tactical maritime operation, high speed navigation and training.

Forsman has been decorated with the Älvsborgs Amphibious Regiment's Medal of Honour for his achievements in developing the navigation methodology, pedagogy and tactical behaviour with the CB90 system.

He has also had the opportunity to train the Mexican and Malaysian navy in handling and operations with the CB90 on location in their environment.

To compliment his military understanding of the maritime domain Forsman is also a trained Master Mariner.

Forsman has later had the position as head of training at the Swedish Sea Rescue Society where he has been responsible for the development of the training organization for the 2000 volunteers. This task has gradually leaded into an academic focus that this thesis is a result of.

Competitive sailing has been important and he has been part of a successful sail racing team with wins in the Round Gotland Race and in 2007 he became World Champion in Offshore Sail Racing, (IMS-600) Corinthian Trophy.

Content

List of abbreviations and acronyms

AMF4	Fourth Amphibious Regiment
C2	Command and Control
C3	Command, Control and Communication
CB90	Combat Boat 90
DYNAV	Dynamic Navigation
ECDIS	Electronic Chart Display and Information System
ECS	Electronic Chart Display
ETTO	Efficiency Thoroughness Trade-off
FRC	Fast Response Craft
GPS	Global Positioning System
HSC	High Speed Craft
HSC3	High Speed Craft Command and Control
IBS	Integrated Bridge System
IMO	International Maritime Organization
KSA	Knowledge, Skills and Attitudes
SA	Situation Awareness
SAR	Search and Rescue

1. Introduction

High speed navigation in the maritime domain poses significant challenges to the crew on-board a vessel (Hill, Forsman, Brandt & Dobbins, 2014). High speeds reduce the time available to make sense of a situation and, consequently, interfere with decision-making and navigation execution (Forsman, Dahlman & Dobbins, 2012). Accidents occurring at high speed will likely result in more severe consequences for injury and asset damage than those at lower speeds. The work environment of a marine craft travelling at high speed is inherently dangerous and the maritime environment is arguably one of the most challenging of work environments for humans (Dobbins, Myers, Stark & Mantzouris, 2010). Whole-body shock, noise, poor lighting and vibration cause fatigue and reduce the operator's perception and interpretation of instruments and information sources. The smaller the High Speed Craft (HSC), the more impaired the senses normally become. High stakes consequences, in combination with deteriorated abilities of understanding the situation and decision-making is important to Command and Control (C2) and increases risk in these environments. It is important to better understand the factors that constitute success in high speed navigation, so that efficiency can be gained while accidents (Fig. 1.1) are avoided.

Fig. 1.1 Combat Boat 90 aground in Stigfjorden north of Tjörn on the Swedish west coast.

HSCs are today used in many vocational applications. The ability to quickly move from one location to another or intercept another vessel are examples of situations where military and Coast Guard use HSCs to their full potential. Search and Rescue (SAR) and Maritime Police are other services where successful outcomes of operations are time critical and thus the need for fast transits becomes obvious.

The organizations mentioned above have several things in common. They all are using relatively small craft (often less than 24 m of length) to accomplish their mission goals, they are commonly represented in most maritime nations and they all are part of the maritime SAR organization. Apart from these governmental and non-governmental organizations there are commercial stakeholders as well. One of the most rapid growing areas of commercial HSC operators is the wind farm industry (Forsman, Dobbins, Hill, Brand & MacKinnon, 2012). The merchant fleet use HSCs with their legislated Fast Rescue Boats (FRB). The general trend is that crafts are getting faster and more powerful which in turn poses increased challenges to the operators of these crafts.

At present not much support is provided to the community of highs speed vessels less than 24 meters of length when it comes to training requirements and regulations. The focus of the International Maritime Organisation (IMO) is mostly aimed at the merchant fleet for crafts above 24 meters in length (Petursdottir, Hannibalsson & Turner, 2001). This absence of rules and regulations do provide some freedoms to owners and operators, but also create constraints and risks. Rules and regulations, wisely and carefully applied, can guide and facilitate safety and efficiency but at present these supports are lacking. It is not just the regulatory bodies that are lagging behind the development. New tools, such as chart plotters, radar, Electronic Chart Display and Information System (ECDIS), and the HSCs themselves are used in different operations. Through technological advances, HSCs are facilitating new kinds of business and operational opportunities. This means that operators, to great extent, are left to develop best practice themselves and old knowledge will not fill the gap between classical navigation of slow going vessels and what is needed to operate a HSC (Forsman, et al., 2012). Too little research is directed towards these issues and best practices are yet to be developed. The problem with developing best practices is the trial and error foundation it rests upon. Learning from mistakes becomes very costly both in terms of human life and economics when it occurs in a high risk domain like HSC operations.

The development of operating procedures for HSCs needs to be underpinned with research that identifies the factors that constitutes success in this domain. By knowing the fabric of success and the specific requirements better, procedures, guidelines and training curriculum can be designed to achieve higher operational efficiency and a corresponding reduction in accidents.

Dynamic Navigation (DYNAV) is a construct developed by the author to describe navigation principles applied among various HSC operators. The word “Dynamic” implies that this methodology of navigation is elastic in nature. This methodology consists of both generic and specific parts. The generic parts are more or less generalizable to most maritime navigation while the specifics need to be dynamically adapted to the context at hand. The sea has certain characteristics that do not vary much regardless of where you are or what you do. Maritime navigation is performed in a two dimensional space, while air navigation is conducted in a three dimensional space, these are generic characteristic of the two domains. . Task, situation, context, weather, speed and many more aspects are varying and the methodology to handle these need to encompass an inherent ability to dynamically adapt.

High Speed Navigation has been the vernacular name for the methodology used in the Swedish Amphibious Corps, while in the British Royal Marines “Assault Navigation” is preferred. In the Swedish Navy standing orders of navigation, the term DYNAV is not explicitly used; instead following phrase is to be found: “Navigational services on Navy high speed boats” (Försvarsmakten, 2003). A common nomenclature, a name for the methodology and operational definitions are needed. Forsman et al. (2012) offers a first attempt to define the DYNAV methodology and its constituent elements. That definition is further developed in this thesis. An attempt is made to suggest a theoretical framework that can aid the understanding of the success factors of navigation in extreme conditions, including factors such as high velocity navigation, time constraints, uncertainty and complexity.

There is always a tradeoff when assessing a system such as high speed navigation - depth or breadth. Here the perspectives of Sociotechnical Systems and Complexity are chosen. This infers that breadth is chosen over depth. The two perspectives are complementary and one single perspective can't entirely compensate for the other. The sociotechnical view is needed to understand the domain from an overarching perspective. Without an understanding of the broader picture it is easy to get lost when the depth of any subject is explored. The goal of this thesis is to attempt to outline an overarching theoretical perspective on navigation in general and draw inferences on the success factors of High Speed Navigation specifically.

2. Theory

2.1. Defining Navigation

The word navigation is frequently used in many vocational contexts and often in general terms. But what is navigation and what does the word imply? The evolution of practical maritime navigation might not be obvious even to those in the vocation. Celestial navigation, and to some extent terrestrial navigation, have been replaced with other more modern techniques and technologies. Navigational aids of today assist the navigator in obtaining and maintaining the understanding of the situation without using the stars and relies less on classical terrestrial principals. These navigational aids create a virtual representation of the physical world. The models navigators use are thus changed, because the navigator is making decisions on information coming from both the physical and virtual representations of the surrounding world. The virtual world is very present in maritime navigation. Navigation in a virtual world could be to operate an ECDIS, menus on a technological/cognitive tool etc. and is an inherent part of the overarching task of maritime navigation. Cognitive technological tools are used for aiding, enhancing, or improving human cognition (Hutchins, 1995).

In one of the most notable manuscripts to describe maritime navigation, Bowditch (2011) defines navigation as a blend of science and art but doesn't go any deeper into what the cognitive or methodological foundations of navigation are. The description of navigation is focused on various technical aspects such as "radar navigation" and "dead reckoning". Not much is written about cognition, teamwork or "sensemaking".

In His Majesty's Stationery Office (1941) a similar definition of navigation can be found: "the science and art of guiding a vessel from one location to another". Even though this references has much in common with Bowditch (2011) they are separated by more than 60 years. Essentially they are communicating the same message. Using the word *art* suggests that navigation is more organic than procedural, and still just partly understood. It is appealing to draw parallels from "art" to occupational skill and/or tacit knowledge. A person may have an "expert" skill set, but is unaware how the task is being performed (Dreyfus, & Dreyfus, 1980). Until tacit knowledge can be made explicit (and thus more easily communicated amongst stakeholders) navigation may still remain more of an "art" than a science.

The understanding of navigation differs considerably between vocational categories. The American Practical Navigator (Bowditch, 2011) is written for practitioners and doesn't represent the scientific perspective. On the other hand, the scientific literature on navigation doesn't say much about how to apply theory into practice, which is to be expected when the application is an occupational skill and thus to a large extent also tacit rather than explicit or conscious.

Hutchins' (1995) work, however, addressed the barriers between relating practical navigation issues with the scientific literature on cognition. Hutchins defines navigation to be "the process of directing the movement of a craft from one point to another". Further, Hutchins reveals the bigger message which is that navigation is a distributed cognitive activity and culturally dependent.

The concept of navigation is elaborated upon by Jul and Furnas (1997) and outlines several basic aspects of navigation as motion, decision-making, process and context. They also highlight that navigation includes orientation as aligning one representation of the world with another or with the world itself. This process can be illustrated by the use of a compass to line the map with the physical environment. Novel to the navigation literature, Jules and Furnas (1997) recognize Error Recovery as a concept important to navigation.

You are climbing to the top of a mountain in order to look at the environment around you. You want to orientate yourself within this space. This process of observing and organizing objects or landmarks to relative position amongst themselves and in relation to you is called orientation. It builds the understanding of the geography and the objects of interest in relation to each other. The difference lies in the intention of movement. As soon as movement occurs so must planning. To get from one place to another infers that one have to apply some form of strategy that can be broken down in tactics - wayfinding. This can be an intuitive process but can also require explicit and deliberate planning.

Throughout this paper when navigation in mentioned it is Darken and Peterson (2002) definition of navigation as an aggregated task constituted from wayfinding and motion. Darken and Peterson (2002)[1] builds on a workshop report of Jules and Furnas (1997) and defines navigation as the aggregated task of wayfinding and motion. Wayfinding is the cognitive part of navigation but it is not separate from motion. Wayfinding, as a process, is carried out both at strategic and tactical levels which infers that wayfinding or motion does not precede one or the other but instead they are two processes needed to be carried out together to achieve navigation. Darken and Peterson (2002) claim that while poorly understood by the contemporary literature, wayfinding reflects a heuristic in which a cognitive or mental map is created.

2.2. Navigation as a Sociotechnical System

In western cultures a reductionist methodological approach is generally adopted to understand a problem (Vicente, 2006, p. 29). A reductionist way of resolving large complicated problems is to break down and reduce them into their basic components and analyse the system on a detailed level. This approach has proven successful in creating knowledge and understanding (Vicente, 2006, p. 30; Leveson, 2011, p. 4; Johansson, 2013). By reducing the problem into its components they can be problematized, analysed and new knowledge can be created. In science this is the very basis for controlled experiments - to isolate a small part of a larger system, control for the confounding factors and test for causality. There is a flipside to this coin and that is perspective (Vicente, 2006, p. 32). We can learn a lot by looking at a system's components and make inferences but there is also a need of looking at the system at an aggregated level as well. The idea of being able to generalize from experiment and research to reality can be impeded by lack of perspective. The sociotechnical perspective is an effort to provide a model of how systems are larger than the sum of its parts.

The technological development is an ongoing process that takes place with an increasing pace (Leveson, 2011). The way navigation is conducted is related to the tools and technology that are available and as these aids constantly change the methodology of navigation needs to adapt. On a historic timescale, the compass was not that long ago a navigational novelty. More recent achievements with Global Positioning System (GPS) and the possibility to plot a ship's position on a

[1] The Jules and Furnas (1997) report summarizes a workshop at CHI 97 that focused on issues in navigation in electronic information environments. The text is available online but unfortunately the illustrations are not. Some of the illustrations are used in Darken (2002) and that is why the article is referenced rather than the original report.

digital map are now as commonplace as similar technologies available on a person's smartphone. New technologies have improved the ability to navigate the sea. Some of the most obvious in the maritime domain is radar, which enables us to see through fog or in darkness, ECDIS, which automatically plots our position on the map, and satellite communications that have opened up the possibility for communication on the high seas. The affordance of those technical tools is also interesting. How new technological tools potentially can be used is poorly understood (Leveson, 2011) thus there are possibilities for both improvements and problems that are hard to detect in advance. New tools create new possibilities and also new problems. The question is how to integrate the tools in a safe and effective way. Adding more possibilities without any scrutinization and prioritization are precursors for cognitive overload (Grootjen, Biermanc & Neerincx, 2006). The cognitive capabilities of man, technological tools and organisation on a system level must be understood in the design process. Competence, organization and technological tools must be designed in consideration of each other in order to be effective (Woods & Hollnagel, 2006). When this aspect is missed, the design of the sociotechnical system will be counterproductive and efforts that are meant to create safety and efficiency could create risk and instability (Woods & Hollnagel, 2006). In the process of developing technological tools an understanding of the sharp end user's needs is often flawed (Vicente, 2006).

The more nodes (potential points for interaction) there are in a system the more potential interactions there can be and the system has a potential of becoming complex and more unpredictable (Perrow, 1984). On a ship's bridge different tools are brought together and those tools are joined into what is claimed to be an Integrated Bridge System (IBS) (International Maritime Organisation, 2002). Integrated, in this case, means that the technological tools are interconnected and can exchange information with each other. The problem is that the single most important aspect of the system design so often overlooked is the needs of the operators of the system. The complexity a poorly designed system creates is what is least needed in human-machine integration (Vicente, 2006, p. 45).

How navigation is conducted depends upon context and circumstances. A definition of navigation as a sociotechnical system can be found in Minding the Helm (National Research Council, 1994, p. 1):

> *"Marine navigation and piloting involve complex, interdependent operations in a large sociotechnical system that encompasses waterways, vessels, navigation aids, and human operators. System elements are supported by an infrastructure for vessel and port management, pilotage, pilotage regulation, and professional development. Marine navigation and piloting occur in an operating environment characterized by extreme reliance on human performance, considerable diversity in geographic and hydrographic features, and great variability in operating conditions."*

This definition helps in the understanding of the contextual aspects of maritime navigation and is further strengthened by Grech, Horberry & Koester (2008, p. 20):

> *"It is obvious that organisations in the maritime domain are consistent with the sociotechnical systems perspective".*

2.3. The Dynamic Navigation Methodology

The origin of the the Dynamic Navigation methodology (DYNAV) was developed to address the navigation demands of high speed vessels in the early 1990's by the Swedish Amphibious Corps. Since then many organizations have adopted and adapted the methodology to their needs; examples of those are UK Marines (Assault Navigation), Swedish Maritime Police and the Swedish Sea Rescue Society (Forsman et al., 2012). The Swedish Maritime Authority has also legislated that all commercial vessels that are not covered by the IMO High Speed Craft Code and have speed capabilities of 35 knots or more to be handled by a person with a certificate to handle HSC (Sjöfartsverket, 2007) based on the same navigational principles described by DYNAV.

DYNAV functions with a team of a navigator and a driver. One of them has the command of the vessel but that responsibility is not fixed to a role. The familiar usage of the term Coxswain is relaxed in DYNAV. The idea of the coxswain is attached to the notion of the combination of driving, being in command and doing the navigation.

> *"the coxswain has the authority to direct all boat and crew activities during the mission and modify planned missions to provide for the safety of the boat and the crew"* (US Coast Guard, 2003)

> *"Coxswain: The helmsman of a boat; the person on board ship having permanent charge of a boat and its crew, of which he has command unless a superior officer is present".* (OED online, 2014)

The term coxswain in rowing is defined as:

> "the person who directs the oarsmen's pace and direction on a crew skiff" (Goens, 1998).

Rowing is a team effort, so is DYNAV and roles have to be clear to avoid excessive workload on any single individual.

To avoid the preconceptions that the word coxswain inherently carries, the term coxswain will not be used frequently in this thesis. In DYNAV the roles of driver, navigator and commander is distributed within the team (Fig. 2.1). The crew has equal competence and thus they can swap between the role as navigator and driver. This strengthens the endurance and adaptive capabilities of the crew and will be elaborated upon further in Section 6.4 on Joint Activity. The navigator has the responsibility for the navigation even if the commander is at the helm. The difference between the roles of navigator and driver in comparison to the role of the commander is that navigation and driving are tied to a workstation, to be the commander is a role that is tied to a person regardless of any other role that person also is fulfilling. Important to note is that these three roles can be manned with less than three people; two have proven to work well in the Swedish Amphibious Corps, and in theory it can be managed by one single person as well. Though reducing the number of people on the bridge team to one individual brings it back close to the definition of the original interpretation of the term Coxswain.

The driver controls the physical handling of the vessel and the navigator does most of the navigation. To be able to control the vessel as a team a considerable amount of communication between the driver and navigator must occur. This is a slight contrast to navigation in low speed where a coxswain takes the larger share of the workload and is normally charged with doing the navigation, boat handling and decision making, a strategy that is efficient when time is abundant but has clear limitations under time pressure. When time is scarce more teamwork is needed to efficiently cope with the challenges of navigation.

The commander of the vessel has the overall responsibility in any given situation but the context will guide who is in charge for specific activities. To have the overall responsibility of the vessel then does not necessarily mean to make decisions as in a hierarchical command and control (C2) structure but rather to make sure decisions are made by those who are best suited and competent.

The navigator has the overall responsibility for the navigational safety. His task is to be in charge of the navigation to see that it is sufficiently conducted. It does not imply that he needs to do all the navigation. Navigating and driving are team efforts; meaning that the navigator not only provides instructions to the driver on how to manoeuvre but also delegates tasks to him and reciprocally acts upon cues from the driver. The driver is thus not a typical helmsman, nor the coxswain or commander by default. The driver manoeuvres the vessel, participates in the navigation and has the responsibility to challenge the navigator and question the team's common understanding of the situation and act upon any suspected uncertainty by slowing down.

Fig. 2.1 Left: Driver in Combat Boat 90, right: driver and navigator in a Rigid Inflatable Boat (R.I.B.)

By having shared responsibilities amongst a crew, it is also the crewmembers' obligation to stop the activity when feeling threatened for their safety or protecting asset integrity (Rochlin, 1999). In high speed navigation, this generally results in the decision to slow down the speed of transit. There is a critical difference between *knowing* that there is a tangible threat compared to *suspecting* there is a threat. Safety in DYNAV is highly reliant on acting on any suspicion of threat.

The crew as a whole has responsibility for the safety of voyage but it is the navigator who has the specific responsibility for the navigation. The navigator isn't a support to the coxswain. In DYNAV the driver is a support to the navigator.

DYNAV methodology should not be considered a new construct for navigation but rather a structured methodology that enables adaptability and depends on communication and interdependency between the team members rather than on technical support. DYNAV does not add any new navigation techniques but it provides a structural methodology that choreographs the crew's activities with the aim of achieving a resilient way of navigation (Forsman et al., 2012). The following section describes some of the techniques used to achieve this in DYNAV.

2.4. Basic Positioning Techniques

Positioning is made both lengthways and sideways. Different techniques are being used to achieve this. The principal is that is not necessary to know the exact position at all time. The goal is to know that the craft is within safe boundaries. This approach to navigation saves effort and when time is scarce it is more efficient to navigate with larger margins to free up cognitive resources too look ahead to the next navigational challenge. The trade-off between accuracy and foresight is being utilized by using simpler heuristics for positioning and thus more foresight can be gained; which is more important the higher the speed becomes.

There are many ways of positioning a vessel. The aim in this section is not to provide a complete set of tools but to describe some of the most salient techniques used in DYNAV (Forsman & Isaksson, 2006). Positioning can be done in many ways and with many tools. Most of the techniques can be used both optically by looking out but is also to great extent transferrable to radar navigation as well. All these positioning techniques are supposed to be used in parallel with all other information sources and particularly the electronic chart display.

An easy adopted and equally efficient way to identify a waypoint is to use distinctive objects along the trajectory. When those objects are perpendicular to the vessels the position lengthwise is known as long as the intended course is steered (fig. 2.2).

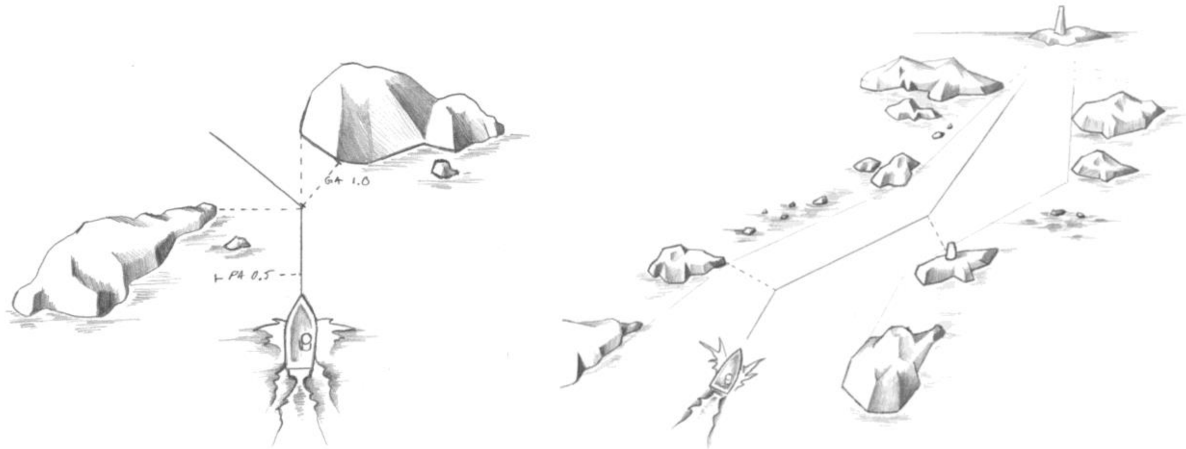


Fig. 2.2 An object abeam to port for lengthwise positioning

Deviations from the course will cause deterioration of the precision of the positioning. Likewise the greater the distance to the object abeam the greater the error generated due to course deviation will be (Fig. 2.3). This technique is thus best used with objects close to the vessel and when extreme precision not is needed.

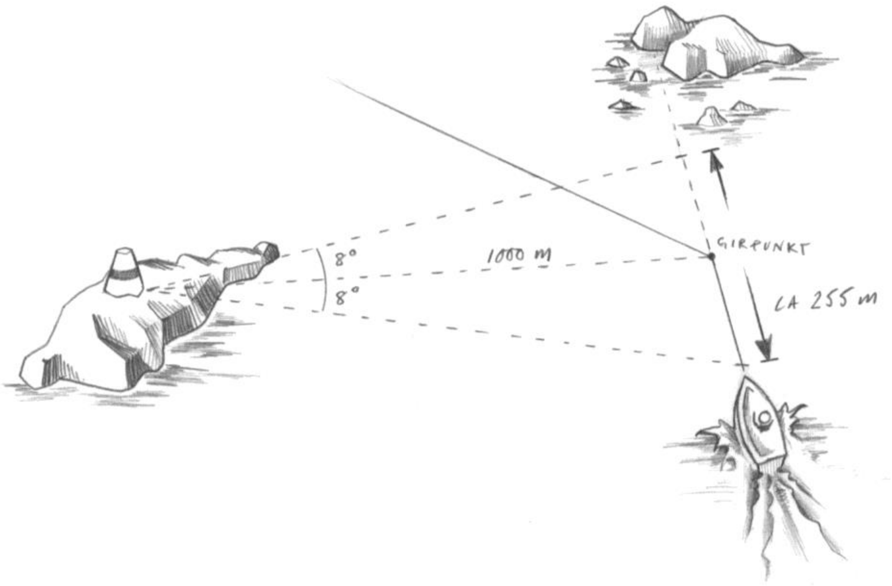


Fig. 2.3 Inaccuracy dependent on errors in the estimation of objects abeam.

More accurate than abeam mark to define the position lengthwise is to use a leading line (Fig. 2.4). These are a few examples of how lengthwise, and in this case sidewise, positioning can be made. It is only the imagination that sets the limitation for what aid to use to achieve knowledge of one's geographical location.

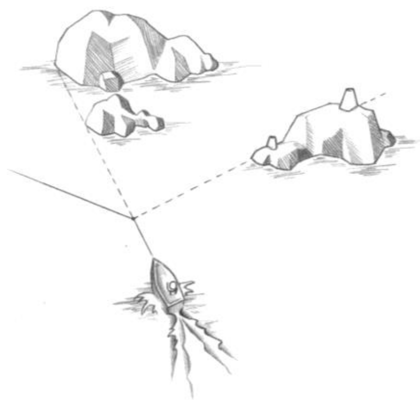


Fig. 2.4 Using leading lines for positioning.

The radar can effectively be used to verify distances (Fig 2.5). As with the optical techniques it is possible to determine when an abject is abeam. The radar technology has some inherent characteristics that make this kind of use less favourable which not is covered here. Using the radar to define a distance sideways or lengthwise is an accurate and a very effective way to identify the waypoint.

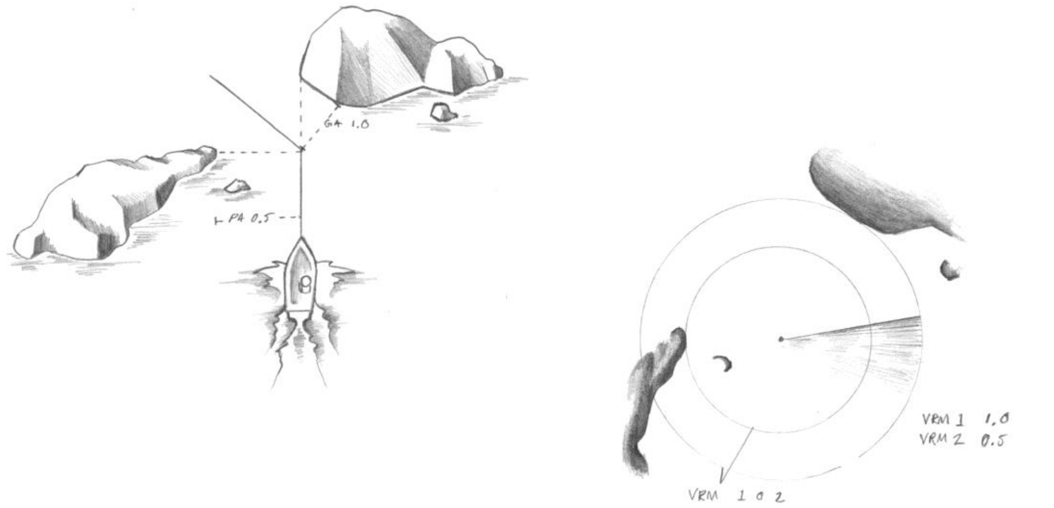


Fig. 2.5 The use of the radar to determine distances.

Positioning lengthwise can be done in equally many ways as position sideways. The most prominent is the combination of a course and a stationary physical object to head at (Fig.2.6). If the object one is heading at is known then the course steered will give the position sideways. If there is shallow water on the starboard side of the route and as long as the course steered at the current object won't fall below a certain number the vessel will be in deep water.

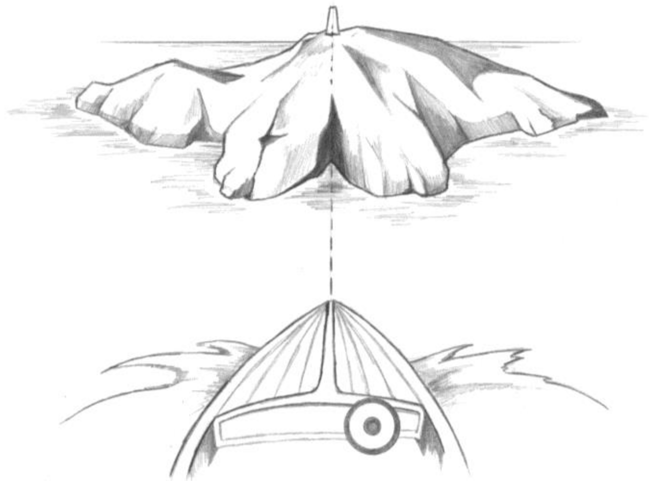


Fig. 2.6 Sideways positioning by combining a course with an object.

Sideways positioning can also be achieved by sectioning sounds and islands from 1-10. The underpinning idea is that estimating distances in numeric values is inaccurate; however, to work with ratios is easier and more precise. Ratios are more efficient to translate from the chart to what's observable in the physical environment. Threats and shoals can also be targeted with this technique and thus is used to describe both where to be and where not to be. In Fig. 2.7 the boat is steering 3 in the sound, the shoal is 8-10.

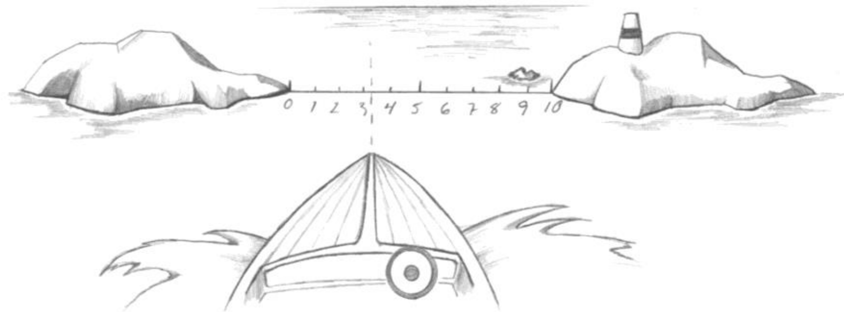


Fig. 2.7 Sideways position by sectioning the sound.

Sectioning of an island can be used to extrapolate the width of the island sideways and create new physical steering marks. Then an order can be to steer 7 to the right of the island (Fig. 2.8).

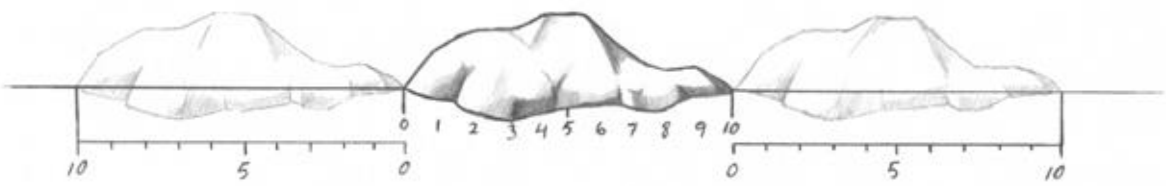


Fig. 2.8 Extrapolation of the width of an object.

There are two ways of using the sectioning technique in a sound. The first is to give the order to "steer 5 *in* the sound" which translates to aim from the present point of view in the middle of the open water in the sound as it appears from the present perspective (Fig. 2.9). This means that if you have an aspect to the sound and are not entering it straight ahead, one will enter close to one side and exit closer to the other.

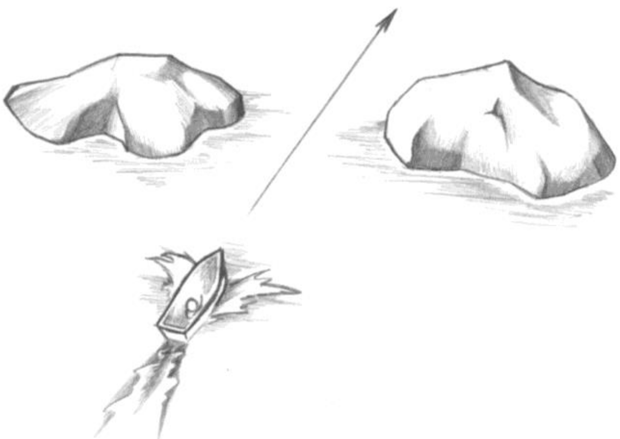


Fig. 2.9 Steering a course in a straight line through a sound.

To be able to stay in the middle through the whole passage the command "steer 5 *through* the sound" is used which means that the driver shall position the boat at equal distance from the shores at all times (Fig. 2.10). If the sound is doglegging, the driver will then adjust his course so that equal distances to the shores are achieved.

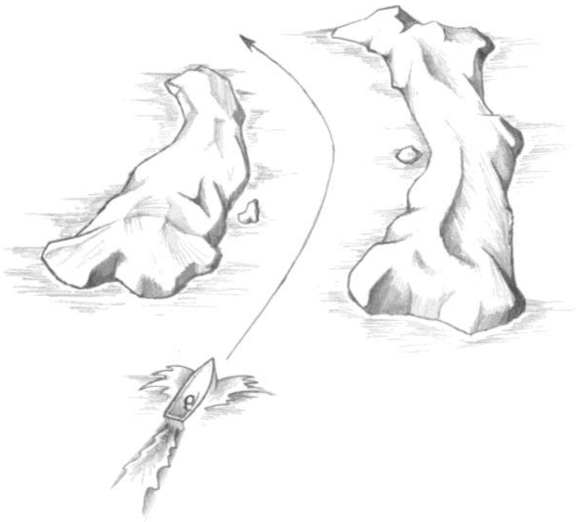


Fig. 2.10 Steering through a sound with kept distances to the shores

For targeting the clock technique is used. A rough estimation of angles is often adequate and can be done quickly. It is used to make sure that the crew is referring to the same object in the environment and thus increases the precision of communications (Fig. 2.11)

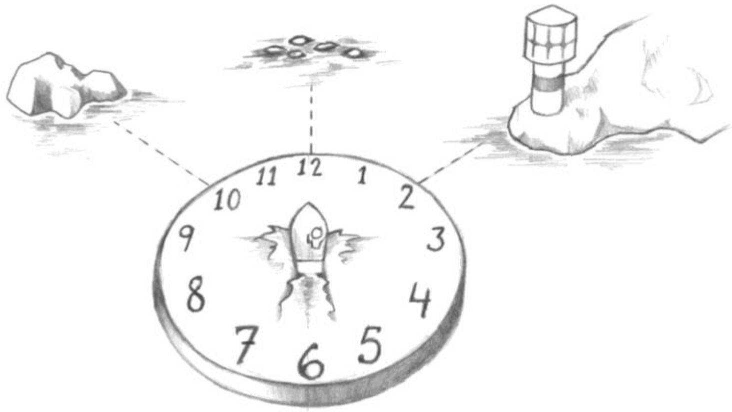


Fig. 2.11 Targeting using the metaphor of a clock.

3. Objectives of the Thesis

The overall objectives of this thesis is to better understand the factors for success in the domain of high speed navigation from a sociotechnical perspective through the elaboration of results from scholarly works produced by myself and colleagues. Specifically, the concepts of Joint Activity, Epistemic Actions, Complexity, Sensemaking and Control are investigated to suggest their roles in the success of small teams operating in challenging maritime conditions.

The aim of Paper I was to demonstrate that the operation of a maritime High Speed Craft requires additional skills and systems than those of slower vessels. The higher speeds, and therefore reduced reaction times, require the development and assimilation of specific operational methodologies that are standardised throughout the HSC community to support safety when operating with both experienced and non-experienced crew members.

The aim of Paper II was to describe the DYNAV navigation methodology used by several organizations in time critical conditions, in high speed. The concepts behind the navigational methodology, its development, how standardized procedures enhance safety, operational effectiveness and interoperability were also described.

The aim of Paper III was to elaborate upon the training needs in relation to maritime navigation in adverse conditions and how simulation can be beneficial to meet these needs. Often trainers are striving to create as high realism as possible. The paper argues that it is more important to identify the adequate level of fidelity to make use of the lesser noise in simulation than in reality.

The aim of paper IV was to argue for a holistic approach to system design. When designing a system for navigation that should be based on how navigation is conducted rather than build the technological tools from a simplified model and hope that the operators adapt.

The aim of paper V was to build an argument that risk, competence, interoperability and competence are inherently interlinked in creating safety within the HSC domain.

4. Method

4.1. Methodology

Papers I-V are written to gain insight on the DYNAV methodology from different perspectives. Selected results from these papers are included in this thesis and are used to draw new inferences from a theoretical foundation not considered by the author at the time the papers were written. The theoretical reflections on the result are based on a broad review of literature.

4.2. Delimitations

The focus of this thesis is on how stable performance under varying conditions is achieved in High Speed Navigation. The domain chosen is small boat crews under challenging and adverse conditions.

The system of interest is not the whole maritime domain but rather the crew, vessel and the close environment. No efforts will be put on wayfinding or navigational techniques as in how to define a waypoint or verify a distance to an object. Instead the working methodology of navigation through teamwork is considered.

4.2.1. System boundaries

The system of interest is the bridge team and the organisation of work. The vessel as a whole or the vessel as a part of an organisation is excluded from this scope. In this definition of the system, the human being is an inherent part of the system and not only defined as the user apart from the technical system. In many other descriptions found in the literature the technology is depicted in the centre of the system (Vicente, 2006; Hollnagel 2002) and described separate from the user. It is a not a semantic question where the human is placed in the system, it actually defines the sociotechnical heuristic. Sociotechnical systems in this thesis are defined with a human centred approach. The system of investigation, in this thesis, is the crew and to some extent the cockpit and the HSC itself (Fig. 4.1).

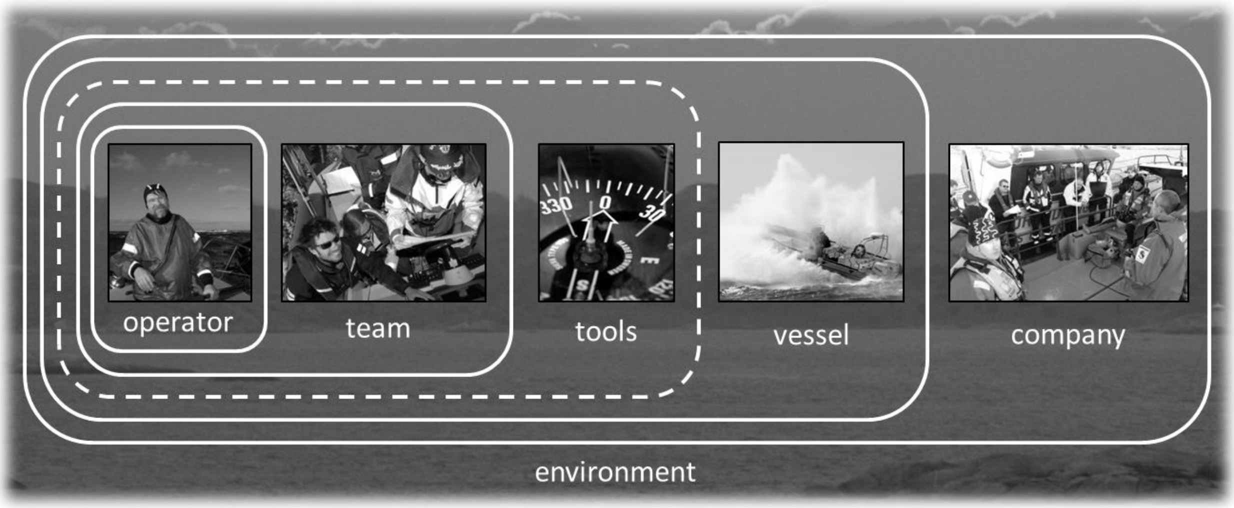


Fig. 4.1 DYNAV as a socio-technical system, showing relative boundaries

5. Result

This chapter highlights selected findings from the papers that subsequently will be used in the thesis to develop a theoretical framework to create a foundation to underpin future research.

5.1. Paper I

The case studies and information described within this paper demonstrate that the operation of HSCs requires additional skills and systems than those of slower vessels. The higher speeds, and therefore reduced reaction times, necessitates the development and assimilation of specific operational methodologies which are standardized throughout the community to support safety when operating with both experienced and novice crew members. The definition of different levels of control, tactical and strategic, are used in general terms in this paper and should not be interpreted as the definition introduced later in this thesis.

5.1.1. Strategic and tactical processes in navigation

How well the crew understands their situation is crucial for the safe and successful outcomes of the task. It is not enough that each crewmember has his or her own understanding of the situation. There must be an overlap between the crewmembers understanding to be able to act interdependently as a team.

Within the tasks of navigation, at least two distinct processes can be found which are a proactive/strategic process and a more reactive/tactical process. The proactive/strategic process is manifested in the preplanning of routes and waypoints and the expectation of the development of the navigation plan. The reactive/tactical process becomes apparent when a modification to the preplanned route are required during the voyage.

The differences between the two processes are best considered from the perspective of the scope of activity or action. For proactive/strategic actions, the scope is the overall transit from beginning to end and any effects on the overall mission. For reactive/tactical action, the scope involves the current state versus the intended state, as planned for in the proactive/strategic actions, and bringing the craft back to the intended state.

The ability to act strategically, whilst under-way, means that the system can evaluate the overall effect that reactive/tactical navigation decisions will have on the goal of the mission, rather than on the next leg of the voyage. This may be seen as analogous to playing chess where moves are made with the end-state in mind, rather than simply considering the next move.

Therefore a greater understanding is required of the cognitive process and skills for strategic and tactical decision making related to HSC navigation; particularly how different phases of the mission require the two processes to be interchangeable and the potential to incorporate creativity or the “art” of navigation.

5.1.2. Command and Control

Smaller high speed boats are often run by a single crew member. Research has shown that as vessel speed increases a single crew member without extensive amount of training is unable to attend to both navigation information sources (e.g. chart plotter) and the cues external to the craft (Dahlman, Forsman, Sjörs, Lützhöft, & Falkmer, 2008). Therefore the C2 of the craft becomes a two-person task requiring a dedicated navigator, and a communication scheme to facilitate effective information transfer between the crew members and off-board platforms and agencies. To understand the requirements of HSC C2 (HSC3) a model has been developed describing the interaction between the HSC navigator (command function) and coxswain (control function), the information required by the navigator to maintain an appropriate level of Situation Awareness, and subsequently the command instructions for the coxswain to action.

Fig. 5.1 is a model of HSC3. It describes the command, control and communication functions built into the DYNAV methodology from a linear perspective. It does not capture the reciprocal replanning mechanisms later developed although it does illustrate how an action propagates through the system.

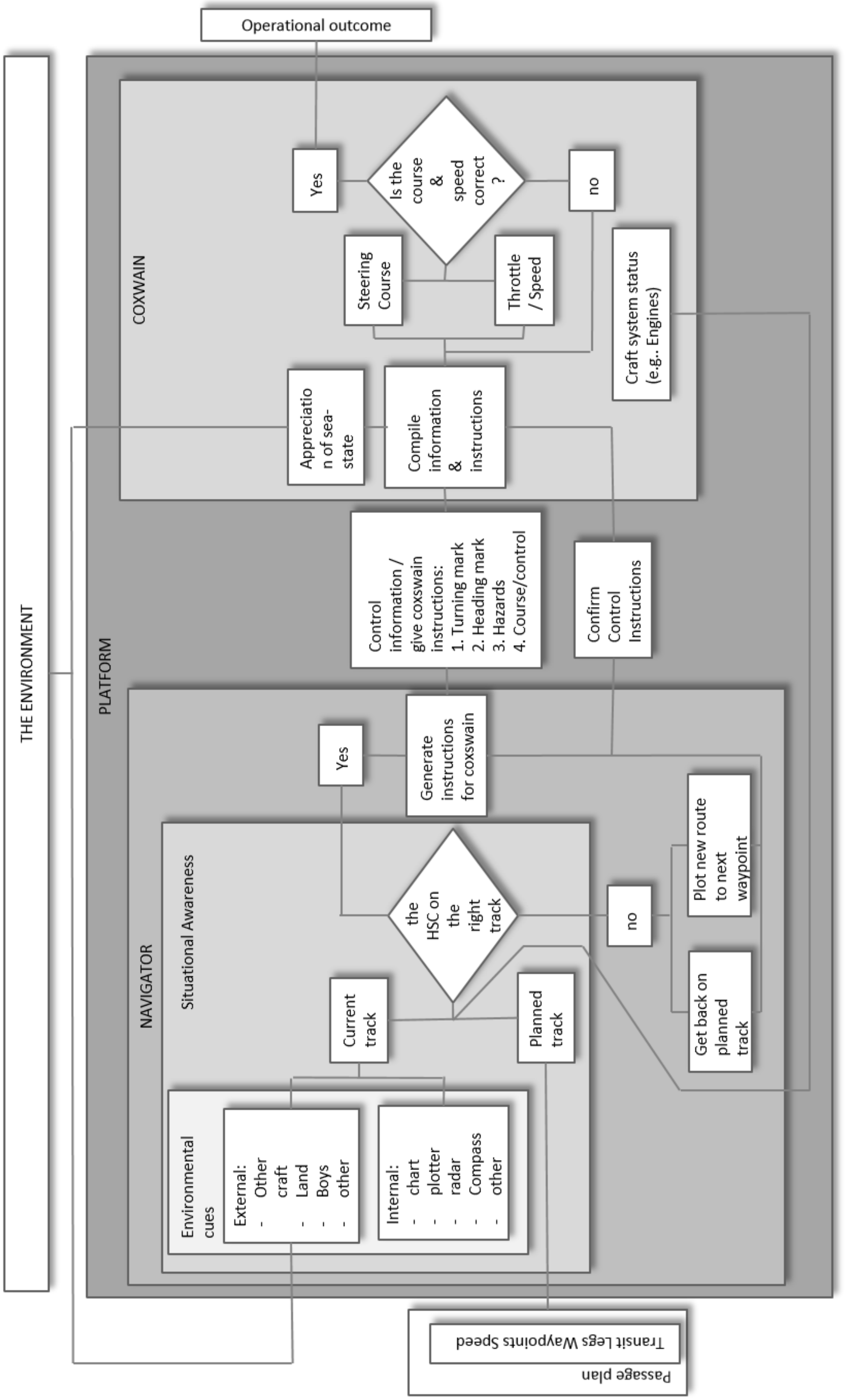


Fig. 5.1 High Speed Craft Command and Control (HSC3)

5.1.3. "Knowing where you are" vs "knowing where you're not"

During high speed navigation, ironically, once you have determined where you are in the environment you are no longer there. It may be more relevant to know where you are not (i.e. you are not near any hazards/obstacles/obstructions and therefore you are in an area that is safe). It isn't essential to know exactly where you are within the safe area. This is not an argument for not conducting proper navigation, on the contrary, it is an argument for slightly different approach to navigation where you define your operating envelope with clear boundaries that you are operating within. Therefore "*knowing where you are not*" may be a faster technique and more effective approach from a cognitive perspective to establish operational effectiveness with an appropriate level of safety.

5.2. Paper II

This paper examines the main constituents of DYNAV, its origin and how it is applied.

5.2.1. DYNAV spawning point

During the early nineties the Swedish Coastal Artillery was restructured to become the Amphibious Corps. In this process the tactic changed from stationary and well armoured to agility and less armour. The boat developed for this was the CB 90. It had speed capabilities of up to 40 knots and this meant that the traditional way of navigation inshore the archipelagos waters of Sweden didn't suffice. A new methodology started to organically grow by a bottom-up process. It was coined High Speed Navigation Methodology. DYNAV is the later interpretation of how navigation at high speed is safely conducted.

5.2.2. Preplanning

The preplanning is often made in advance if possible or underway if the circumstances allow for it. The purpose is to make the overarching decisions as what general route to take, how to handle specific problems and be able to make a risk assessment. If time is available the general plan can be developed in much greater detail (Dobbins et al., 2010; Forsman et al., 2012).

The preplanning enables the crew to focus on the upcoming needs of replanning and adjustments that are unavoidable in the execution of the navigation. The paper chart is often used for the preplanning (Fig. 5.2) to be able to make the navigation intentions graphically tangible by a two-dimensional representation on the map.

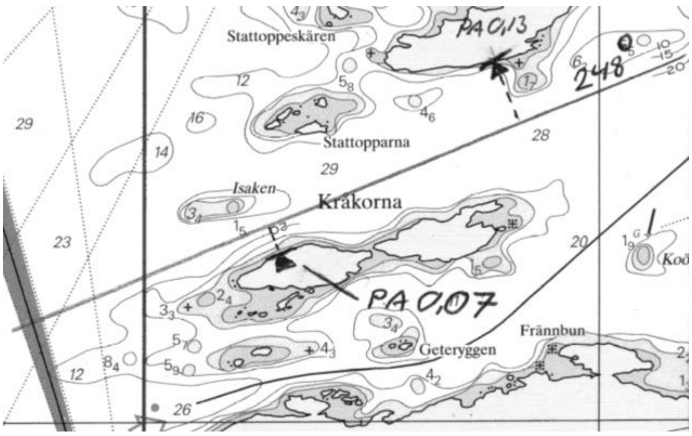


Fig. 5.2 Example of preparations made in the paper chart.

Planning in DYNAV is done both prior to the voyage and during it. The preplanning takes place in advance and it is then the routes are chosen, the overarching risk analysis is made and the charts are prepared. Planning and replanning are made continuously throughout the navigation.

5.2.3. Phases

The Phases is a model of how the work of navigation is sequenced and developed as a tool for the crew to know what to do in relation to an upcoming event, in this case a waypoint. The crew orientates themselves in the world, find their way, plan what tools and techniques of navigation to use and communicates.

Each turn or activity is broken down into four components. The phases of the DYNAV Methodology are (Fig. 5.3):

1) Plan
2) Communicate
3) Execute
4) Verify

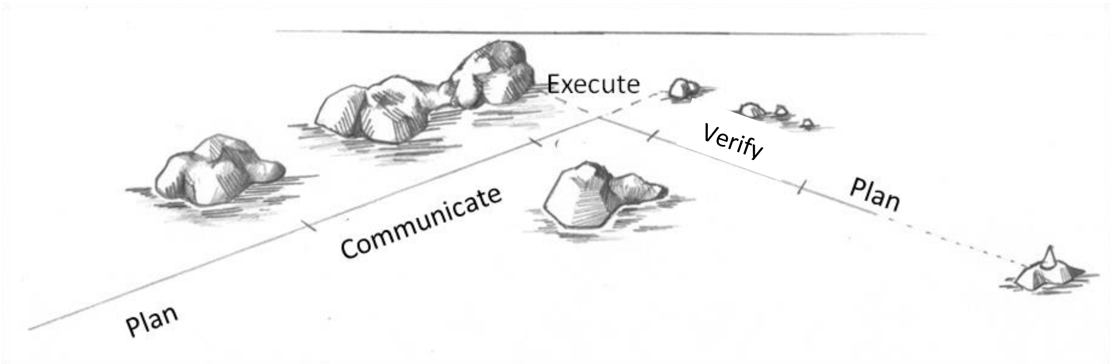


Fig. 5.3 Graphical representation of the basic phases in DYNAV methodology

These phases give the crew a starting point to organize their work. When time is of essence it is crucial to have the work organized into roles, tasks and task order.

Plan:

The crew assess the situation and calibrates the orientation of the environment. When they are approaching the next waypoint they construct a plan, based on the preplan in the chart, how to hit the waypoint and how to get a pertinent trajectory towards next waypoint.

Communicate:

The plan is formalised and communicated within the team, in most cases by the navigator. The plan will be broken down into a set of standard instructions based on the need of basic navigational information. The navigator communicates his plan to the driver. The driver and navigator communicate through a closed loop protocol in order to make sure that both persons know that the message has been received and understood.

Execute:

During the execution phase the navigator has the delegated responsibility to lighten his/her workload and uses the crew to its full potential through avoiding excessive workload by distribution. The driver reads back to the navigator as he is approaching the waypoint and repeats the navigational information while executing the manoeuvre. The navigator monitors the development during the phase to make sure they have the same understanding of the intended navigation outcome.

Verify:

When the turn is conducted the crew follows the development to verify that the outcome is as intended or if not; at least safe. This phase of verifying the outcome is in it selves a crucial safety barrier. By checking and comparing several types of data, the crew can identify inconsistencies or unwanted variability during early stages before safety is potentially compromised. This is a very important step to perform in order to achieve stable performance under varying conditions.

5.2.4. Basic Navigation Information scheme

Planning, communication, execution and verifying are based on an information protocol. There are five concept pieces of information that is the foundation of the navigation. In all of the phases the actions are guided by the basic information protocol. The content is summarized by five basic questions:

- Where are we going now?
- Where and how to do the next turn?
- Where are we going next?
- Where shouldn't we be?
- How do we know we are safe?

The information is embedded in a structured way of communicating utilizing both gestures and speech and technological tools, such as the radar. The information is read back by the driver in a closed loop. Equipped with this information the driver is able to conduct the next turn or the next navigation element. The navigator has the opportunity to monitor the process without being overloaded by the burden of giving extensive instructions and can monitor the outcome of the turn simultaneously which, presumably, lowers workload.

5.2.5. Trapping errors

The crew needs to be able to identify mistakes, distorted or false data before there is a significant impact on safety. If the crew is making its judgments mainly on one source of information the possibilities to scrutinize own actions or perceived data are limited. One tactic to scrutinize or verify data is to use many sources of information and multiple tactics for problem solving (Fig. 5.4). The key to error trapping is to get more than one set of data so that they can be compared. If there are inconsistencies in the data or in the outcome of the manoeuvre, depending on what control function the crew uses, it is to be considered a risk and the speed should be reduced or come to a halt.

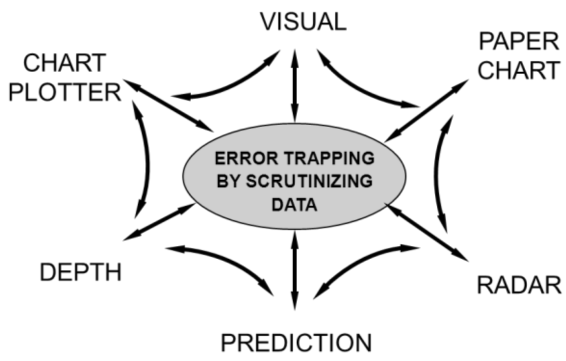


Fig. 5.4 Error trapping by scrutinizing data

5.3. Paper III

This paper describes DYNAV from the scope of interoperability and training with reflections on simulation. The concept of mental models and qualifications are here brought into the results.

5.3.1. Mental models

Team members must have an understanding, or mental models, on several different levels of how a team is constituted and operates, to effectively work within and as part of the team (Mathieu, 2000).

1. Team members need to understand the technology and equipment used on their craft. What it is, why it is there and how the technical parts of the system are interlaced. In navigation this relates to the use of the vessel and the navigational aids/tools (e.g. Radar, ECDIS/Electronic Chart Display) that must be learned to such a level that they don't create an unnecessary cognitive workload when used.
2. Team members must hold shared job or task models. These models tell the crewmember how the task is accomplished in terms of procedures, task strategies, likely contingencies and environmental conditions. The crewmember must understand the goal(s) of the activity and how it is undertaken. If not, there will be discrepancies in the way different crewmembers try to contribute to the completion of the task, and in the worst case the initiatives will be counterproductive.
3. Team members must have shared conceptions of how the team interacts and an understanding of each team member's roles and responsibilities, interaction patterns, information flow and communication channels. In a situation with a high level of cognitive workload, such as operating a HSC in a harsh and congested environment, it is essential to use the scarce individual and collective cognitive resources effectively and efficiently.
4. Finally, each individual must share the team member model. This model represents the teammate's knowledge, skills and attitudes, preferences, strength and weaknesses. Such knowledge is crucial for team effectiveness because it allows team members to tailor their behaviour in accordance of what they expect their teammates to perform, or do, in a specific context, - especially in high risk / dangerous situations.

5.4. Paper IV

In this paper C2 is elaborated on and the importance of how information is displayed and C2. It highlights the special circumstances navigation has in austere conditions. The result brought into this thesis focuses on the four phases of DYNAV in C2.

5.4.1. Buffer

Within the DYNAV methodology there is latency between the HSC's current position and its next turn or manoeuvre point. Within this time, the Navigator must ensure that the DYNAV planning task is completed with a tolerable level of risk, the manoeuvre instructions are developed and checked, the instructions are communicated to the driver/pilot/coxswain and confirmed, and then the manoeuvre executed. It can be expected that the time required for the DYNAV communication phase is minimized by the use of the crew being trained and familiar with the standard DYNAV communication protocol. Therefore to give the Navigator the maximum amount of time (i.e. a buffer) for option assessment and subsequent decision-making, they must gain a minimum level of situation awareness (Endsley, 1995) as quickly as possible. Gaining Situation Awareness (SA) faster involves a trade-off between thoroughness and efficiency/accuracy. It supposes, or assumes that information displays are more intuitive and provides the navigator with exactly the information required at the right time. This concept of maximizing planning time by reducing the time required to gain SA is illustrated in Fig. 5.6.

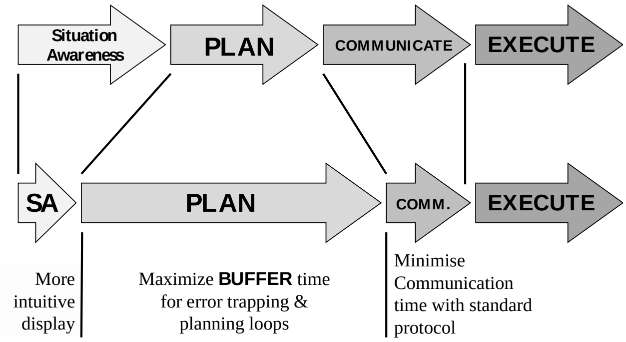


Fig.5.6 Maximizing time to create the plan.

5.1. Paper V

The operation of a fast craft, particularly in challenging environmental conditions has an inherent risk. As the proficiency of the high speed craft and its systems have improved, so have the physical and cognitive demands on the crew. This paper elaborates the concepts of risk, competence and training. The results brought into this thesis are the sections on general problem solving skills.

5.1.1. General problem solving skills

It is essential that the crew practice for unlikely but high-risk events to help ensure operational safety. In addition to teaching recognized competences and SOPs it is important to facilitate general problem solving skills to enhance the ability of the individuals and teams to adapt to the situation, as well as having coping strategies for unexpected developments. The teaching of more generic problem solving skills provides the ability to adapt and therefore adds resilience to the system.

5.1.2. Managing and reducing risk

The risks typically related to fast craft operations can be identified but the challenge is how to practice high-risk scenarios in a low risk training environment. Understanding risk and coping with it requires experience. An important goal is to be able to identify inherently and developing risky situations and construct mitigating strategies against the risks. There are a number of options that the trainers and instructors may draw upon and include but are not limited to:

a. Discreet tasks

Part-task training may be used to focus on specific methodologies and techniques that need to become ingrained within both the individuals and team.

b. Holistic approach

It is essential for instructors to recognize a level of risk within training exercises so that the teams gain experience from high-pressure situations. Although the level of personal and physical risk may be relatively low during controlled training, by forcing the individuals / team to make decisions whilst under pressure means that they will have an increased level of transferable skills / experience to bring to real emerging situations.

6. Discussion

6.1. High Tempo Navigation

High Speed Navigation is a term often used in this thesis and the adjoining papers. The definition of what high speed actually is hasn't been outlined so far. The definition of "High Speed" might better be coupled to the time available rather than to the physical speed of the vessel. Speed and movement is of cause intimately connected. In navigation when the speed increases the time to conduct the navigation often decreases. The term speed is more connected to physical movement rather than time to achieve something.

> "*Speed* is a *scalar quantity* that refers to - how fast an object is moving. - Speed can be thought of as the rate at which an object covers distance. A fast-moving object has a high speed and covers a relatively large distance in a short amount of time." (The Physics Classroom, 2015).

It is probably not the speed *per se* that defines whether navigation is to be considered high speed or not. It is rather the time constraint imposed by high speed that states the nature of navigation. Speed reduces the available time to conduct navigation, which has to be compensated for by changing the way the work of navigation is performed as there are fewer margins for performance variability. If there are time constraints, then navigation becomes high tempo. High speed can, and often does, induce high tempo in the navigation. On the other hand navigation can become high tempo without an increase in speed. When a merchant vessel enters a harbour approach, takes on-board the pilot and communicates with other vessels and shore authorities, lots of things are happening simultaneously. In this situation time can be scarce and the situation as a whole resembles the one in high speed when it comes to the tempo of the sense making of the situation and the navigation as a whole.

Navigation can be conducted in a vessel in very high speed, although it isn't High Tempo navigation by default. If a boat with a single operator on-board is driven at such high speed that most of the operator's attention is focused on the task of driving it is high speed manoeuvring rather than High Tempo Navigation. At least as long as successful navigation can be achieved without Joint Activity which also normally require a team. It is therefore suggested that High Tempo Navigation is used, rather than High Speed Navigation, to better represent the characteristics of the context. High speed has been used previous in this thesis but from here on High Tempo Navigation is going to be used for the purposes of this discussion for these reasons.

6.2. Complexity and Variability

A system that is complex is characterized by the inability to predict with great accuracy what output the system will generate. A system becomes complex when there are a large amount of nodes within the system that is both tightly coupled and complex in their interactions (Perrow 1984). A node is a point in a system where potential interaction can occur between other parts of the system. Complex interactions cannot be described as linear system. In a linear system things propagate in a manner that is more easily predicted, there are limited ways the system can interact within itself. Complex interactions are those that are more unpredictable and spontaneous to change. The system then has emergent properties where different phenomena can arise due to spontaneous interactions in between nodes. This isn't necessarily something bad or unwanted. An example of a system that is characterized by complex interactions is the educational system within a university; the variety of ways students may achieve and demonstrate competency of the prescribed learning objectives is wanted and not to be avoided. The system is inherently adaptive and can withstand perturbations because it can find other ways of obtaining its outcomes. In a loosely coupled system the interactivity between nodes is low. The university is also a loosely coupled system depending on its character with a low level of interactivity. Problems occur when complex interactions are paired with tightly coupling. In a loosely coupled system there are buffers that can absorb perturbations. There are also other ways that can be utilized to get to the desired end state if one interaction has become obstructed. In complex systems a perturbation can occur that potentially propagate throughout the system and can cause unwanted outcomes in a way impossible to predict (Perrow 1984).

Complexity wouldn't be an issue if stability was a system trait. As everything has some level of intrinsic variability from a simple wrist watch to a person's blood pressure, no system is truly stable. Everything has an inherent variability (Hollnagel, 2004, p 142). This variability is normal and something that should be accepted and accounted for and not necessarily dampened because variability, in the right place, is a desired attribute. The controlling function of a system must have requisite variety to keep the system performance stable under varying conditions (Ashby, 1958). The larger the variety of actions available to a control system, the larger the variety of perturbations it is able to compensate (Heylighen, 1992).

Resonance occurs when system nodes interact with each other in an unforeseen way due to the variability within the system (Hollnagel, 2004). If the system not only has complex interactions but also is tightly coupled, such resonance might propagate through the system. These new system states can lead to either successful or unwanted outcomes. Serendipity and disaster are created by the same mechanisms (Hollnagel, 2011).

In the classical interpretation of Command and Control there is logic that builds on a firm belief in cause and effect as a general model for system performance (Builder, Banks & Nordin, 1999; Van Creveld, 1985). Cause and effect is a paradigm that is mostly built on the premise of linearity. If an event should be attributed as an effect, the cause must have happened before the effect. The cause must also be related to the effect and there should be no other plausible explanation. Most of what we think of as causes are rather so called INUS conditions – *"an insufficient but non redundant part of an unnecessary but sufficient condition" (INUS-Condition)* (Shadish, Cook, & Campbell, 2002). Very few events can be attributed to pure causality but are rather INUS-conditions. The sociotechnical perspective tells us that there are many aspects on one and the same topic. Causality will often be simplifications beyond Occam's Razor Redux with low explanatory power when we are dealing with complex sociotechnical systems (Vicente, 2006). This has implications for system design. If causes can't be attributed to effects, then the occurrence of unwanted variability in the system must be handled in an adaptive manner. The so called friction, or better phrased as variability, must be handled. In all systems there is variability. To be able to control a system the regulator needs to be able to show the same (if not more) amount of variability as the part of the system to be controlled. If the regulating function cannot do this it can only to some extent effect the outcome. An over belief of causality in complex systems is a thought that invites the implementation of too simple and ineffective measures to gain and/or maintain control.

The variability within the controller of a system is a main contributor to stable system performance when dealing with complex systems. However, when the system is designed in such way that the variability of the controller also can create unwanted situations with large negative impacts this variability of the controller can be focused and guided by a set of rules or working methodology. DYNAV is an effort to create requisite variety within the controlling unit (the crew). According to Ashby's (1958) law of requisite variety only variety can absorb variety. The system variability as such can be dampened by design as a complementary action to increase the variability of the controller. By working at both ends of the problem better control can be achieved (Beer, 1974).

6.1. Planning

Within the tasks of navigation two processes of planning has been identified: one as a proactive (strategic/tactical) process and the second as a reactive (tactical/opportunistic) process. The proactive process is seen in the preplanning of routes and waypoints and in the in-situ-operational planning (*in situ* as feed forward).

In Paper IV a model of planning is proposed (Fig. 6.1). The top row in that model is coined the Phases and can be found described in all the papers I-IV. The top row is based on the model that is taught in the training of DYNAV. The second row is suggested to illustrate the idea of maximizing the buffer for planning. The plan phase, as taught, is what the navigator does *in situ* to understand how to conduct the next set of turns. What the model does not capture is the potential advantage of making a plan that is quickly communicated so that the crew, as a whole, can contribute in the reassessing of it (Fig. 6.3). By doing this, opportunity is created for iterations in the planning process and enables the crew as a whole to participate with potential higher control of the outcome of their actions. This also affects the ability for deliberate and systematic sensemaking, an important mechanism for creating safety which will be touched upon later in this chapter.

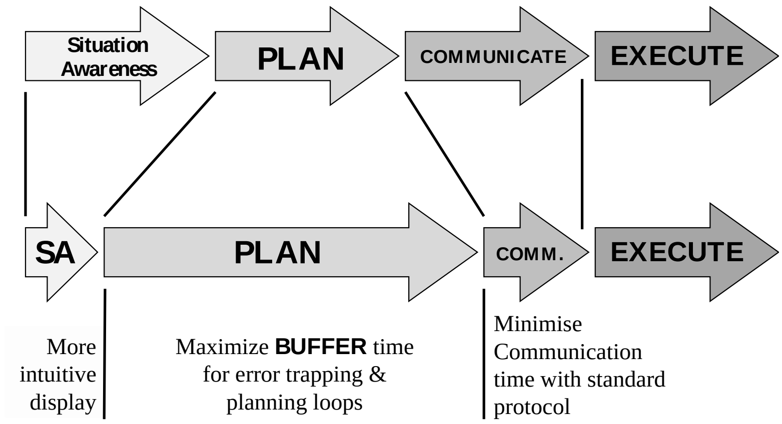


Fig. 6.1 Phases and maximization of a planning buffer.

6.1.1. Replanning due to emergence

No plan is ever flawless; there are always unanticipated events. The aim of preplanning is to make the adaption to the reality easier, to ease the workload and the burden on the crew. Some element of replanning is always needed (Klein, 2007[c]). Replanning is quite different from monitoring the execution of the plan to recover from deviations from the plan. Replanning is about adapting to an emerging, unanticipated situation.

A good plan needs, as its genesis, well-defined outcomes and goals. The goals may be ill-defined which in turn makes preplanning hard or even impossible to some level. Handling complex problems infers that emergence in a system is a property to be regarded as fact. Handling emergence can't be achieved with preplanning alone. To be able to handle the emergent properties of a system, a level of adaption is needed. Without any preplanning people are left to improvisation alone which rarely turns out to be an efficient methodology. Too strict and detailed planning with no or little room for adaptation or replanning causes constraints. To be able to handle ill-defined and emergent goals a flexible execution is needed where the broad lines and overall objectives are clear but where the details and sub goals must be derived from the situation. Plans are a weak resource for what is primarily an ad hoc activity (Suchman, 1987). Plans then become the resource for replanning (Klein 2007[c]). The concept of replanning and planning in DYNAV is going to be discussed later in this chapter but first after the introduction of the concept of Epistemic Actions.

6.1.2. Epistemic actions

Epistemic actions differ from pragmatic actions in the sense that they don't bring one closer to the goal. Instead they are actions that simplify problem solving. Epistemic actions are actions that have a primary function to reduce the:

1. memory involved in mental computation (i.e. space complexity)
2. number of steps involved in metal computation (i.e. time complexity)
3. probability of error of mental computation (i.e. unreliability)

(Kirsh & Maglio, 1994)

Movement in navigation serves probably both purposes as being both a pragmatic and epistemic action. Movement is pragmatic because it is a necessity for getting from one place to another, at the same time movement is used to better understand the situation and thus can be an epistemic action. An example of an epistemic movement/action is when the vessel is approaching a waypoint to enter a narrow channel (Fig. 6.2).

With the sight lines obscured, the crew can either rely on their instrumentation, charts and plans to get sufficient understanding of the situation, or they can replan, open up the turn by taking route *b* instead of the preplanned route *a,* thus reducing the level of abstraction (reducing space complexity, time complexity and unreliability) by being able to see in advance what the channel looks like and what constraints it might pose when meeting traffic, for example.

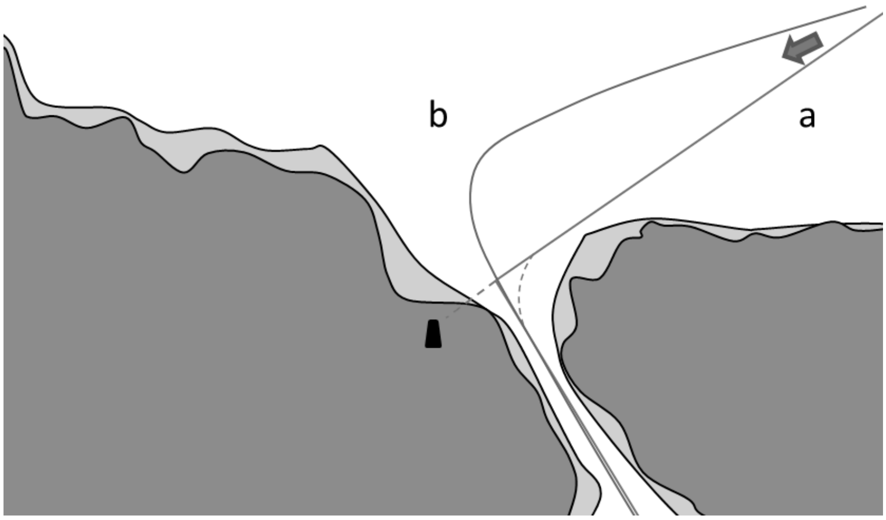


Fig. 6.2 Extraction from Defence Training Simulation Education (DSEI) conference contribution (Forsman, 2013).

Epistemic elements are intrinsic to DYNAV. When the crew replan and choose route *b* they are doing this to improve their process of understanding. However, this action increases the magnitude of translation over water and likely takes more time to arrive at the target (unless there is a concomitant increase in speed). The action of taking route *b* can be seen as epistemic. A slight modification of the previous model of planning and phases (Fig 6.3) might better represent the notion of replanning and the use of epistemic actions.

Fig. 6.3 represents the process of planning and replanning in conjunction to a waypoint. The assessment of the situation is a continuous process. Nevertheless the simplified model starts with a situation assessment process that the crew uses to form a plan to be further communicated amongst the team. The difference from the model in Fig 6.1 is that the planning and communication is done as fast as possible to allow for replanning while under way. This is illustrated by Fig. 6.3, where the crew realizes that their plan does not fulfil their need of information when their view is obscured. Replanning is conducted and route b is taken.

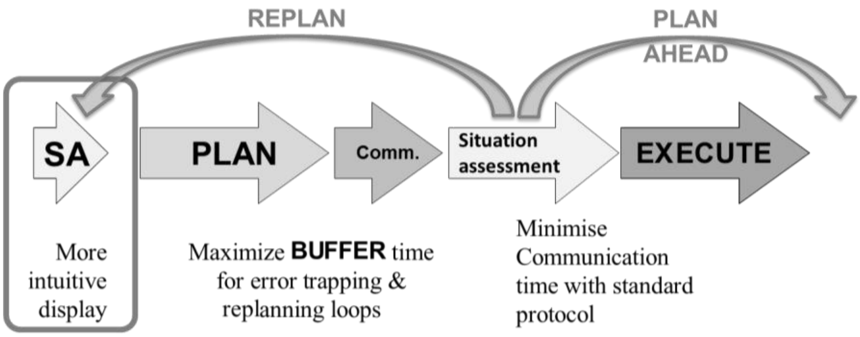


Fig. 6.3 Extraction from Defence Training Simulation Education (DSEI) conference contribution (Forsman, 2013).

Replanning is undertaken primarily for two reasons. First, and most obvious, is that things didn't turn out as expected. The second reason is to make incremental adjustments/alteration (replanning) which in the short term view could be explained with the concept of epistemic actions (i.e. to make an action that will aid the understanding of the situation). Accepting the occurrence of epistemic actions strengthens the need of building in mechanisms for replanning in the methodology of navigation.

An example of how epistemic actions, replanning and adaptation probably would have helped avoid an accident is when Combat Boat 90 ran aground at Stora Brorn (Statens haverikommision, 2003) (Fig. 6.4). The crew was coming from the north entering a channel known to them from previous training and operations. It was dark and they navigated by radar as their primary source of information supported with ECDIS and optical references. The turn they had to make was slightly more than 90 degrees heading from south east to south west. They adjusted the scale on the radar in the middle of the turn and hence they were more or less blind for a moment. As they were charging on in full speed (approximately 36-38 knots) they covered quite some distance and were late to make the turn. The crew then saw an island in the light of the port lantern and compensated with hard rudder to starboard, still full speed ahead. Now the starboard island becomes visible in the light of the lantern which they compensated for by turning to port. The vessel then crossed the channel and running hard up on the rock with such a force that the entire boat was lifted out of the water. Taking an epistemic action as in Fig. 6.2 would probably have given them better conditions to succeed. Another alternative would also have been to slow down, which in this sense reduces time complexity. A breakdown in the replanning or in the process of applying the pertinent epistemic action will potentially lead to unwanted outcomes. In this example the plan for how to make this turned failed and there were several salient warnings, still the crew did not take effective measures.

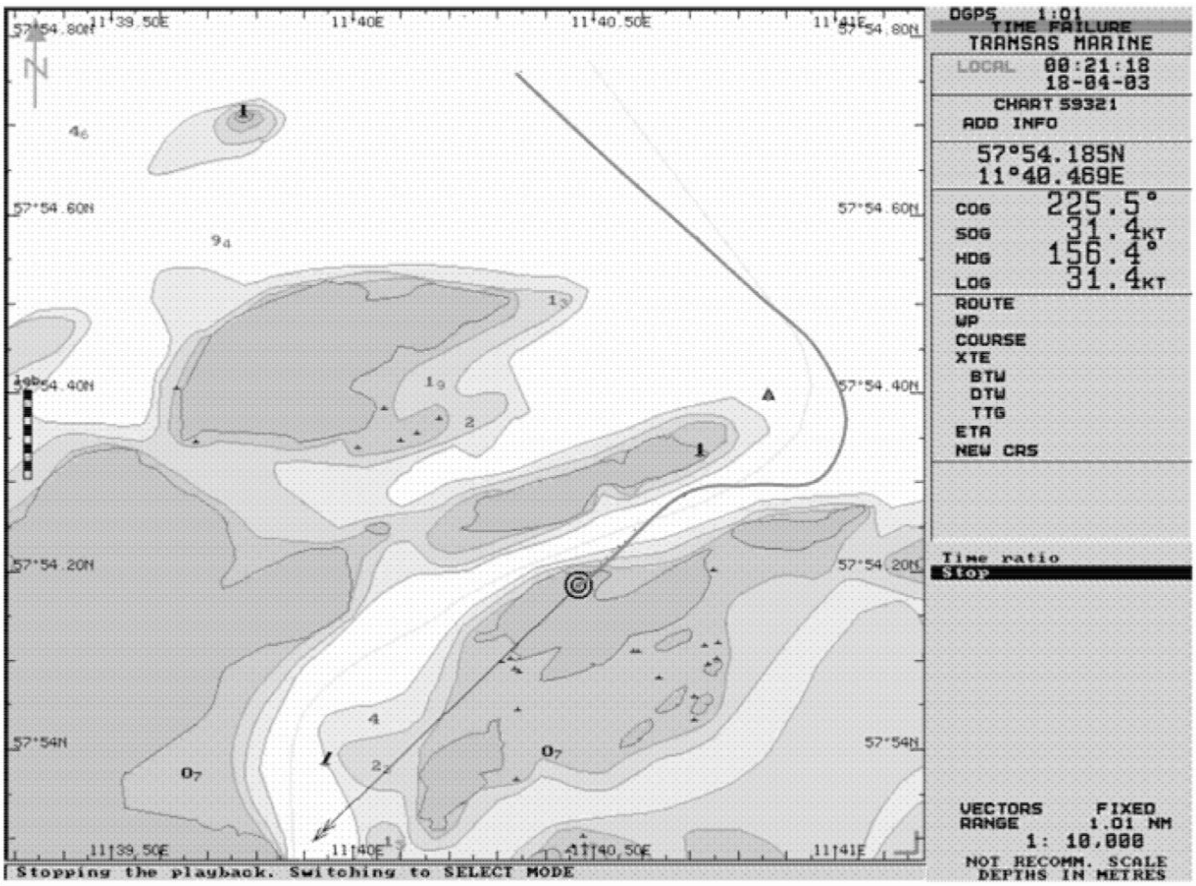


Fig. 6.4 Grounding of Combat Boat 90 H, No. 881

6.1.3. The concepts of 'knowing where you are' vs 'knowing where you're not'.

Getting lost is an agonizing and often frustrating experience. To be mildly lost is being "not exactly locked into a map, but not suffering any consequences either" (Klein, 2007). The level of being lost ought to be dependent on the perspective. I might know where I am in a village but not how to get from here to the next village. Being lost is inherently connected to the purpose of the navigation in any given moment.

To be exactly locked into a map isn't necessarily the same thing as knowing where you are. The Micronesian way of navigation doesn't even consider the use of a map (Hutchins, 1995). The Micronesian way of navigation is a totally different way of looking at the world. They are moving the world around them instead of moving in the world. Maps are not known to them and to get from one place to another is about taking actions that eventually lead to an outcome. Parallels can be made to how we live our lives. There is no map to follow. Situations emerge and have to be dealt with. Micronesian navigation has similarities to this metaphor. In essence Suchman's (1987) notion on contextual situated actions is to a great extent bringing these two concepts together when she says that planning is a contextual ad hoc activity. If they navigate without maps and are thinking in different ways does that mean that they are then lost? If so how can they succeed in navigation?

The ECDIS accurately positions a vessel on a map in real time. Thus, users are expected to be able to exactly lock their position and have an awareness of their physical position in the surrounding world and therefore should not be lost. But knowing your position on a map is not be the same as knowing where one is in the real environment.

The idea of a map is a construct; it is a representation of reality. There are many other representations available and some are even embodied. Navigation could be embodied in the sense that even if a person can't lock her position exactly on a map, they may know how to transit from the current position to the next. It is therefore proposed that navigation should not be about making and sticking to a plan but rather support the embodied perspective of the reciprocal relationship between plans and epistemic actions.

Navigating a HSC at high speeds inherently means that time is a scarce commodity. Most subject matter experts on this topic adhere to the principal of establishing a safe, operating envelope for each navigation situation. This could be inferred as knowing where I'm not rather than knowing where I am. By defining the envelope with simple rules, the precision of the navigation becomes less important. An example of this is when a course is steered towards an object; the course then mustn't exceed a specific value because there are shoals on the port side of that bearing. The crew then knows exactly where they are not. As long as the compass reads less than the stipulated course they are not in the shallow area. There is not a direct relationship between safety and how well the position can be defined. This is what DYNAV exploits in order to gain efficiency without the trade-off of lower safety. The principle of *knowing where you're not* corresponds to the notion of epistemic actions as *knowing where you're not* aims to reduce space complexity, time complexity and unreliability. In that sense DYNAV can to some extent be regarded as an epistemic methodology.

It is thus hypothesised that navigation should embrace replanning as in implementing epistemic actions as a pillar for creating safety and efficiency. Replanning should not be seen as a compensation for low quality preplanning or low quality execution of a good plan. The need of epistemic actions drives the need of replanning and thus should be taken in account for in the system design.

6.2. Sensemaking

In Paper II, error trapping by scrutinizing data is described as a technique to catch faulty understanding or distorted data (Fig 5.4). An alternative theory to describe the phenomena is "sensemaking" (Klein, Phillips, Rall & Peluso, 2007[b], p. 113-155). Sensemaking differs from SA but does have some overlap with Endlsey's (1995) definition of SA, "the perception of elements in the environment within a volume and time and space, the comprehension of their meaning, and the projection of their status in the future". In contrast sensemaking is an approach that describes the process of making a construct out of data and its reciprocal relationship to the overall understanding of the situation (the frame). SA on the other hand is more a state of knowledge although there is some overlap in projecting the future. Sensemaking is defined as the deliberate effort to understand events (Klein et al., 2007[b], p. 114).

6.2.1. The Data Frame Theory of Sensemaking

The understanding of a situation is based on a pre-understanding, a story, a representation or maybe some sort of map which is called the frame. This frame for how the world is understood is created out of data. The data used to build the sensemaking on is guided by the subject's attention. This in turn is guided by the story, or the pre-understanding of the situation (the frame). The frame also excludes data that doesn't fit with the frame and that data is explained away as distorted, false or noise. There is a reciprocal relationship between the data and the frame as the frame is made out of the data at the same time it guide what data to include and discard (Klein et al., 2007[b]). The frame is contingent on a few key anchors. Anchors are pieces of information regarded to be key or highly salient data elements. Only a few pieces of information are able to be used, and no more than four, as anchors in the sensemaking process (Klein et al., 2007[b]).

6.2.2. Deliberate sensemaking as methodology of work in navigation

One purpose of the DYNAV methodology is to make sense of the navigational context to be able to act appropriately. It is suggested that DYNAV can be viewed as an applied and deliberate method to achieve effective sensemaking. DYNAV, as a sensemaking methodology, is not triggered by an *a priori* surprise but is an on-going process based on the expectation of being surprised if no methodology is applied due to the shortage of time, ambiguity and the lack of clarity of the situation.

Sensemaking anchors are probably used in DYNAV. The concept anchors is, to our understanding, manifested as positioning techniques used in the basic information protocol and as planning tools. Example of anchors as positioning techniques are the course to steer, distances measured with the radar to object ahead, odometer set for a specific distance, expectations of what to see next based on information in the paper chart and ECDIS. The anchors are crucial for building the frame and how data can be explained, discarded or used to reframe, preserve or modify the frame itself. The use of basic positioning techniques in High Tempo Navigation can be seen as representing this functionality in DYNAV.

The navigation loop (Minister of Defence, 2010) (Fig. 6.5) and Circle of Methodology (Försvarsmakten, 2009) (Fig. 6.6) and the model for error trapping by scrutinizing data described in Paper II (Fig. 6.7), are efforts to illustrate steps in the process of sensemaking. The idea is to work according to this principal through the four phases of navigation, not only the phase of verification. By comparing data from different sources in a structured way, discrepancies between expectations and confirming data or in between data can be captured. When this happens the discrepancy can be addressed in different ways. Navigational safety is strongly dependent on the crew’s ability to constantly question their framing in order not to be surprised by the propagation of corrupted data into their sensemaking or being surprised by a frame that no longer fits the situation. The consequences of a collapse in the sensemaking process are potentially life threatening in high tempo navigation.

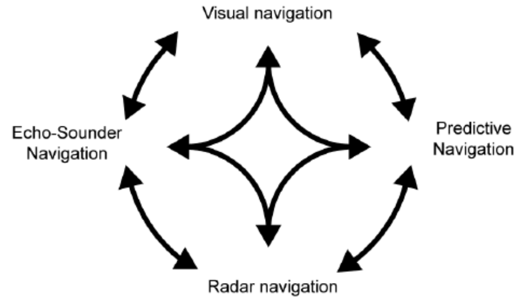


Fig. 6.5 The navigation loop

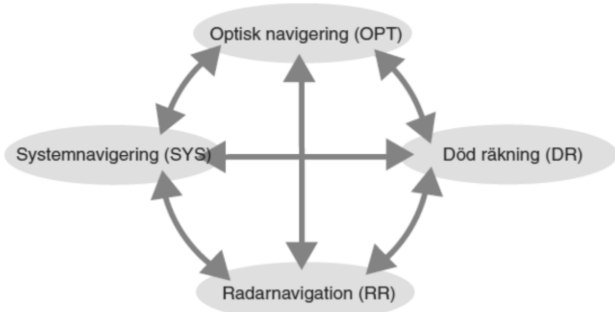


Fig. 6.6 Circle of methodology

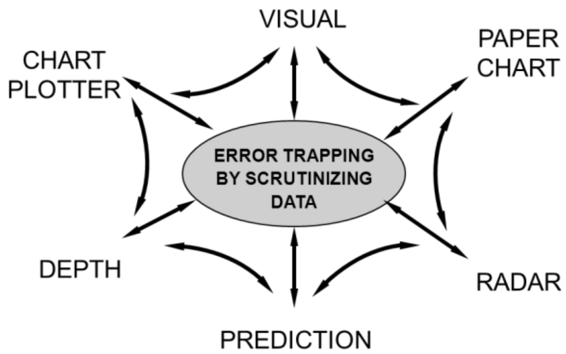


Fig. 6.7 Error trapping by scrutinizing data

The term used in Paper II, “error trapping by scrutinizing data” infers that there are errors that can be identified and avoided. The notion of error is of interest. An error is the antipode of correct. The term error is also vitiated with the notion of an anomaly and something unwanted. The previous model of *error trapping by scrutinizing data* is seeking to eliminate unwanted anomalies – errors. Unwanted outcomes, as for example, different understanding of an event by crewmembers, isn’t necessary an error. It is expected that in complex situations understanding differs (to some extent it always does) and thus shouldn’t be seen as an error *per se*. This might cause problems though when the outcome of the event is depending of a common understanding of the event. The expectation is to create an appropriate level of common understanding, or dampening the variability between crew members. We need proactive methodologies to create this critical level of common understanding rather than reactive approaches to catch errors.

An alternative model to “error trapping by scrutinizing data” proposes a process of “deliberate sensemaking by questioning data and frame” (Fig. 6.9) The model is, at first glance, very similar to the previous one, but taken the forgoing argument in account they differ significantly and is loaded with an inherently different meaning.

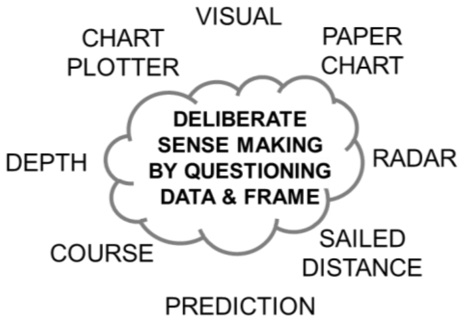


Fig. 6.8 Deliberate sensemaking by questioning data and frame

In the High Tempo navigation situation there is an abundance of data. There are data that are accurate and important and there are data that are false, unimportant, or distorted. This creates a situation that is hard to make sense of. Therefore the crew need skills to sort out the data that are important to the task, discharge the false data and neglect the unimportant.

There is a risk with dismissing data as false or irrelevant and maybe an even greater risk in explaining away data. Data will be contradictory and there is a need to adjust or reframe. The navigation methodology proposed will serve as a support for sensemaking so that reframing can be done very early in the process so that the crew will detect contradictions and discrepancies (unwanted variability) at an early stage so they don't get lost and therefore don't need to find themselves again.

Fig. 6.9 is taken by the author during a navigation exercise in Lake Vättern in Sweden where the GPS position and the alignment of the map in the Electronic Chart Display did not match up properly.

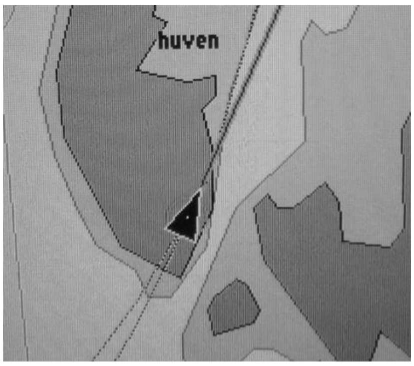


Fig. 6.9 Position of the vessel presented wrong in the chart plotter.

In this particular case the vessel was charging on in high speed in the middle of the sound but the position was presented as being on land. This exemplifies the need of a methodology that aids sensemaking from several information sources to be able to catch distorted data before it compromises the sensemaking as a whole. If the sensemaking is built on a single anchor that isn't deliberately questioned and balanced for consistency against other anchors, sensemaking is very likely to break down. In this situation the consequence could result in the vessel running aground.

The process of deliberate sensemaking by comparing data and frame requires that data are gathered. This is seen in the navigation of CB90 (Fig. 6.10) where they methodically pay attention to multiple data sources and actually compare them (Fredriksson, 2013).

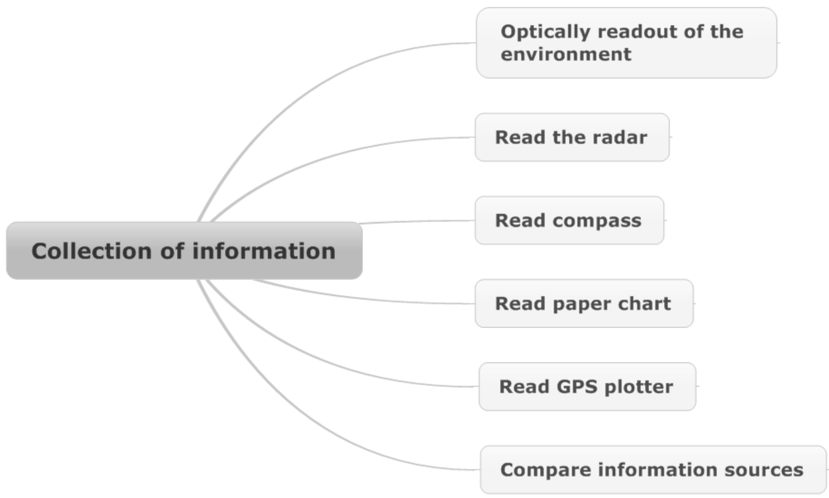


Fig. 6.10 Part of Hierarchical task analysis of navigation on CB 90. Adopted from Fredriksson, 2013.

6.2.3. Sensemaking as epistemic actions

So far epistemic actions have been discussed in terms as an *ad hoc* activity to aid understanding. The arguments provided in this discussion have focused on the need of a flexible execution in order to allow for replanning which both can be pragmatic and epistemic. However epistemic actions aren't only *ad hoc* activities. It should probably be possible to view many of the navigation techniques (basic positioning techniques) as epistemic in purpose (i.e. they are actions taken to reduce space/time-complexity and unreliability) (Kirsh & Maglio, 1994).

If the basic positioning techniques are interpreted as anchors in sensemaking, they also might be interpreted as an embodiment of cognition as in being structured tools for epistemic activity. Thus DYNAV as a methodology has inherently epistemic elements. Epistemic actions might then not only be an *ad hoc* activity but also a feature of the design of work within a system.

6.3. Control or "Command and Control"

In the military literature, C2 is described in hierarchical and linear terms (Builder et al., 1999; Van Creveld, 1985). The focus is on the commander's intentions and feedback from the battlefield and is based on a linear hierarchical structure with centralized leadership and command.

In a hierarchical organisation, and especially in the military, a single individual always has the responsible for making decisions (Snook, 2000; Granström, 2006). At any specific level in the hierarchical system the commander at that level is fully responsible for the subordinates' accomplishments and failures (Snook, 2000, p. 33). To be true to the hierarchical system, following conditions have to be met:

- Vertical chain of command
- Blind obedience
- Uniformly behaviour on lower levels to assist predictability.
- Knowing ones specific role and task.

Orders are given from above and are expected to be carried out by the level below the decision maker. Any personal initiatives on lower levels are regarded as disobedience (Granström, 2006). The organisation of work according to hierarchical principles means that the commander's task is to make decisions. A fundamental premise of the hierarchical system is that every individual in the organisation must have a clearly defined role and task to fulfil. This linear, hierarchical way of organizing work builds on the principle mechanisms and processes alike those of cogs in clockwork (i.e. causality). The purpose of the C2 system is to support the commander with adequate information to make decisions rather than aid decision making on a local level and improvisation in chaotic situations (Ljungberg, 2000).

Information is the key to be able to monitor the progress and to be able to react (Builder et al., 1999). The concept of C2 is an internal mental process in the mind of the commander. Command is the expression of the commander's will or orders. The control is facilitated through feedback from the battlefield/operations. In other words it is a reactive rather than proactive way of control. These feedback loops are susceptible to resistance and lag which could affect the system performance negatively.

In a classical C2 model, subordinates should be given all the information they need but not all of the information within the system (Van Creveld, 1985). The flow of information is crucial in C2 concept. To give subordinates all the information that is needed but not more implies that the information provider must know the quality of the information and anticipate how the battle or operation will develop. This means that there mustn't be any unthought-of events – which is highly unlikely (Hollnagel, 2004). How can one know what is enough information in relation to the unknown or unexpected? A kind interpretation of the claim is that it is wise not to bury the subordinate staff in irrelevant information that will potentially lead to confusion, noise and problems. However as the text is written it communicates a bureaucratic hierarchic perspective where the commander, at a supervisory level, will be the best one to make the decisions (Van Creveld, 1985). This is a classical organizational approach that many public agencies are constructed around (Walker, Stanton, Salmon and Jenkins, 2009).

Classical C2, despite its ambition to be a means to effectively handle emerging situations as conflicts or crisis, is ironically resulting in a different outcome (Walker et al., 2009). By centralizing the control, a machinery of information flow is essential. By channelling and centralizing decision making, the focus on the commander and his/her understanding of the situational risk, impedes the system's ability to respond adequately to a perturbation because of the lag and the friction in the flow of information.

When time is of crucial importance and the situation is characterized by complexity (Perrow, 1984), the linear nature of C2 organisation creates its own bottleneck– information will not flow as intended due to friction and there will always be unthought-of situations that the linear and hierarchical system wasn't designed to cope with (Walker et al., 2009, p 11). Looking at this from an organisational point of view, hierarchy provides transparency but many times at the cost of bureaucracy inhibitors (Granström, 2006).

In the hierarchical C2 organisation decisions are often made at a level apart from the end user. This is because the end users are not, or not thought to be, skilled to make the decisions themselves or there is a need of system coordination. Skill is something that can be developed. Skill and competence are also a prerequisite to be able to handle complexity. The more skilled and competent the end user the better complex conditions can be handled. To develop skill and competence is expensive. Some things can't be created withing a loosely coupled linear system and the only way to achieve efficiency, or the stipulated goals, is by working within a complex system. Coordination on the other hand is essential in all systems. Depending on the art of coordination needs coordination can be achieved in different ways. The C2 notion on coordination is centralizing the governing mechanisms. An alternative is to use local coordination or self-coordination, which might have benefits of increased resilience or robustness.

Where then should the skill of decision-making be allocated? In the classical C2 paradigms found in many military organisations and public authorities the idea is that these competencies and abilities should be centralized - highly efficient for linear problems but not as much when to handle complexity. Could the decisions be made on a lower level with less communication within the different nodes in the organisation, can goals and priorities be that clear that the subgroup of the organisation know how to handle upcoming events to reach goals and how to replan for unexpected perturbations in the preplan? Some level of self-organisation is of crucial importance in the sense that the description of the goals comes before the plan. Coordination between units can mean the difference between life and death in SAR as well as in military operations. However, this cannot be an argument for units to execute an operation as close to the plan as possible. DYNAV is facilitating control where command is relaxed. DYNAV builds on the principals of sharing the responsibility jointly and work interdependent.

6.4. Joint activity

A joint activity is an extended set of behaviours that are carried out by an ensemble of people who are coordinating with each other (Clark, 1996 p. 3). In order for activity to be regarded as "joint" the parties have to *intend* to work together and their work has to be *interdependent* (Klein, Feltowich & Woods, 2004). A joint activity is not a question of either I do it or you do it. Joint activity is when something genuine is created together that can't be replicated by any singular stakeholder.

People engage in joint activity for many reasons. The most salient is the need of accomplishing something that is difficult or impossible to do by any single person. It can be that multiple competencies and skills are necessary for the achievement. It can also be that the demands and constraints are that tough that the task can't be solved without joint activity. Tasks with high constraints are often solved by teams who are working jointly. The advantage of joint activity is that it enables an ensemble to work coordinated and interdependent.

6.4.1. Interdependence

In a joint activity what party "A" does must depend in some significant way on what party "B" does and vice versa (Clark, 1996, p. 18). The efforts in joint activity must have mutual influence. If the activities are sequential then it is not likely a joint activity. When work is done interdependent any friction within one part of the system will propagate throughout. At a first glance this can be seen as something negative but actually it is not. People working in concert with technology are depending on each other for the completion of the task. People are simultaneously creating the conditions for the next step in the work process. Any frictions and problems in the teamwork will be noticed in an early stage within the joint system and thus can be managed before they create negative consequences.

Joint activity is described from three different aspects: requirements, choreography and criteria for joint activity (Fig. 6.12).

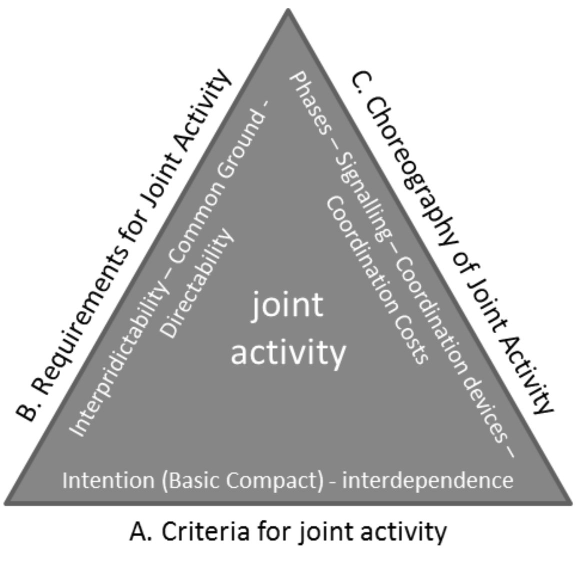


Fig. 6.12 Joint activity. Adopted from Klein et al. (2004)

6.4.2. Intention/Basic Compact

Joint activity requires a "basic compact". The basic compact is an agreement between the parties in the joint activity to participate and to carry out the required coordinated responsibilities. An aspect of basic compact is that it often means that the participants in the joint activity have to relax their personal goals and prioritize the global and long-term goals of the system. This implies that the shared goal(s) must be of enough importance for the participants to do this. The basic compact also is a commitment to try to detect and correct any loss of common ground that might disrupt the joint activity (Klein et al., 2004). The locus of responsibility in the basic compact is distributed among the members. This is an essential part in any organisation that aims for safety (Rochlin, 1999). The basic compact is not a definite; it is not agreed upon and then exists. It needs to continually be reinforced and confirmed and communication is an essential part in this process.

6.4.3. Common Ground

Perhaps the most important basis for interpredictability is common ground (Clark & Brennan, 1991). Common ground is the pertinent knowledge, mutual beliefs and mutual assumptions that support interdependent actions in a joint activity. When people have common ground an abbreviated language can be used that in context carries lot of information that any outside observer would not understand. This is a huge gain when signals and language can be loaded with meaning. With a low level of common ground the communication must be very specific and comprehensive and that comes with great operational and efficiency costs.

The basic compact also includes the expectation that the parties will repair faulty knowledge, beliefs and assumptions when detected. Common ground is what makes joint activity and coordination work. In turn, every action taken will change common ground. Common ground can be characterized in terms of three basic categories (Clark, 1996):

- initial common ground
- public events so far
- the current state of the activity

Initial Common ground is the pertinent knowledge and the prior knowledge brought to the system. It is not only about their knowledge of the world but also conventions and norms.

Public event so far is the understanding of the events, actions and happenings up to present time. Some of these action have had influences on future possibilities and an action previous taken has generated a new option or closed a previous.

The current state of the activity provides cues that aid in predicting subsequent actions and appropriate forms of coordination. In many cases the physical scene is providing strong cues so that there is no ambiguity in understanding the next action. The situation is salient. There is a problem in this situation when an apparently salient situation can fool the participants to frame the situation falsely by looking at the same thing and interpreting it the same way when it still is something differently. It is therefore important to systematically question the understanding/framing of the situation according to the principals suggested in deliberate sensemaking by questioning data and frame (Fig. 6.8).

To maintain or repair common ground in DYNAV the participants have to act upon suspicion of threats. The uncertainty itself is a threat on a meta-level. The uncertainty is the cue to act upon in order to be able to repair the common ground. The loss of common ground is the actual thing to avoid and secondly the consequences of it being lost. The loss of Common Ground is a breakdown in safety and not the consequence itself. Loss of common ground can have negative outcomes such as collisions or groundings but they can be seen as symptom rather than the threat.

Creating and maintaining Common Ground requires a way of assessing the information. The theory of Sensemaking and epistemic actions offers tools on how Common Ground is created, maintained and lost *in situ*. It is hypothesized that the loss of common ground also can be described as a breakdown in the process of Sensemaking.

6.4.4. Interpredictability

To be able to work jointly there must be a level of interpredictability among participants. The participants need to be able to predict and expect how the other participants will behave and react under certain circumstances in order to adapt or to give directions. This is also important for the maintaining of the common ground, to be able to predict when there is a risk that common ground is about to be corrupted. Shared scripts are of assistance in interpredictability because it helps participants to expect how the other participants will behave (Klein et al., 2004).

6.4.1. Directability

Directability is an important aspect of coordination that builds the team's resilience (Christoffersen and Woods, 2002). In joint action interdependence is essential. This interdependence also means that participants must be able to adapt to changing situations both when there is internal changes as well as external. Within the team, one participant's behaviour might signal that the work needs to be directed or that a participant needs direction or must direct (adapt) his work and not only try to give directions to others. This is a fundamental function in adaptability that is a keystone in resilience.

6.4.2. Choreography of joint activity

The basic navigation information presented in Paper II can be viewed as a set of coordination devices that builds on a pre-understanding that aims to reduce the coordination costs in situ, although there are extensive costs in creating the common ground (pertinent knowledge, beliefs and assumptions that are shared among the involved parties) by the preceding training. By introducing a communication scheme that has a preformatted shape the team knows what to expect and will identify when the communication is deviating from the norm which is a signal that the common ground is intact. The abbreviated communication reduces the costs of coordination in the execution but does require that this knowledge has been gained in advance and increases the need for training. The cost of coordination is moved from the execution to the preparations and training instead.

6.4.3. Signalling

How work is conducted is in itself telling. It is closely linked to predictability. When work is coordinated and performed in concert the participants are given the opportunity to respond to variations in the patterns of work. In the navigator-driver duo it is seen when the navigator's communication pattern is changing to contain less information, or even become silent. It is often a strong key for the driver to act upon. Not all coordination is driven by orders and command. In this case, the navigator is giving directions to the driver without being aware of it. The driver, as a result of training and experience, recognizes the communication pattern as a signal of threatened common ground. An appropriate response to that kind of situation can be to slow down the speed and thus create more time for the crew to assess the situation and repair common ground.

6.4.4. Coordination

Every effort to coordinate is Joint Activity and the composite of those is the Joint Activity (Clark, 1996, p. 3, 30-35, 125).

> *"The choreography of a joint activity centers on the phases of the activity. The choreography is also influenced by the opportunities the parties have to signal to each other and to use* ***coordination devices. Coordination costs*** *refer to the burden on joint action participants that is due to choreographing their efforts."* (Klein et al., 2004. p. 11).

The phases in DYNAV present in paper I-V are suggested to be phases in Joint activity. They serve to structure the work in an orderly manner. The basic navigation techniques are suggested to represent a set of coordination devices.

6.4.5. Coordination Costs

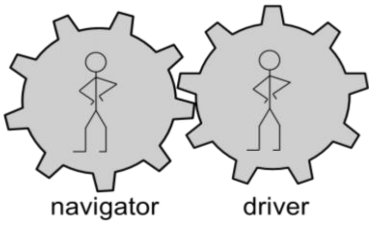
For a system to fulfil all the preconditions and requirements for being able to engage in joint activity is costly. It is costly to create the prerequisites for joint activity and it is costly to engage in joint activity. Work that is not interdependent is easier to conduct with higher efficiency albeit with a trade off when it comes to the ability to handle complex situations.

Is the coordination costs justifiable to engage in Joint Activity? It depends on the context and purpose of the task at hand. The distinction that has to be made is whether the task can be accomplished with lesser risk without working jointly. Can the risk be reduced? In the case of DYNAV – can the goal be accomplished with lesser speed or tempo? If it can, it is not obvious that it is worth to take the costs of coordination in Joint Activity to achieve the goal. As long as there is a need of navigation within high tempo operations, time will be a critical asset and both safety and efficiency are dependent on the ability to engage in Joint Activity and thus, the coordination costs probably worthwhile. High performance tasks as High Tempo Navigation requires Joint Activity. If it does not, it isn't High Tempo Navigation.

It is hypothesized that Dynamic Navigation is Joint Activity, the multi-agency concept of utilizing the available crew in an adaptive manner with the purpose to optimize efficiency but without sacrificing thoroughness.

6.4.6. Adaptability in DYNAV

The roles of the driver and navigator in DYNAV and the distribution of the tasks of navigation create an interdependent crew. In Fig. 6.13 the two cogs representing the driver and navigator must rotate synchronized in the same pace. The navigator has to do his part of the work in order for the driver to do his and vice versa. Disruptions in one end of this system will propagate into the other. This is not a bad thing because any small disruptions will possibly be caught before they have any serious implication on safety thanks to the interdependent model of organizing work. The propagation is signalling which in turn has relevance to interpredictability and directability.



6.13 Interdependent work

An example of this interdependence and propagation in the system is when the navigator is going silent in a situation where that's not to expect. The driver is predicting an action from the navigator that does not occur. This is a signal to the driver that the navigator isn't in phase with the procedure of navigation and thus the driver can slow down to create time to repair the potentially corrupted/degraded common ground. By working interdependent the driver can't do his job without the navigator doing his and thus there is a need for a function to catch corrupted common ground. This also illustrates directability and the function of responding to other crewmembers' behaviours.

6.4.1. Intrinsic Control in DYNAV

By working interdependently, the mechanism for deliberate sensemaking has partially been enabled. The reciprocal relationship between the driver and the navigator is in itself a function that helps to catch loss of common ground. There are many examples of bridge team organisations that don't support joint activity. The classical supervisor-operator or hierarchical relationship is an example where the joint activity is of less emphasis.

In hierarchical C2 the supervisor or the commander monitors the operator or troops and their work. It is well known that humans in general perform poorly in monitoring. People get bored and lose their focus (Bainbridge, 1983). Another problem with supervisory control is that it often is a situation that creates bottlenecking. It takes two persons to do a one man job. One who is actually doing the job and one that is monitoring and supervising. Adding more people might not be the solution to the bottleneck problem but instead introduces more complexity. Realistically, the operator is the only one directly working on completing the task at hand. When the situation starts to get too demanding for one person, the supervisor can step in and assist. This is a good thing but not without problems. To be able to change the way the task is being conducted under stress is not trivial. When the crew is becoming stressed the ability to solve new problems decreases drastically (Osvalder & Ulfengren, 2009). In extreme situations only well trained patterns will work. Another problem that arises is the skill fade the supervisor suffers. Often the supervisor is the senior of the two and as soon as the supervisor is assigned to the supervising role he starts to lose his vocational skills (Bainbridge, 1983). The irony here is that the senior team member might have the least current skill sets to manage the problem, but because of the hierarchical structure, the organisation of work does not compensate for that.

The act of balance is to have a modicum number of people in the organisation unit to be able to share the workload but not more than necessary to counter complexity. Joint Activity in this interpretation is an alternative to classical hierarchical C2 ways of organizing work to be able to achieve this.

The idea of organising work to achieve intrinsic control by Joint Activity also says something about the locus of responsibility. In a hierarchical organisation in its purest form any own initiatives are looked upon as disobedience (Granström, 2006). In the example above it is the own initiative that enables reparation of common ground. The distributed locus of responsibility in the team is a key factor for safety (Rochlin, 1999) by maintaining common ground (Klein et al., 2004).

To certain extent heterogeneity is an asset in a team to be able to see things from different perspectives and can act as a barrier to counter crew member bias or false beliefs. On the other hand, when advanced coordination is needed the participants mustn't be too heterogeneous in their experience and competence in order to be able to interpret the situation in a similar way, being detectable, and predictable. The Swedish Navy extends this position and claims that the driver and navigator must have the same High Speed Navigation training and competences (Försvarsmakten, 2003). It has implications on the roles and what possibilities the crew have to share work between themselves. In the DYNAV methodology the main responsibility is shifting between roles depends on context and situation. The person with the best possibilities to assess the situation has the responsibility. In a mooring process it is the driver who has the responsibility, in navigation it is the navigator. The individual that has been assigned as the commander can in any given situation choose what task to fulfil but he can't take the responsibility for the actual navigation from the helmsmen.

It is hypothesized that by organising work to be conducted jointly, the safety assessment idea that the supervisor represents is built into the system with higher efficiency in both output and safety.

6.4.2. Shifts in the characteristics of joint activity depending on context

During a mission the crew or the bridge team will act differently depending on where they are in the process of navigation. For example, in a SAR mission it is likely that a small rescue vessel manned with a crew of three to four only one person will be left in the wheelhouse when the actual rescue or boarding activity occurs. The rest of the crew might be needed on deck. This alters the circumstances and the crew need to be able to handle this change of roles and adapt to the constraints. Effectively this can mean that the bridge as a system goes from working jointly to not working jointly. It is therefore necessary for all parties to understand that the cognitive capabilities of the vessel as a system has been seriously impeded when it comes to bridge team related issues. From a bridge team or a navigating perspective it is true. At the same time one can argue that by having crew on deck working jointly in concert to address a situation the cognitive capabilities of the vessel as a system have changed and more effort and capability is directed towards new operational demands.

Realistic expectations must be put on the vessel not to cause overload and breakdown of common ground. An example of such behaviour is when the shore management wants updates and information from the rescue mission when they are in the middle of critical activities. The bridge is now down-manned and has less capacity to undertake reporting functions. At this time the bridge crew are more prone to failures.

6.4.1. Joint activity and resilience

There are more reasons to engage in Joint Activity than to obtain efficiency. One reason is that Joint Activity is the foundation of "resilience" (Klein et al., 2004). In this case it is interpreted as in recovering from an unwanted situation, or to anticipate it so it can be avoided. Working interdependent is in itself a function to catch degraded Common Ground, which too is an unwanted situation.

6.4.2. Navigation becomes High Tempo when Joint Activity is required

The speed of the vessel is subordinated the time constraints of the work of navigation as discussed in paragraph 6.1. Navigation becomes High Tempo when Joint Activity is required to solve the task of navigation. It is thus suggested that DYNAV is a methodology aimed to facilitate and aid Joint Activity in a navigation team in high tempo navigation.

6.5. Control

To maintain control during varying conditions and counter the effects of disturbances are typical traits of Joint Cognitive Systems (Hollnagel, 2002). Control in joint cognitive systems is evaluated by the outcome of the system, its behaviour as a whole.

The Contextual Control Model provides us with four levels of control (Hollnagel & Woods, 2005): scrambled, opportunistic, tactical and strategic. The four levels are defined by four characteristics: number of goals, subjectively available time, evaluation of outcome and selection of action.

The notion of Deliberate Sensemaking by questioning data and frame is by its use of sensemaking anchors providing the crew with multiple goals. The evaluation of the outcome of the activity is manifested in the phases and especially in the phase of verification. The sensemaking anchors are not only providing goals but are also key for evaluation of outcome. Replanning is both a reactive and proactive measure i.e. feedback and feed forward. DYNAV is also designed to create structure in a context that often can be subjectively perceived as having lack of time. Thus it is suggested that DYNAV also can be defined as a methodology that drives the system to operate at a level of tactical or strategic control in order to maintain safe and stable performance

7. Validity

As I pursue this research, coming from a background of being a practitioner and expert user of the same system can be considered both an asset and a problem. It both clouds the perspectives and at the same time aids with the discourse of this thesis and how I want to investigate the problem further. What are real data and what are my experiences? *Tabula rasa* can never be achieved!

By using mostly peer-reviewed references and being meticulous about not introducing insufficient underpinning concepts, measures have been taken to keep the validity as intact as possible given the design of the papers and the thesis.

8. Conclusions

The problem of High Tempo Navigation can be looked upon from different perspectives. In this thesis a sociotechnical perspective is chosen as a framework of research. Still it is not possible to cover that perspective fully. In fact that is an impossible task. Holistic views need delimitations in order not to be infinite. The scope is sociotechnical but not truly holistic. There are a couple of theories chosen and the purpose of those is to present a model of the constituents of effective teamwork in high tempo navigation/DYNAV.

The high tempo navigation domain is complex in its nature and thus it is hard to foresee in detail how events will unfold. Complexity then infers that the system must be able to adapt to changing circumstances. Things never go exactly as anticipated. To be able to maintain stable performance under varying conditions the system has to adapt. The controlling part of the system needs to have requisite variability in order to be able to achieve stable performance under varying conditions. This is not achieved by constraining and striving for stability alone. There must be a balance between attenuating and amplifying variability in different parts of the system. For a HSC to adapt to emergent situations the requisite variability needs to be built in the methodology of work, in this case navigation. The concept of replanning is an example on how variability is amplified in the controlling part of the system used to mitigate effects of variability in other places of the system.

DYNAV as a navigation methodology aims at making the situation more understandable and easier to handle. It reduces space and time complexity and unreliability and thus can be seen as a methodology supporting epistemic actions; actions taken to better understand the situation rather than action taken to get closer to the objective or goal. Replanning is driven both from the need of adaption to a situation that didn’t play out as expected (or from a bad plan/assumption to start with) but also from the need of epistemic actions that eases the process of sensemaking. Another angle on epistemic actions is seen in the way DYNAV as a positioning technique is conducted. Instead of focusing on what the actual position is, the aim is to know whether the vessel is safe or not. This means that as long as certain criteria are fulfilled there is no need of knowing the exact position of the vessel which eases mental computation and minimizes the risk of cognitive overload.

Sensemaking is the deliberate effort to understand events. DYNAV facilitates the sensemaking process by introducing techniques to both sample pertinent data and questioning their accuracy and the interpretation of them in the context (frame).

Organizing work according to the principals of joint activity is a way of achieving intrinsic control as a contrast to supervisory control. Joint activity is a prerequisite for effective sensemaking and a foundation for how DYNAV is constructed.

9. Future research

9.1. Quick decisions as epistemic actions and foundation for replanning.

Cognition as a system ability might be possible to monitor and observe in contrast to the classical interpretation as cognition of the mind which can be hard to measure. The arguments made in this discussion on complexity, variability and epistemic actions all underpin the importance of replanning as a key ability. If replanning is enabled within the navigation then the need for high quality decisions might be more relaxed. Preliminary decisions can be made that act as a frame. By making decisions a frame to relate to other activities are provided and thus making a decision quick might be an epistemic action as it reduces time complexity. Crews on the Combat boat 90 have shown to be twice as fast in coming to a decision then fourth year master mariners students (Eliasson & Gustafsson, 2012). Although this study had a very small sample it indicates that this might be a factor of success that is worth further investigation. Coming to a decision quickly might be a technique that underpins the notion of replanning, foresight and thus higher levels of control.

It is therefore suggested to study navigators' decision making strategies and couple that to factors of success in navigation. Can any specific decision making tactic be attributed to more success than any others?

9.2. Performance in terms of control in a naturalistic experiment in a SAR context.

By using control as a construct for system cognition, avenues for studying and measuring cognition becomes more apparent. Team performance might be assessed in terms of control (Palmqvist, Bergström & Henriqson, 2012), this is underpinned by Stanton, Ashleigh, Anthony and Roberts (2001). Palmqvist et al. (2012) demonstrate that team performance can be measured in terms of control although the link to the outcome of the team's effort might be criticized to be weak as it only relies on instructor judgement.

> *"A question that needs to be raised in future studies is whether control as measure of team performance actually can be coupled to outcome measures (e.g. mission success, task completion speed and goal fulfilment). Such an analysis has not been included in the aim of the present study but is of great importance for the argument of future use of control measures rather than traditional behaviour assessments."* (Palmqvist et al., 2012)

It is thus suggested to design and conduct a study of HSC navigation in challenging conditions based on Palmists control protocol (Palmqvist et al., 2012) that is correlated to the outcome of the activity. By doing so it might be possible to verify the protocol against performance and if so to see if any level of control is more beneficial for the outcome of high tempo navigation than any other.

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11. References

Ashby W.R. (1958): “Requisite Variety and Implications for Control of Complex Systems”, Cybernetica 1, p. 83-99.

Bainbridge, L. (1983). Ironies of automation. *Automatica*, *19*(6), 775-779.

Beer, S. (1974). Designing Freedom. Chichester: John Wiley & Sons

Bowditch, N. (2011) The American Practical Navigator Handbook.

Builder, C. H. Banks, S. C. Nordin, R. (1999) Command concepts – a theory derived from the practice of command and Control. Santa Monica: National Defence Research institute

Christoffersen, K., and Woods, D. D. (2002). How to make automated systems team players. *Advances in Human Performance and Cognitive Engineering Research, 2*, 1-12.

Clark, H. H., & Brennan, S. E. (1991). Grounding in communication.*Perspectives on socially shared cognition*, *13*(1991), 127-149.

Clark, H. (1996). *Using language*. Cambridge: Cambridge University Press.

Dahlman, J., Forsman, F., Sjörs, A., Lützhöft, M., & Falkmer, T. (2008). Eye tracking during high speed navigation at sea: Field trial in search of navigational gaze behaviour. In *6th annual meeting of the Society for Human Performance in Extreme Environments, September 21-22, 2008, New York*.

Dahlman, J., Forsman, F., Sjörs, A., Lützhöft, M., & Falkmer, T. (2008). Eye tracking during high speed navigation at sea: Field trial in search of navigational gaze behaviour. In *6th annual meeting of the Society for Human Performance in Extreme Environments, September 21-22, 2008, New York*.

Darken, R. P., & Peterson, B. (2002). Spatial orientation, wayfinding, and representation. *Handbook of virtual environments*, 493-518.

Dobbins T., Dahlman J., Stark J. (2009) High Speed Craft Command & Control - A Preliminary Model. *Conference Proceedings, European Human Factors & Ergonomics conference*. Linkoping, Sweden.

Dobbins, T., Stark, J., Myers, S., & Mantzouris, G. (2010). *Modelling human performance in maritime interdiction operations*. stresearch ltd chichester (united kingdom).

Dobbins, T., Harris, D., Smoker, A., Hill, J., Dahlman, J., Forsman, F., Brand, T., Dahlman, J., and Stark, J. (2010, November). High speed craft command & control: a model of navigation and crew interaction to enhance performance and safety in the harsh shock and vibration maritime environment. In *Conference Proceedings*.

Dreyfus, S. E., & Dreyfus, H. L. (1980). *A five-stage model of the mental activities involved in directed skill acquisition* (No. ORC-80-2). California Univ Berkeley Operations Research Center.

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *37*(1), 32-64.

Eliasson, F. Gustafsson, E. (2012) Navigatörer I kontroll (Diploma theisi) Department of Shipping and Technology. Chalmers University of Technology.

Forsman, F. Isaksson, A. (2006) Handhavanda av snabba fartyg – Arbetsutgåva version 14. Unpublished training course book.

Forsman, F. Dahlman, J. and Dobbins, T. (2011). *Developing a Standard Methodology for Dynamic Navigation in the Littoral Environment.* Paper presented at Royal Institute of Naval Architects, International Conference, Human Factors in Ship Design and operation, 2011, London, UK

Forsman, F., Dobbins, T., Hill, J., Brand, T., & MacKinnon, S. (2012). Exploiting simulation to enhance operational effectiveness and interoperability in littoral maritime operations. *NATO Science and Technology Organization Modelling and Simulation Group, Paper*, *22*.

Fredriksson, J. (2013). En femma I sundet klockan 12 – en uppgiftsanalys över navigaring ombord på Stridsbåt 90 H.(Diploma Thesis) Linköpings universitet.

Försvarsmakten (199?) Navigation 3 – Teletekniska hjälpmedel.

Försvarsmaken. (2003). Bryggtjänstinstruktion för marinen BryggI M. Försvarets bok- och blankettförråd

Goens, G. A. (1998). Too many coxswains: Leadership and the principalship.*NASSP Bulletin*, *82*(600), 103-110.

Granström, K. (2006). Dynamik I arbetsgrupper. Lund: Studentlitteratur AB.

Grech, M. R. Horberry, T. J. Koester, T. (2004) Human Factors in the Maritime Domain. Taylor & Francis.

Grech, M., Horberry, T., & Koester, T. (2008). *Human factors in the maritime domain*. CRC Press.

Grootjen, M., Bierman, E. P. B., & Neerincx, M. A. (2006). Optimizing cognitive task load in naval ship control centres: Design of an adaptive interface. In *IEA 16th World Congress on Ergonomics*.

Heylighen, F. (1992). Principles of Systems and Cybernetics: an evolutionary perspective. *Cybernetics and systems*, *92*(1992), 3-10.

Hill, J. Forsman, F. Brandt, T. Dobbins, T. (2014) Risk, Competence, Interoperability and Qualifications for Fast Craft Operations. *Human Factors in Ship Design & Operation, 26-27 February 2014, London, UK*

His Majesty's Stationery Office, (1941) Air Navigation Volume 1. Air Publication 1234 Volume 1.

Hollnagel, E. (1993, October). The modelling of loss of control. In Systems, Man and Cybernetics, 1993.'Systems Engineering in the Service of Humans', Conference Proceedings., International Conference on (pp. 44-49). IEEE.

Hollnagel, E. (2004). *Barriers and accident prevention*. Aldershot: Ashgate.

Hollnagel, E. (2002). Cognition as control: A pragmatic approach to the modelling of joint cognitive systems. *IEEE Journal of Systems, Man and Cybernetics*.

Hollnagel, E. (2011). Prologue: Prologue: The scope of resilience engineering.*Resilience Engineering in Practice. Burlington, VT: Ashgate*.Internatinal Maritime Organisation (1996) Resolution MSC.64(67)

Hollnagel E, Woods DD (2005) Joint cognitive systems: foundations of cognitive systems engineering. Taylor & Francis, Boca Raton, FL

Hollnagel, E. (2012). The ETTO principle as ETTOing–or Occam's Razor redux. In *Human Factors: a view from an integrative perspective. Presented at the Human Factors and Ergonomics Society Europe Chapter Annual Meeting, Toulouse, France*.

Hutchins, E. (1995). *Cognition in the Wild*. MIT press.

Interdiction Operations. Conference Paper at RTO- MP-HFM-202 - Human Modelling for Military Application

International Maritime Organisation. (2002). SOLAS chapter V safety of navigation.

Johansson, P. (2013) Podcast on Swedish radio P1. Människan och maskinen, episode 1/10.

http://sverigesradio.se/sida/poddradio.aspx?programid=2332&pid=4462

Jul, S. Furnas, G. W. (1997). Navigation in Electronic Worlds: A CHI 97 Workshop. SIGCHI Bulletin, 29(4), 44-49.

Kirsh, D., & Maglio, P. (1994). On distinguishing epistemic from pragmatic action. *Cognitive science*, *18*(4), 513-549.

Klein, G.A., Feltowich, P.J. & Woods, D.D. (2004) Common Ground and Coordination in Joint Activity. In W.Rouse & K. Boff (eds), *Organisation Simulation*. Chichester, UK: John WWiley & Sons. (pp.139-84).

Klein, G. (2007). Corruption and recovery of sensemaking during navigation.Decision making in complex environments, M. Cook, JM Noyes, and Y. Masakowski, Editors, Ashgate, Aldershot, UK, 13-30.

Klein, G., Phillips, J. K., Rall, E. L., & Peluso, D. A. (2007[b]). A data-frame theory of sensemaking. In *Expertise out of context: Proceedings of the sixth international conference on naturalistic decision making* (pp. 15-17). Psychology Press.

Klein, G. (2007[c]). Flexecution as a paradigm for replanning, part 1. *Intelligent Systems, IEEE*, *22*(5), 79-83.

Klein, G. (2009). *Streetlights and shadows: Searching for the keys to adaptive decision making*. MIT Press.

Koester, T. (2007) Terminology Work in Maritime Human Factors – Situations And Sociotechnical Systems. Frydenlund Publishers

Leveson, N. G. (2011) Engineering a Safer World: Systems Thinking Applied to Safety. Page 3. UK: MIT press.

Ljungberg, J. (2000) Att tala och handla på slagfältet. In K. Ydén (Ed.), IT, organisarande och ledarskap (pp. 144-163) Stockholm: Bokförlaget BAS

Mathieu, J. E. Heffner, T. S. Goodwin, G. F. Salas, E. Cannon-Bowers J. A (2000) *The Influence of Shared Mental Models on Team Process and Performance.* Journal of Applied Psychology 2000, vol 85, No 2, 273-283

Minister of Defence. (2010). Assault Navigation Precis. 10 Squadron Poole Dorset

Moltke, H. Graf Von, *Militarische Werke*. vol. 2, part 2., pp. 33-40. Found in Hughes, Daniel J. (ed.) *Moltke on the Art of War: selected writings*. (1993). Presidio Press: New York, New York

National Research Council. (1994). Minding the Helm – Marine Navigation and Piloting. Washington: National Academy press

OED Online. September 2014. Oxford University Press. http://www.oed.com/view/Entry/43546 (accessed November 24, 2014)

Osvalder, A. Ulfengren, P. (2009) Human Technology systems. In Work and Technology on Human Terms. Prevent. P. 377-376.

Palmqvist, H. Bergström, J. Henriqson, E. (2012) How to assess team performance in terms of control: a protocol based on cognitive systems engineering. Cognition, technology and work. Volume 14, Issue 4, pp 337-353

Perrow, C. (1984). *Normal accidents: Living with high risk technologies*. Princeton University Press.

Petursdottir, G. Hannibalsson, O. Turner, J. M. M. (2001) Safety at Sea as an Integral part of Fhiseries management. FAO Fisheries Circular No. 966

Rochlin, G. I. (1999). Safe operation as a social construct. *Ergonomics*, *42*(11), 1549-1560.

Shadish, W. R. Cook, T. D. Campbell, D. T. (2002) Experimental and Quasi-experimental Designs for Generalized Causal Inference. Belmont USA: Wadsworth Cengage Learning

Statens haverikommission. (2003) Grundstötning med Stridsbåt 90 H 881 vid St Brorn, O län, den 25 april 2003. ISSN 1400-5735

Suchman, L. A. (1987). Plans and situated actions: the problem of human-machine communication. Cambridge university press.

Sjöfartsverket (2007) Sjöfartsverkets föreskrifter och allmänna råd om utbildning och behörigheter för sjöpersonal. Bilaga 19. Utbildning för handhavande av snabba fartyg.

Snook, S. A. (2000). Friendly Fire. Princeton, Princeton University Press.

The Physics Classroom. (2015). Retrieved from: http://www.physicsclassroom.com/class/1DKin/Lesson-1/Speed-and-Velocity

U.S. Coast Guard (2003) U.S. Coast Guard Boat Operations and Training (BOAT) Manual - Volume I

Walker, G. H. Stanton, N. A. Salmon, P. M. Jenkins D. P. (2009) Command and Control: The Sociotechnical Perspective.UK, Ashgate

Van Creveld, M. (1985) Command in War. Cambridge: Harward University Press.

Vicente, K. 2006. The human factor: Revolutionizing the way people live with technology. New York: Taylor & Francis.

Woods, D. D. Hollnagel, E. (2006) Joint Cognitive systems: Patterns in Joint Cognitive Systems Engineering. USA: Taylor & Francis Group, LLC