Interface Design for Sonobuoy Systems

by

Huei-Yen Winnie Chen

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Modern sonar systems have greatly improved their sensor technology and processing techniques, but little effort has been put into display design for sonar data. The enormous amount of acoustic data presented by the traditional frequency versus time display can be overwhelming for a sonar operator to monitor and analyze. The recent emphasis placed on networked underwater warfare also requires the operator to create and maintain awareness of the overall tactical picture in order to improve overall effectiveness in communication and sharing of critical data. In addition to regular sonar tasks, sonobuoy system operators must manage the deployment of sonobuoys and ensure proper functioning of deployed sonobuoys. This thesis examines an application of the Ecological Interface Design framework in the interface design of a sonobuoy system on board a maritime patrol aircraft. Background research for this thesis includes a literature review, interviews with subject matter experts, and an analysis of the decision making process of sonar operators from an information processing perspective. A work domain analysis was carried out, which yielded a dual domain model: the domain of sonobuoy management and the domain of tactical situation awareness address the two different aspects of the operator's work. Information requirements were drawn from the two models, which provided a basis for the generation of various unique interface concepts. These concepts covered both the needs to build a good tactical picture and manage sonobuoys as physical resources. The later requirement has generally been overlooked by previous sonobuoy interface designs. A number of interface concepts were further developed into an integrated display prototype for user testing. Demos created with the same prototype were also delivered to subject matter experts for their feedback. While the evaluation means are subjective and limited in their ability to draw solid comparisons with existing sonobuoy displays, positive results from both user testing and subject matter feedback indicated that the concepts developed here are intuitive to use and effective in communicating critical data and supporting the user's awareness of the tactical events simulated. Subject matter experts also acknowledged the potential for these concepts to be included in future research and development for sonobuoy systems. This project was funded by the Industrial Postgraduate Scholarships (IPS) from Natural Science and Engineering Research Council of Canada (NSERC) and the sponsorship of Human*systems* Inc. at Guelph, Ontario.

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Chapter 1
Introduction

Sonar (sound navigation and ranging) technology has played an important role in underwater warfare since World War I, due to its superb ability to detect objects in the sea. The Canadian Navy currently employs a number of underwater acoustic sensors designed specifically for anti-submarine warfare. The Canadian Towed Array Sonar System (CANTASS), the Hull Mounted Sonar (HMS), the Variable-Depth Sonar (VDS) and the Sonobuoy Processing System (SPS) can be found on the Iroquois Class and Halifax Class frigates. Active and Passive Acoustic Sensors can be found on the Victoria Class Submarines. The CP-140 Aurora Class Maritime Patrol Aircraft (MPA) also carries a SPS and often joins frigates on missions (National Defence of Canada, 2007).

Historically, sonar research and development has focused on sensor technology and signal processing to improve the performance of sonar systems. While sensors have advanced considerably and signal processing has become more effective due to the increase in computational power, the displays for sonar data have not changed significantly over the last few decades (Barton et al, 2000). Today, technology advancement in all kinds of sensor and communication systems has also caused a growing emphasis to be placed on the integration of sonar data and tactical information across a wide variety of sonar systems and naval platforms. The problem of information management for sonar systems has therefore become even more pressing. Concept-demonstration systems set up at the Defence Research and Development Canada (DRDC) – Atlantic, such as the Integrated Multistatic Passive-Active Concept Testbed (IMPACT), the Towed Integrated Active Passive Sonar (TIAPS), and Networked Underwater Warfare (NUW) Technology Demonstration Projects (TDPs), are all means of demonstrating and evaluating new research in sonar data management and display concepts.

Inspired by the NUW TDP and the IMPACT project, this thesis details the design of innovative interface concepts to facilitate the tasks of an operator for the sonobuoy system on a MPA and to support their overall awareness of the tactical situation. Sonobuoys are small, expendable sonar devices that can be deployed by aircrafts or ships, usually for anti-submarine warfare. They can be used either independently or fully integrated within joint operations conducted by allied or coalition forces. An operator for the sonobuoy system deploys and manages the sonobuoys, and performs the usual sonar tasks of detecting, localizing, identifying, and tracking known and potential contacts. In addition to handling and processing the sonar data, the operator is also expected to improve their performance by building a strategic picture, which requires high level comprehension of the tactical situation and effective communication across all platforms involved.

1.1 Research Approach

The work in this thesis follows the well-documented approach of Ecological Interface Design (EID), which emphasizes fundamental constraints and relationships present in the system. This approach to interface design is intended for complex, real-time, and dynamic systems where operators solve problems using expert knowledge and experience. Sonobuoy management is a good example of such a system. Evaluation of the resulting interface concepts is done in the form of user testing, providing both quantitative and qualitative measures, and remote questionnaires for Subject Matter Experts (SMEs) to complete.

1.2 Contributions

The contributions of this thesis can be summarized as follows:

- Examination of a sonar operator's decision making processes.
- Examination of the mental and physical work environment of a sonobuoy operator.
- Exploration of EID as a framework for supporting a sonobuoy operator's performance and awareness of tactical situation in the military domain.
- Proposal and evaluation of a number of display ideas for a sonobuoy system.

1.3 Thesis Organization

The remainder of this thesis is organized as follows:

- Chapter 2: Literature review.
- Chapter 3: Summary of key findings from two interview sessions with SMEs.
- Chapter 4: Analysis of the decision making process by sonar operators.
- Chapter 5: Description of the Work Domain Analysis (WDA) conducted.
- Chapter 6: Summary of information requirements extracted from the Work Domain Models (WDMs), and description of the concepts designed based on the information requirements.

- Chapter 7: Description of the designs that went into prototype implementation and the organization of the prototype.
- Chapter 8: Description of the user testing methodology applied to evaluate the designs and a summary and discussion of the key findings.
- Chapter 9: Summary and discussion of questionnaire responses from SMEs to provide feedback on the designs.
- Chapter 10: Conclusions of the study in terms of its limitations, theoretical and practical contributions, and a list of proposed changes to the design concepts. Directions for future work are included at the end of the chapter.

Chapter 2
Literature Review

This chapter summarizes a literature review conducted in a number of relevant areas. Section 2.1 provides a brief explanation of sonar and its use in the domain of underwater warfare (UWW). This includes topics such as how sound is transmitted and behaves underwater, the particular impact of the ocean as a medium, and the propagation paths that are commonly used in anti-submarine operations. This section also describes the differences between passive and active sonar systems, the nature and use of broadband and narrowband signals, and how acoustic data are interpreted. Section 2.2 describes what sonobuoys are and their functions in UWW. Section 2.3 looks into recent and current research and development on the display of sonar data. The auditory modality of sonar interface, its roles and limitations, are discussed in Section 2.4. Section 2.5 is dedicated to describing Ecological Interface Design (EID), the analysis and design approach chosen for this thesis. Finally, Section 2.6 explains the use of the term "situation awareness" in the context of this work.

2.1 Sonar

Sonar uses sound propagation under water to navigate or to detect underwater targets. Among the many techniques for underwater target detection (e.g., the use of magnetic, optical signatures, and hydrodynamic changes), sonar techniques have been the most successful and widely implemented (Waite, 2002). Sound travels at an average speed of 1500 metres per second in seawater, but the speed varies depending on water temperature, salinity, and pressure. Under ideal conditions, sound signals can be transmitted over hundreds and even thousands of miles in the water (Cox, 1974). Although the dynamic nature of the sea environment presents many challenges for the use of sonar, there is no other known type of energy propagation that travels as far in the ocean without significant losses.

Sonar has been applied in a wide range of underwater activities, including fish finding, deep sea mining, monitoring of marine animals, and military operations. Submarines, ships, and aircraft that are on surveillance or UWW missions all use sonar to detect other vessels (e.g., enemy submarines and ships). Traditionally, naval sonar performs the following functions (Cox, 1974):

- Detection: decide if a target is present or not.

- Classification: identify the specific category (e.g., submarines) to which a detected target belongs.
- Localization: measure any of the instantaneous position and velocity components (e.g., range or bearing) of a target. The measurement can be relative or absolute.
- Navigation: determine and/or steer a course for a vessel through a medium, including obstacle avoidance and navigation within boundaries.
- Communication: transmit and receive acoustic signals.
- Countermeasures: act to neutralize or oppose the plan of another.

The success of tactical sonar performance depends not only on the capabilities of the sonar equipment, but also on the ocean where the mission is conducted. Some parts of the ocean transmit sound more readily than others, and this capability varies from season to season, and even from hour to hour (Cox, 1974).

2.1.1 Sound in the Ocean Environment

Cox (1974) defines three fundamental concepts of sound from the perspective of anti-submarine (underwater) warfare:

1. Sound, as a form of energy, is subject to the laws of physics that deal with conservation of energy. An important law is "the notion that the quantity of energy in the universe is constant and may not be destroyed but only translated or changed in form."
2. Three elements are essential for the transmission and detection of sound: a sound source, a medium, and a detector.
3. Acoustic energy is a form of mechanical energy.

When an object immersed in water is caused to vibrate by electrical or mechanical means, energy transferred to the object translates to the water medium surrounding it. Sound is therefore a disturbance of mechanical energy to a medium and propagates through the medium as a wave. It is characterized by the properties of waves: frequency, wavelength, period, amplitude, and speed.

Because acoustic energy travels through a medium that consists of molecules, some of the original energy will be passed to the molecules of the medium. The additional energy in each molecule results in an increase in the motion of the molecule, analogous to the idea of friction in other mechanical applications (Cox, 1974). Absorption is therefore a form of transmission loss into the medium that involves the conversion of acoustic energy into heat. Another major form of transmission loss is 'spreading,' a geometrical effect of the regular weakening of a sound signal as it spreads outward from the source (Urick, 1983). In addition, ocean, as the medium, has boundaries (i.e., the bottom and the surface) which influence sound travel and also absorb energy in the form of heat. The characteristics of the boundary surfaces cause sound energy to impede, divert, or diminish (Cox, 1974). Within the boundaries, there are also foreign objects such that when a sound wave strikes them, some of that sound is reflected and re-radiated. Loss of energy results as the sound wave strikes an object, because a portion of the wave will scatter away from the main, original direction the wave is traveling. Reverberation also occurs: it is the part that is reflected back to the sonar source/receiver as sound reflects from an object. Reverberation is treated as 'noise' because it is from everything in the ocean that is not the actual target. Reverberation is therefore a problem for active sonar operations, where the sonar system is the source of the sound (Naval Maritime Forecast Center, 2007).

2.1.2 Sound Propagation Paths

The paths of sound propagation are particularly of interest to underwater warfare operations. Several major paths are described here (Cox, 1974 and Naval Maritime Forecast Center, 2007):

- Direct path: a straight line direct from source to detector.
- Bottom Bounce Path: a path utilizing sound energy either beamed or bent towards the ocean bottom and results in sound energy being bounced (reflected) off the ocean bottom. This kind of path is highly dependent on depth and the absorption of sound by the ocean bottom.
- Convergence zone sound path: intense increase in sound velocity due to pressure increase may cause sound rays to bend upwards. A temperature gradient can cause rays to bend downwards. When these rays converge, it is called a convergence zone sound path, and a significant gain in energy can be noted in the convergence zone. Multiple convergence zones may occur in one sound path.
- Sound channel propagation paths: a path that confines the horizontal travel of sound within the boundaries of a channel (or duct) that is formed. The channel may be caused by either velocity structure (refraction) alone, or refraction and reflection from the surface or bottom boundaries of the ocean.

Besides velocity structure, some factors that may affect the propagation paths include the characteristics and features of the ocean bottom (composition and type) and features of the ocean (fronts and eddies).

2.1.3 Oceanic Sound Speed Profiles

As mentioned in the previous subsections, understanding of the velocity structure of sound in the ocean is essential in underwater warfare operations. To begin with, sound propagation depends strongly on the properties of the medium. In the water, these properties are ambient temperature, pressure, and salinity. While the speed of propagation is a fairly complicated function, the effects of these three independent parameters are generally stated using the following rules of thumb:

- **1^{o} C** increase in temperature results in **3 m/s** increase in speed.
- **100 meters** of depth increase results in **1.7 m/s** increase in speed.
- **1 ppt** (part per thousand) increase in salinity results in **1.3 m/s** increase in speed.

Given these numbers, changes in temperatures are by far the most significant contributors to changes in the speed of sound. Changes by as much as 30^{o} C are possible in the water in which a submarine operates. To achieve the same change in propagation speed, a change in depth of more than 50,000 meters would be needed. Variations in salinity are limited to regions where fresh and salt water mix (FAS Military Analysis Network, 2005).

At a fixed location, the speed of sound varies with depth, the season, the geographic location, and time. In general, the velocity structure of the sea is described in terms of layers (Urick, 1983). From the surface downward, four layers have been observed (see Figure 2-1):

- The surface layer, or mixed layer, is heated daily by the sun. The wind and surface storms cause waves, resulting in mixing of the water. As a result, the temperature is the same throughout this layer (isothermal). Remarkably strong sound propagation is observed in this layer, so target detections can be made at a longer range than normal.
- In the second layer, the seasonal thermocline, the temperature decreases with depth. The season of the year determines the depth at which this layer starts. In winter, it is possible that the strong wind mixes the surface layer so deep down that the layer of seasonal thermocline is not identifiable.

- The next layer is the main thermocline. This layer is not affected much by surface conditions. Its temperature decreases as the depth increases. The reduction in temperature causes a steady decrease in sound velocity.
- In the deep isothermal (constant temperature) layer, the velocity of sound increases with an increase in depth, due to the increase in pressure at lower depths.

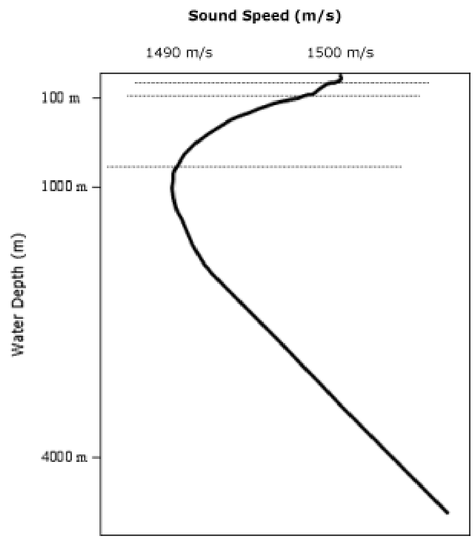


Figure 2-1: Sound Speed Profile (University of Rhode Island, 2006)

In the littoral (shallow) waters of coastal regions, the velocity profile above no longer applies. The velocity profile of shallow waters is usually irregular and unpredictable. Surface heating and cooling, salinity changes caused by nearby sources of fresh water, and water currents all have significant influence on the sound velocity (Urick, 1983).

2.1.4 Passive vs. Active Sonar

There are two major classes of sonar: passive and active. A passive sonar system listens via a hydrophone (a simple sensor that receives acoustic signals) or a set of hydrophones and pickup all acoustic signals, both ambient noises and signals of interest (e.g., merchant ships or potential enemy submarines) within its detection range. Depending on environmental conditions, passive sonar can detect targets several miles away, but with limited attributes about the targets. Passive sonar provides directional information (i.e., bearing) of the target, but not the range (i.e., distance) to the target. By tracking a target (or contact) over time, more complete information, including bearing, range, course, and speed, can be determined using a process called Target Motion Analysis (TMA).

An active sonar system is based on the echo-ranging principle. The system transmits a high-energy acoustic signal or "ping". Objects in the area then reflect the transmitted signal and the resulting echoes are picked up by the system's sonar sensors. The direction of the returning echo indicates the bearing of the object. The time from the initial transmission to the reception of the echo reveals the range to the contact without the need to conduct a TMA. However, active sonar risks exposing itself since the transmission of the "ping" can also be received by enemy ships and used to locate the transmitting sensor (Sonalysts, 2004).

2.1.5 Broadband vs. Narrowband

Underwater targets emit both broadband and narrowband signals, both of which are detectable by sonar systems. For example, a ship's movement through the water and its propeller and shaft generate acoustic energy over a wide range of frequencies, which can be captured by broadband receivers. A broadband sonar receiver is used primarily to detect and track contacts for TMA and also can contribute to classification. A narrowband acoustic source is typically generated by a specific piece of equipment such as a pump or a motor, and emits energy at a distinct frequency. When the distinct frequency associated with a particular target (i.e., sonar signatures or sound profile) is known, narrowband sonar can reject ambient noise outside the frequency band of the target signature and thus increases the possible range of detection. Narrowband frequencies can also be used to classify contacts based on their sonar signatures (Sonalysts, 2004).

2.1.6 Interpretation of Sonar Data

Acoustic energy is traditionally presented in the form of a power spectrum spanning a particular frequency range. The actual (fundamental) frequency of the emitting source is not often captured by the frequency range provided on a sonar display. Therefore, often what is detected by an operator is a subset of the harmonic frequencies associated with the fundamental frequency. To interpret the sonar data, an operator must take several steps: extraction of harmonic frequencies, association of harmonic frequencies into correlated sets, determination of the fundamental frequency associated with the harmonic set, identification of the acoustic source based on the correlated sets of harmonic frequencies, and identification of the platform containing the source (Sonar Data Interpretation website). Identification of the signal source is made possible because different types of vessels have their own harmonic frequency profiles, or signatures. These signatures are based on the noises that vessels make underwater. Three major classes of such noises are (Urick, 1983):

- Machinery noise:
  - Propulsion machinery (diesel engines, main motors, reduction gears)
  - Auxiliary machinery (generators, pumps, air-conditioning equipment)
- Propeller noise:
  - Cavitation at or near the propeller
  - Propeller-induced resonant hull excitation
- Hydrodynamic noise:
  - Radiated flow noise
  - Resonant excitation of cavities, plates, and appendages
  - Cavitation at struts and appendages

Machinery noise and propeller noise generally dominate the spectra of radiated noises. The relative importance of the two depends on the frequency, speed, and depth of the sound wave. High frequency lines that show up on the display may be due to a loud propeller or particularly noisy reduction gears. At higher sound speeds, however, the continuous spectrum caused by propeller cavitation overwhelms many of the line components and dominates over the spectrum.

2.1.7 Summary

This section surveys the theory behind sonar technology and the purpose it serves in the military domain. The brief overview aims to raise an appreciation for the complexity of applying sonar technology in the UWW environment. While the scope of this project is the use of sonobuoys in the UWW environment, the background review of how sound behaves in the dynamic ocean environment is nonetheless significant and is taken into consideration for further analyses and design efforts. The distinction between passive and active sonar systems is not explicitly modeled in the project, but the fact that there are two types of sonar is recognized throughout the project, since sonobuoys of both types are used in the UWW operation. Finally, the only sonar functions of interest to this project are detection, classification and localization because they constitute the work of sonar operators. Navigation and countermeasures are handled by other personnel in an underwater task group.

2.2 Sonobuoys

This project focuses on the sonobuoy system on a MPA. Sonobuoys are expendable sonar devices that can be dropped from an aircraft or a ship into the ocean to perform underwater warfare sonar tasks. Depending on their class, the sonobuoys can provide either passive reception of underwater acoustic signals or a controllable, acoustic signal source for active sonar operations. Received signals are transmitted to the monitoring units, which then process, display, and record the signals on magnetic tapes for post-analysis. Sonobuoys can be used either independently or fully integrated with other sonar platforms in joint operations conducted by allied or coalition forces. On the MPA, an operator for the sonobuoy system performs the sonar tasks described earlier, but must also manage and deploy the sonobuoys. The airborne sonar operator must deal with widely-distributed, drifting sensor fields, while participating in dynamic tactical situations.

Sonobuoys can also be used to determine environmental conditions. Bathythermal sonobuoys, when activated, deploy a temperature probe. As the probe descends into the sea, the temperature gradient is measured, converted to an electronic signal, and transmitted back to the monitoring platform. The temperature profiles created are extremely valuable to the analysis of data from the tactical sonobuoys. However, a bathythermal sonobuoy allows one use only, and a very limited number of bathythermal sonobuoys are allocated for each mission. Data provided by bathythermal sonobuoys, but not the sensors, are important to this project because of their direct impact on the capability of tactical sonobuoys.

2.3 Sonar Displays and Recent Research and Development Efforts

Traditional sonograms of frequency versus time (“waterfall displays”) are still the major component of sonar displays (Waite, 2000). Recent improvements to sonar displays have largely been concerned with automated detection and tracking algorithms, which are used in most commercial systems today (Kessel, R.T. and Hollett, R.D. 2006). Colour has also been used to code and segment acoustic data to enhance saliency of certain signals (e.g., Zelter, D. and Lee, J., 1995). In commercial sonar simulation products (e.g., ASWTT by ECA-Sindel of Italy, and CAE’s STRIVE-SONAR) and military research (e.g., IMPACT, TIAPS), some designs incorporate geographical and tactical information. The Naval Undersea Warfare Center Div. Newport RI and the Fraunhofer Center for Research in Computer Graphics in the United States jointly conducted a large scale interactive data visualization project for undersea warfare applications. They developed a unique set of sonar display tools named EZ-grams, which aimed to help a sonar operator transform raw sensor data into useful information by allowing them to rapidly test hypotheses and search for confirming data. The following subsections describe two specific projects: IMPACT, for its relevance to sonobuoy systems and its continuing advancement in design; and the EZ-Gram sonar display tools, for their distinctive approach to supporting sonar tasks.

2.3.1 Integrated Multistatic Passive-Active Concept Testbed (IMPACT)

The on-going project of IMPACT, a testbed for airborne sonar operations, was initiated by Defence R&D Canada - Atlantic (DRDC Atlantic) in 1987 (Fraser, Collison and Maksym, 2002). The testbed has supported numerous implementations and evaluations of research projects in airborne sonar operations, including signal processing techniques, displays that provide both acoustic data and tactical information, and automatic algorithms for detection and localization. The IMPACT system supports both passive and active sonar data. Lofargrams, the commonly adopted sonograms for passive sonar data, are generated concurrently for the multiple channels of passive sonar data. In multistatic active sonar, concurrent processing also takes place for all kinds of signal waveforms.

Another important feature in IMPACT is that a real-time tactical plot can be called up on the monitors. This display includes sensor and radar target locations, bathymetry and coastal overlays, and estimates of target position plotted automatically as related acoustic events are captured and tagged. Currently, a Global Command and Control System–Maritime (GCCS-M) display is installed. This node is expected to serve as a foundation for acquiring and displaying both non-acoustic data and imported tactical and environmental information, and for sharing contact information with other players. In addition, an automatic detection algorithm is implemented to search frequency vs. time series for groups of peaks that match the ping sequence. The algorithm then maps successful detections as intensity highlights at the corresponding locations in the tactical plot (Fraser et al., 2002).

Interface design efforts that have gone into IMPACT also include several human-computer interface (HCI) features:

- Colour-coding of the display to provide directional information (i.e., matching bearings to colours) in an effective, intuitive manner.
- "What-if" tools to guide the operator towards display regions where contacts are most likely to appear.

- Tools to facilitate the classification of sonar echoes.

Some snapshots of the IMPACT interface are shown in Figure 2-2. Given the capabilities provided by IMPACT, a problem that has been identified is information overload for operators. The continuing increases in the number of sensors and in the processing power of modern sonar systems, as well as the growing emphasis on sharing information between multiple platforms, have now far surpassed the ability of operators to absorb and act upon all of the available information in a timely fashion.

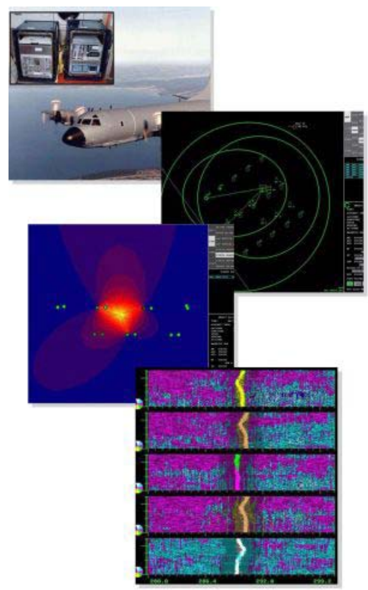


Figure 2-2: Snapshots of the sonobuoy system of IMPACT Testbed (DRDC – Atlantic, 2000)

2.3.2 EZ-Gram Sonar Display Tools

"EZ-grams" are sonar data display tools for testing hypotheses, searching for corroborating data, and building confidence in the solution (Barton, Encarnacao, & Rowland, 2000). The research began by investigating some of the useful interaction tasks for exploration of data in the traditional desktop environment:

- Selection: isolating a subset of the data for highlighting, deleting, exploring in detail, or processing.
- Navigation: moving through the data while maintaining overall context to ensure coverage and avoid getting lost.

- Filtering: removing or altering data that falls within or outside of a user-specified constraint (e.g., noise removal, smoothing).

Applying what they learned from these traditional data manipulation tasks, the researchers explored some of these concepts in the context of sonar displays:

- *Gisting*: an interactive, data navigation concept to allow the sonar operator to move through an information space with the support of a "visual mapping" of an experienced operator's analytical protocols and operational guidance.
- *Compact information icons*: allow low priority data to be concealed in the information presentation process. This hopes to increase the probability of detection and correct classification by eliminating low priority data from the display.
- *Harmonogram*: a tool based on the hypothesis that energy of interest exists in some or all of the harmonics associated with a given or selected frequency band. The frequency bands of the harmonogram are arranged in order to enhance the dynamic representation of Doppler, while reducing non-correlated data in the display. The harmonogram also displays time record data, giving "replay" functions to view local history and target or contact motion.

2.3.3 Summary

Literature review shows that little research and development has been conducted for sonar displays. More importantly, there is a lack of design effort that is based on a structured method. In most cases, the involvement of sonar operators in a design process is minimum, rarely any prior to the stage of prototype testing. Specifically regarding sonobuoy system, there has been no work found that examine the multi-tasking of sonobuoy operators to handle both tactical information and resource management (i.e., the level of sonobuoy inventory for specific types and classes of sonobuoys). While display tools such as those of IMPACT and EZ-Gram projects explored the visualization of sonar data, it is not obvious from the literature whether there was any effort in aggregating the tactical picture for sonar operators through the visual displays. These are all issues that this project wish to address.

2.4 The Roles and Limitations of Auditory Interfaces

Sonar operators have historically performed detection and classification tasks using the auditory modality. After World War II, development in digital signal processing and improvements in visual display technology made presenting acoustic data visually possible (Urick, 1983). Sonar operators today interpret complex information from both auditory and visual channels, and often do so simultaneously.

Arrabito, Cooke, and McFadden (2004) list three major limiting factors in auditory interfaces: noise levels, vigilance decrements, and hardware limitations. All three limiting factors may pose similar concerns on a visual display, but in a different form. In particular, the problem of noise levels is a higher concern in auditory displays than in visual displays. Since sonar operators often work in a team environment, the noise for auditory interfaces, besides ambient signals in the ocean, includes human voices, such as conversations between the team members, machinery noises in the physical work environment (especially distracting on a MPA), and auditory alarms.

The choice of modality also differs depending on the type of signals being detected. When the duration of the acoustic pulse is long, the operator tends to rely more on visual displays due to the short integration period of the human ear (Urick, 1983). A common class of longer acoustic pulses is the FM pulses, which are valuable in littoral waters because they provide accurate range and reduce the interference from reverberation. There is also a greater use of visual displays when using active sonar systems (Arrabito et al., 2004).

Given the limitations of auditory displays, it may be surprising that the auditory modality still plays an important role in sonar tasks, according to a questionnaire conducted by Kobus et al. (1990). One advantage of auditory processing lies in its superior ability in detection of transient signals such as hull popping (e.g., caused by a submarine changing depth), clanking (e.g., caused by dropping a wrench), engine start-up sequences, and squeaks (e.g., caused by rudder motion). Transient signals, while unable to provide information to classify a vessel, are difficult to disguise, despite the continuous effort that goes into constructing quieter submarines. Transient signals are more likely to be perceived by a listener because the human ear is very good at detecting transient sounds in the presence of noise. Therefore, they often serve to alert the operator to the presence of a potentially threatening situation (Arrabito et al., 2004).

The importance of auditory displays has been rather degraded in modern sonar systems. Research and development in sonar data displays have been conducted mostly on the visual modality. Arrabito et al. (2004) suggest in their study that the auditory modality could be enhanced by applying existing knowledge of auditory displays and decision support systems. An interesting example is to adopt three-dimensional audio in the sonar interface to provide a sense of direction in a listener's auditory detection of signals. The potential of applying three-dimensional audio in military applications have been identified and reviewed by Arrabito (2000).

This project recognizes the importance of both visual and auditory modality in sonar interfaces. In modeling the work domain of a sonobuoy system operator, both modalities are considered as means of perceiving sonar data by the sonobuoy operators. While design concepts generated from this project are mostly visual displays, due to limited resources for examining and prototyping auditory interfaces, concepts for integrating auditory and visual modality are also discussed.

2.5 Ecological Interface Design

Ecological Interface Design (EID) is a theoretical framework for interface design for complex socio-technical systems (Vicente and Rasmussen, 1992). It is based on two seminal concepts from cognitive engineering research, the abstraction hierarchy (AH) and the skills, rules, knowledge (SRK) framework (Rasmussen, 1986).

2.5.1 Abstraction Hierarchy

The AH is a 5-level functional decomposition used to develop physical and functional work domain models (WDMs), as well as the mappings between them. The AH is used to identify the information content and structure of the interface (Vicente, 1999). The levels in an AH are characterized by "why" and "how" questions, in which the highest levels define the designed purpose while the lowest levels define the physical components of the work domain. Each level is a unique and complete description of the work domain (Burns and Hajdukievicz, 2004).

The five levels of AH are as follows (Burns and Hajdukievicz, 2004):

- Functional Purpose: Purpose(s) for which the system is designed. Distinct and potentially conflicting purposes demonstrate the trade-offs and constraints between elements of the work domain. It is important to differentiate between purposes and tasks, which are often mistakenly identified as purposes. A set of actions that people perform within the system is a task, not a purpose, although understanding the tasks often helps to understand the system.

- Abstract Principle: Fundamental, first principles, and basic laws of nature that govern the domain and cannot be violated. Conservation laws are often included.
- Generalized Process: Processes that explain the causal relationships in the system that determine *how* it works. These processes are governed by the Abstract Principle defined above and must be monitored by operators of the system.
- Physical Function: Components of the system and their respective capabilities and limitations. These components are to be found in the processes described by the processes at the Generalized Process level.
- Physical Form: Description of the physical existence of the components listed in Physical Function. Attributes at this level include the condition, location and appearance of components.

2.5.2 Skills, Rules, Knowledge Framework

The SRK Framework defines three qualitatively different ways in which people can process information. This framework is used to identify how information should be displayed in an interface. The three levels in the SRK classification are:

- Skills: sensorimotor behaviours that require very little or no conscious control to execute an action after forming the intent to execute. In most skill-based actions, the performance is smooth, automated, and consists of a highly integrated behaviour pattern (Rasmussen, 1990).
- Rules: behaviours characterized by the strict use of procedures or rules to select a course of action in familiar work situations (Rasmussen, 1990). Instructions given by the supervisors are examples at this level. Operators are not concerned with knowing or understanding underlying principles.
- Knowledge: behaviours that demonstrate advanced level of reasoning by the operator (Wirstad, 1988). This is particularly necessary in novel or unexpected situations. At this level, operators make use of the principles and fundamental laws that govern the system. Cognitive workload is typically greater when performing knowledge-based behaviours than when employing skills- and rules-based behaviours.

Combining the two concepts, EID makes the following proposals:

- Information presented on the display space should support skill-based and rule-based behaviours to enable operators to complete their tasks in a relatively efficient and consistent manner.
- The interface must be rich in information and, following the AH representation of the work domain, structured to visualize the system and its intrinsic dynamics and complexities. In short, the interface should provide sufficient knowledge for users in novel and abnormal situations. As a result, operators become adaptive problem solvers (Vicente, 1999).

2.5.3 EID in the Military Domain

EID has been applied to diverse domains, including process control, aviation, computer network management, software engineering, medicine, command and control, and information retrieval (CEL, 2005). In the military domain, Work Domain Analyses (WDA), the main technique for modeling the system, have been performed on naval command and control (Burns and Chalmers, 2005), and employed to model the work domain of frigates (Burns, Bisantz and Roth, 2004). The use of WDA has also been found in military applications of uninhabited aerial vehicle (UAV) (e.g., Rasmussen, 1998 and Castro & Pritchett, 2005). The WDA performed in this project proposes a dual domain model that addresses the tactical, intention-driven side and the physical resource management side separately.

2.6 Situation Awareness

As stated earlier, new interface concepts proposed and outlined in this thesis aim to support the sonobuoy operator's overall awareness of the tactical situation. Throughout this report, the term "situation awareness" is used to express the notion that an operator must be aware of their environment, the tactical components contained, events occurred, as well as the usage and inventory status of their resources. A more formal definition of situation awareness is given to further clarify what it entails in the research community. How the concept of SA applies to the work environment of a sonobuoy operator is further discussed in Chapter 4.

Situation Awareness (SA) is a relatively new concept that has received much attention in the research fields of cognition and human factors. Endsley (1988) describes Situation Awareness as "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future.” Although there have been numerous attempts at defining SA, Endsley’s definition has been the most widely applied in the context of decision making. Of particular relevance in this thesis is how Endsley’s model defines three levels for the amount of SA one possesses:

- Level 1: Perception of Elements in the Environment. The perception of relevant cues in the environment is the first step in the development of SA.
- Level 2: Comprehension of the Current Situation. The second level involves the integration of the perceived cues from Level 1 that are relevant to decision goals. In achieving level 2 SA, operators acquire a holistic picture of the environment that includes the significance of the objects and events within it. Novices typically do not have the knowledge or experience needed to develop level 2 SA.
- Level 3: Projection of Future Status. The ability to predict future actions of elements and events represents the highest level of SA (i.e., highest level of understanding). This level is built upon the perception and comprehension of the situation from Level 1 and 2. A vast amount of resources is required to provide the necessary support for expert decision makers at this level, allowing them to make projections that are then used for proactive decision making.

Although situation awareness is adopted loosely from Endsley’s definition in this project, the general idea that an operator needs to perceive an event, comprehend it and then project about the future is the driving force behind the interface concepts developed. Stemming from this 3-level definition, a good display needs to make important elements or events obvious, provides enough information for the user to general an understanding of the situation efficiently, and to allow them to anticipate events in the future.

Chapter 3
Subject Matter Expert Interviews

The purpose of conducting interviews with subject matter experts (SMEs) was to gain a deeper appreciation of how expertise is developed and utilized in a sonar operator's job. Two subject matter experts were interviewed separately. One was an acoustic (sensor) operator from the air force and the other was a sonar control supervisor (SCS) from the navy. Questions prepared covered the operators' decision making process, if and how a mental model may be created, and the kinds of information that may be particularly useful for the operators. Lists of questions are attached in Appendix A. This chapter summarizes the findings from the interviews.

3.1 Responsibility and Work Environment

The acoustic operator from the air force works onboard the Aurora class maritime patrol aircraft (MPA), which provides frequent support to frigates and other naval platforms. Generally, there are two acoustic operators on a mission, and together they are responsible for deploying the sonobuoys and monitoring sonar data through the sonobuoy processing system (SPS). Passive and active sonar tasks are usually split between the two acoustic operators. The more junior operator is responsible for active sonar tasks because it requires less analysis than passive sonar tasks. The tactical team on a MPA works in a small space; their work space is arranged in a way that facilitates open communication between all six of the team members, and thus tactical and acoustic information are available to all.

On the ship, the team structure is much more rigid. Sensor operators have no access to tactical displays and information. The SCS has access to the tactical display, and is responsible for integrating all the sensor information, coming from CANTASS (Canadian Towed Arrays Sonar System), HMS (Hull-Mounted Sonar System), and SPS, before information gets passed to the command level. The SCS interviewed described his main responsibility as 'quality control', or making sure that the information that gets passed to the command level makes sense.

3.2 Cues and Supporting Information

In the most general sense, the basic visual cue that a sonar operator looks for in their display is what does not fit in. A potential target should appear as a visible change of pattern that can alert the operator. Since the sonar systems employed are a collection of data from multiple sensors, it is important to have summary displays that can condense information and provide a high level visual cue to any unusual pattern from any of the sensors. For example, onboard the Aurora is a summary display for all 16 sonobuoys they have deployed. The amplitude line display shows frequencies built up when there is a contact. The CANTASS station on the ship also has a summary display showing all beams in a condensed gram format. Almost always a potential target is spotted on such a summary display before it can be investigated further on a single beam display, or other more specific displays.

The most important cue for an operator, however, seems to be the expectation formed in their head. Threat information received prior to mission enables operators to anticipate what could happen and what to look for. Prior study of what the target signature should look like on sonograms helps them recognize the pattern during the mission. Additional knowledge about the target, especially with submarines, is often what distinguishes between experts and novices. Experts utilize knowledge such as the model of the target submarine, its country and their tactical doctrine, and the capability of their equipment to speculate where the submarine may attempt to hide, and what tactical strategies the submarine may adopt. Simply put, experts are very familiar with underwater warfare tactics and apply them well in their job.

Based on threat information and knowledge about sonar signatures, assumptions about a contact are made quickly after it is noticed. If the mission involves searching for a submarine, operators would quickly classify the new contact as either a submarine or not a submarine in their mind. Most of the time, vessels encountered, such as a merchant ship, have straightforward signatures and are easy to identify. However, operators always investigate their hypothesis further before making a final judgment about a contact. The Aurora operator said that he looks for information to confirm his hypothesis that something is there, while the navy SCS said that he investigates any possibility to prove it wrong. Perhaps the more conservative approach taken by the SCS may be attributed to the differences between the two platforms. The naval ship holds a great amount of passive sonar information from both sonobuoys and the towed arrays. With less flexibility in their own movements, the ships are more likely to monitor an area by listening to the sounds within the area. The Aurora aircrafts can go on a more active search or set sonobuoy barriers for a specific target, and hence able to gather enough information to quickly confirm their hypotheses.

3.2.1 Information They Seek

Frequencies and frequency shifts (i.e., dopplers) are the primary data sonar operators use to confirm their contact and its activities. The contact is established (i.e., "hot") only when the operator can determine the bearing of the contact. While there are procedures in calling a contact 'hot,' they are generally a set of informal routines. These routines involve declaring which system is holding the bearing, and comparing the data with the current tactical picture for confirmation. At this point, the tactical crew onboard takes over and either approves or rejects the contact. The acoustic operators feel more comfortable making calls and judgment about less likely contacts from knowing that there is another level above them who make the final decision.

3.2.2 The Intricacies of Sonar Tasks

The SMEs identified a number of difficulties involved in a sonar operator's task. The first and foremost factor is the tactical nature of underwater warfare. A submarine will likely try to hide in an area of high ambient noise or an oceanographically difficult location. Just as the sonar operators will continuously modify their search, the submarines will also change their tactics continuously to adapt to new situations. An expert operator needs to have a constant mental picture of the situation, and must also proactively think about the tactics involved. A successful operator is one who is eager to advance their knowledge about tactics, new sonar knowledge, and oceanography. They are also the ones regularly found training at the simulators on a self-initiated basis when they are not at sea. However, even with experienced sonar operators, a lone ship often finds itself of limited use when localizing and tracking a contact. Given a ship's reliance on other assets in the area, ineffective sharing of information between platforms is also a contributing factor to the difficulty of the mission.

Underwater warfare is directly influenced by oceanographic and weather conditions of the mission environment. The operators need to have a strong understanding of such conditions to make sound decisions. Tasks such as localization and tracking are further complicated when the environment is harsh. Under strong current, positioning and tracking of sonobuoys becomes very tricky. The presence of sea mountains also creates good hiding spots for enemy submarines and makes detection harder.

Finally, stressors present in their work environment also contribute to the difficulty of the task. Fatigue from long hours of watch shifts and the uncomfortable environment induced by rough sea conditions are both common stressors. The frustration that builds up during an unproductive search may also negatively affect mission performance. There are few or no strategies for handling these stressors. The operators said they learned to cope with these conditions and continue their tasks as well as they can.

3.2.3 Mental Model and Situation Awareness

Both SMEs said that they form mental pictures of the situation in mind. They need to know what other assets (i.e., friendly or neutral contacts in vicinity) are in the area that could provide support, and possible directions of the target contact, if such information is available. They have to know physically where they are located in relation to all the known or possible contacts. They must also be able to share useful information with other platforms. The Aurora operator said having access to a tactical display helps in this aspect, although often he becomes too focused on just tracking the sonar lines and loses overall awareness of the situation. Also, compared to the tactical display, which is 2-dimensional and marked by symbols, what he picture in his minds is 3-dimensional, and resemble real-life objects.

On the ship, however, sensor operators have no access to tactical pictures; paper logs from the SCS are the only source of tactical information. The SCS interviewed stressed the importance of thinking ahead of what is likely to happen in the future, not only just being aware of the current picture. For example, questions operators may consider include:

- What tactics could the target submarine employ?
- Does the current picture make sense in light of what they are anticipating?

This anticipation of future events is an example of what Endsley (1988) defines as the highest level of situation awareness.

Various sources provide references to these mental models. The tactical display, as pointed out by the Aurora operator, helps them create a visual sense of the location and the types of contacts that are already known in the area. Incoming acoustic data is also continuously integrated and updated mentally to picture the location and actions of their potential target. Knowledge about the target and its intentions improves the ability to anticipate the target’s future actions. Finally, the operators acknowledged the importance of environmental conditions and oceanography, but they also admit that it is hard to integrate such information into their mental space. It is not uncommon that the oceanographic data is not considered initially, but have to be brought up at a later time to act as a tactical cue.

3.2.4 Communication

Both operators agreed that effective communication is the key to a successful mission. Communication takes place at two levels, internally and externally with other platforms. Internally, most of the conversation is done verbally using headphones. All operators are trained to communicate quickly and succinctly. When a group of operators develops into a team, each team member can understand what other team members need and can communicate much more efficiently. This is also where experience makes a difference. Not only are experts able to recognize a target more quickly, they also have more confidence in calling whether or not there is a contact. A novice may suspect a contact and try to track it for a long time before they are confident enough to bring it to the others' attention, and therefore slow down communication within the team. On the ship, experienced sensor operators know exactly what information the SCS needs and they can communicate the information in a much more efficient manner.

Externally, there are many issues associated with platforms not sharing a 'hot' contact immediately. This leads to overlapping and sometimes misleading information. Both SMEs welcome the idea of sharing low level information (e.g., raw acoustic data) in an almost forced manner as proposed by the NUW technology demonstration project. Two concerns that they raised were that sharing of information should not mean overlapping in any way, and any useless information should not clutter their pictures. Finally, novice operators face the common problem of not being able to distinguish the important and relevant information from all the communication going on internally and externally.

3.2.5 Monitoring Sonobuoys

When asked what is the most physically and mentally demanding aspect of their job, both operators reported it to be manipulating and retrieving information from the sonobuoys. With the Sonobuoy Processing System (SPS) on ships, the SCS noted that there are 21 manual steps to bring up a particular sonobuoy and locate its bearing information. For an aircraft, it is an on-going process to re-establish a reference system of where the sonobuoys are. To complicate things even more, sonobuoys can also be shared by different platforms on a mission. Although sonobuoys are generally split up across platforms prior to a mission, confusions often arise still about which sonobuoys are being used by which platform, and the more important information of which sonobuoys are hot.

3.2.6 Audio vs. Visual Interfaces

The interviews found that audio and visual components are simultaneously used in sonar tasks. The operator will put on their headphones and listen to sounds as much as possible during their mission. The only times they are not monitoring by audio means is when they have to listen to or talk on other communication channels. It is not uncommon for a sonar operator to aurally pick up a contact that never shows up on the visual display because the receiver did not maintain the contact long enough. While the operators may hear such a contact on the audio channel, they have little means of further investigating it without seeing it on display. Operators also tend to 'hear' a signal of interest before they could 'see' it on the visual display. This indicates that the audio interface acts as an alert for the operator to locate their contact on the visual display.

The interview with the SCS from ship identified several plausible ideas for integrating visual and audio modalities better. Currently the operator can select to listen to a specific beam or channel of sonar data, but this selection needs to be manually input. An idea is to align what they are looking at to what they are listening to automatically. An immersive environment may also be helpful if it provides a sense of direction where the contact is coming from. However careful considerations are necessary in designs involving immersive technology to avoid confusion over multiple sensors.

3.2.7 Other Interface Ideas

Interactive components were generally welcomed by the operators. The current interactive components mostly involve manual input of selection, settings of displays, and updating a contact. The SMEs saw much room for improvement for these selection and inputting device. However, they had not given much thought to the possibility of more flexibility in terms of manipulating the information space. Better use of colors was repeatedly stressed by operators as a key area for screen improvement. The concept of color coded bearing information is already implemented in the Canadian Force's post-analysis stations for trials and missions and has been found effective. Automation tools for any of the tasks would be nice, given that they work properly and realistically. The SMEs found that these new tools were often not practical, such as a target motion analysis

(TMA) tool requiring the target to be stable. An up-to-date sonar signature database would be very helpful, but the SMEs were doubtful about implementing such a huge and dynamic database on their platforms.

Chapter 4
Decision Making by Sonar Operators

While monitoring complex and continuously updated data, sonar operators are constantly picking out signals from a pool of background noise. These signals can originate from friendly, neutral, or enemy forces, all immersed in the huge amount of ambient noise present in the environment. The sonar operator's tasks are to detect, classify, localize and track any potential or known targets. Figure 1 below is a typical visual display with which sonar operators perform their primary tasks. All white pixels shown indicate some kind of sound sensed by the sonar equipment. As can be seen in the figure, the level of irrelevant data, or noise, is very high. The white lines shown on the displays signify noticeable patterns and are the primary concern of the sonar operators. Furthermore, how the operator goes about performing the tasks varies according to the platform and the type of sonar employed. Different sonar systems have different displays and data presentation formats, which makes integrating information very difficult. The limited tools provided by the sonar interface means that these tasks are done in a highly internalized manner, involving numerous mental processes at the skills, rules and knowledge levels described by Rasmussen (1983).

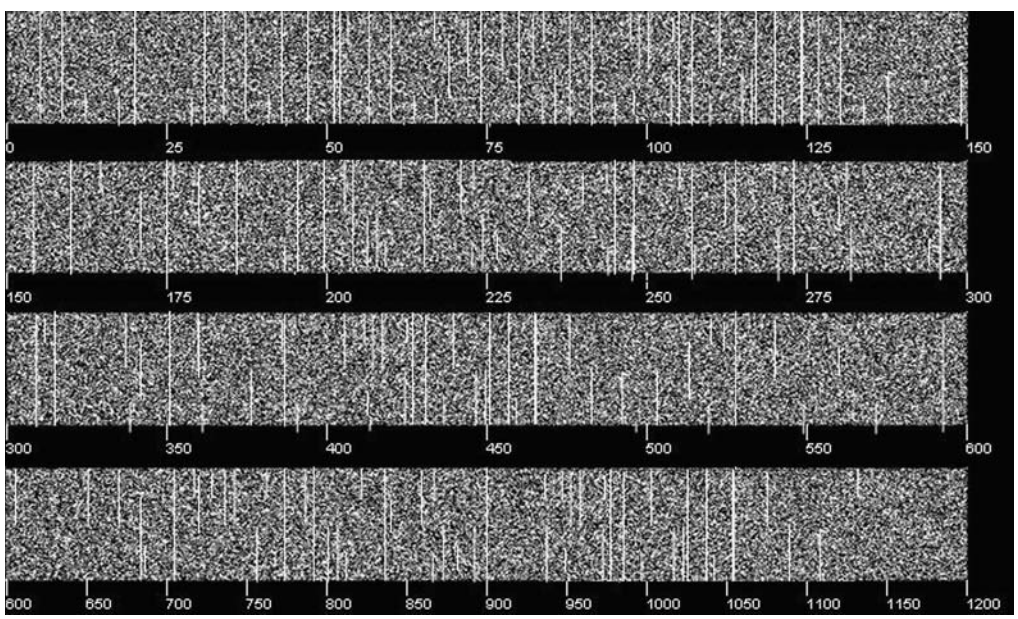


Figure 4-1: Frequency/time/intensity display depicting sonar lines (courtesy of Human*systems*® Inc.)

A thorough understanding of the decision making process can identify the development and use of expertise in sonar operators and take advantage of this knowledge in designing decision support tools, including displays and automation tools, for sonar systems. The objective of this chapter is to provide a stand-alone analysis of the decision making process of sonar operators which, besides supporting the design process of this project, may also benefit future research and development on sonar systems. Findings from SME interviews, outlined in the previous chapter, were examined using an information processing approach based on the model presented by Wickens and Hollands (2002). This model (see Figure 4-2) depicts information processing as a set of sequential stages in the mind. The information in the environment must be first sensed and registered by the human sensory system, and then the information may be perceived and recognized. Long term and short term memory then both interact with the information in order to arrive at certain decisions. The following sections discuss how each component of the information processing model can be applied to certain aspects of the sonar tasks and how this understanding may be critical in designing interfaces for sonar systems.

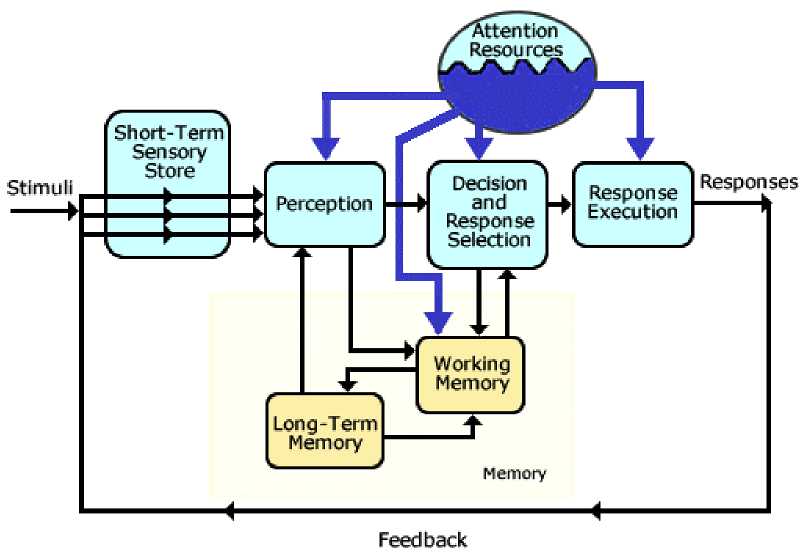


Figure 4-2: Human Information Processing Model (Wickens and Hollands, 2002).

4.1 Cues and Perception

Decision makers must seek cues from the environment in the form of sensory information. These cues are often processed through uncertainty and hence may be ambiguous or interpreted incorrectly. In the case of a sonar operator, two aspects of perception are involved: visual and aural perception. The operator visually searches for lines of interest in the sonar display and simultaneously listens to all sounds received by the sonar sensors. Ideally, the target of interest emits sounds in an identifiable pattern, which translates into a pattern of lines on the visual display, and the operator will recognize such patterns in a straightforward manner. However, there is a high level of uncertainty present due to the large amounts of background noise that can easily drown out the sounds produced by a quiet target such as a submarine.

Aural perception was identified in the SME interviews (see Section 3.2.6) as a means of alerting the sonar operator to the presence of a potential contact, which may be further located and investigated on the visual display. This is due to the fact that the human ears have an advantage of short integration time compared to the time required for electronic integration for displaying sonar information visually. However, there is no means of reviewing aural history, as no recordings are available, possibly due to the overwhelmingly large amount of acoustic data that would need to be stored. Moreover, while the operators may hear a contact on the audio channel, they have little means of further investigating such a contact without seeing it on the display. Recognition and identification of the contact of interest cannot be done without investigation performed on the visual display.

To distinguish a potential contact of interest from the background noise, the salience of a cue, or its attention-attracting properties, is of great value. The first visual cue that a sonar operator looks for in their display is what does not fit in. This could be a line forming over time at the same frequency, lines forming at a set of known frequencies, etc. The salience of such a cue will be enhanced by stimulus properties such as highlighting, abrupt onsets of intensity or motion, and spatial positions near the front or top of a visual display. Simply put, a potential target should appear as a visible change of the pattern on the display. Since the sonar systems on board a navy platform are never a single sensor, condensing and summarizing data into a single and separate display makes the processing of relevant cues much easier for the operator.

Salience of information can also be represented by the use of colours. Better use of colours is repeatedly stressed by operators as a key area for screen improvement. The concept of colour coded bearing information has been implemented in the Canadian Force's post-analysis stations for trials and mission, and it has been found to be very effective.

A relevant human factors concern relating to the role of perception in seeking cues is the decrease in vigilance level over time in sonar watchstanding. The long duration of shifts, the monotonic nature of looking at displays and, most of all, the low probability of detecting signals from true militarily significant targets are all factors that make operators' attention wane. However, maintaining a high level of vigilance for the occurrence of such signals is extremely important (Mackie and Wylie, 1994). Providing performance feedback for the mission would improve the operator's vigilance, but such feedback is not available because the presence of targets and duration of activities are not known (Mackie et al, 1994).

4.2 Situation Awareness

The cues that are selected and perceived form the basis of an understanding of the situation, or situation awareness (Endsley, 1995), from which an effective choice can be made. Studies show that good decision makers take longer in understanding the situation, even though they may select and execute the choice rapidly (Orasanu & Fischer, 1997). The quality of this understanding is influenced by the limitations of the decision maker's cognitive resources. As an initial limitation, not all information provided by the environment can be perceived and processed by the operators. The role of long-term memory in providing background knowledge also affects the operator's capability to establish possible hypotheses about the situation. Finally, the operator depends on their working memory to update and revise hypotheses based on new information.

In sonar watchstanding, successful operators maintain a situation awareness that goes beyond assessing the current situation. In fact, expert sonar operators consistently report an anticipation of future events given the current understanding of the environment. This is an excellent example of what Endsley (2000) defined as the highest and most effective level of situation awareness. Operators, using their knowledge and experience, may predict the location or actions of a target and thus be able to make more effective and timely decisions. Successful sonar operators should always be anticipating what will happen next. For example, they should anticipate events based on the possible tactics a submarine could employ and compare the current situation to the anticipated picture. Any discrepancies between the anticipated and current pictures should alarm the operator as an unusual event.

Furthermore, in the networked underwater environment, individual situation awareness must lead to team situation awareness. Team situation awareness enables operators to share the same knowledge and anticipation of events in order to communicate and collaborate effectively. Team situation awareness requires that operators have a grasp of what information they are missing, what information may be found in other operators' understanding, and how information can be shared between the team members. Therefore, team situation awareness is different from individual awareness, which only depends on a single operator's understanding of the situation. Therefore, communication and information displays are critical contributors to team situation awareness.

4.3 Working Memory

In the sonar operator's decision making process, memory is used in a variety of ways. First and foremost, working memory, or short-term memory, is the workbench for all decision making processes. Working memory is temporary, demanding attention for the short-term storage of information in the mind. New information is held here until it is utilized or until it is encoded into long-term memory, which is used to store a more permanent knowledge about the world and how to do things (Wickens and Hollands, 2002).

In sonar tasks, the use of working memory is evident as operators recall recent events occurring on a particular sonar trace to match with the current signals they are perceiving. Sound patterns are observed over time to recognize a new contact or to track a known contact. There are also occasions when relevant knowledge for a particular mission is retrieved from long-term memory and put to use in working memory to process certain mental representations. For example, the knowledge about a particular submarine may be used to compare and evaluate the current target's identity. Situation awareness, as described earlier, also requires the operator to hold information about the current state of the world in order to maintain their awareness.

With the limited capacity and duration of working memory, the cognitive activities to transfer and retain information are highly vulnerable to disruption, especially when attentional resources are diverted to other mental activities (Wickens and Hollands, 2002). In the case of sonar tasks, operators are often engaged in communication using various channels, as well as logging data on paper. To avoid loss of information due to interference and confusion, displays should be designed to reduce workload required on working memory. The display should also represent information in an organized way to enhance the effectiveness of working memory. For example, factors that increase the discriminability of display objects will help the performance of working memory. This means that information must be grouped in a more meaningful way, and a clear history of contacts must be incorporated into the display.

4.4 The Role of Long-term Memory

As mentioned earlier, cue salience is important in seeking and processing information from the environment. However, besides the physical features for perception, another form of cue comes from the operator's own mind: the expectation an operator constructs using long term memory. A correct expectation enables a higher level of situation awareness, as previously discussed. Overall, expectations help operators to make a decision more quickly. In a case where there are not enough cues for hypothesis forming, expectations also help to provide suggestions for investigations.

Prior to a mission, operators usually receive a package of threat information; this information allows operators to anticipate what could happen and what to look for. The operator can use a sonar database to determine what the target's sound signatures may look like on grams. This sort of information helps them to better recognize the patterns during the actual mission. Over time, such information may be stored in the operator's long-term memory and retrieved for various purposes during missions.

Underwater warfare is known as a thinking (wo)man's game, hence the knowledge about tactics is particularly useful in sonar tasks. Different countries own different models of submarines, which generate different patterns of noises. An experienced operator may also learn which equipment and weapons are on board a particular class of submarine. In addition, different countries employ their own doctrine of tactics, which enables an operator to anticipate the possible actions of a target: what likely route the submarine would take, how close the submarine would attempt to approach before firing a torpedo, etc. All this knowledge is stored, through training and experience building, in long-term memory. The frequent utilization of long-term memory is the primary reason for developing expertise in sonar watchstanding.

Learning and training are the best means to build the knowledge required for these tasks. At the same time, long-term memory can be facilitated by providing relevant information to the sonar operators on the job, such as integrating an electronic database about submarine sonar signatures into the system. Such tools must present information to the user in a timely manner, but without cluttering the perception space, as that may end up putting more mental demand on the operator. The database should be complete and up-to-date, while still allowing the user to manoeuvre between different levels of detail.

4.5 Mental Model

A successful sonar operator requires a lot of expertise built from both training and experience. The extensive use of memory demands that the operators have efficient methods for representing and working with both long-term and short-term memory. One particularly useful approach found among the operators is the use of a mental model. In fact, a significant difference found between experts and novices is their ability to develop an effective mental model.

Carroll and Olson (1987) defined a mental model as a mental structure that reflects the user's understanding of a system. In particular, they noted that a mental model requires sufficient knowledge about the system to allow the user to mentally try out actions before choosing one. In sonar watchstanding, the operator builds a mental picture of the environment as well as the objects within the environment that may be relevant. Their understanding of the overall situation is important for quickly making decisions concerning the presence of a target or for monitoring a particular target's activities.

For an individual operator, mental picture building integrates various kinds of information. The first type of information is basically the questions of 'what is out there and where is it.' At a given instant, the operator needs to know as much information as possible about the known contacts in the area, and the location and activities of other navy ships in the area. Known contacts may include other military assets in the area, such as other ships and aircrafts on the same mission, fishing boats, merchant ships, and military vessels of neutral or friendly forces. The operators need to know where they are physically located in relation to all these known or possible contacts in order to track them, to rule out possibilities when a potential contact is found, and to share useful information with other platforms.

Currently, the type of mental picture that focuses on known contacts at the present time is supported by the use of a tactical display. The tactical display shows the most current location of contacts, drawn in symbology to indicate their classification (i.e., merchant ships, own navy ships, submarines, etc.), and is contributed to by all involved operators. However, the mental picture an operator uses is much more complicated than what is seen on the tactical display. Instead of a two-dimensional view shown on the tactical display, the operator uses a mental model of three-dimensional space, in real time, with non-symbology images. The mental model also contains background, supporting information. A particular useful element of background information is the knowledge of the oceanography. The operator may mentally picture the sea bottom contour and recall the presence of a sea mountain that a submarine may try to hide behind. Incoming sonar sensor information is also continuously integrated mentally to help picture the location and actions of the potential target. According to SMEs, knowledge about the target and its intentions improves the scope and correctness of their anticipation of future events. Therefore, it seems safe to assume that when an operator has a good mental picture, they are more aware of the overall situation and make better and timelier decisions.

4.6 Communication within a Team

Within a group of sonar operators, the purpose of communication is to share information to build the team situation awareness, as described earlier. However, there are crew members who are not sonar operators in the ship's operating room, or onboard a MPA. Occasionally, non-acoustic sensors provide significant information to the sonar operators, and sonar operators have to maintain communications with the command level in order to achieve the overall mission goal. This inherited structure of communication is further complicated by rules and practices that are commonly found in military platforms. The issues of team communication are therefore included in the project's modelling analysis, since naval norms, values and policies are all taken into account in the modelling effort.

One important requirement for communication effectiveness is the formation of a 'team'. SMEs interviewed brought up the point that a *team* is much more effective in communication than a *group*, and team formation depends on individual experiences in their current roles, and shared experiences as a crew. Wickens, Gorden, Lee, and Liu (2003) defined groups as "aggregations of people who have limited role differentiation, and their decision making or task performance depends primarily on individual contributions." A team, on the other hand, is a group of people with "complementary skills and specific roles or functions, who interact dynamically toward a common purpose or goal for which they hold themselves mutually accountable" (Wickens et al, 2003). Given this definition, it is not difficult to understand why SMEs stress the importance of forming a team in their work environment. While each team member has a specific role, the nature of their work is highly interdependent.

At times, the high workload and stress caused by a tactical situation may reduce the ability of team members to communicate effectively, which can undermine team performance. Trust and confidence in the other team members is important. Equally important is that each operator has the confidence in her/himself that is necessary to accurately judge what information should be communicated to other team members. Team cohesiveness and the team’s developed ability to provide support for team members are keys to successful missions.

Chapter 5
Work Domain Analysis

This project concerns the design of an interface for the sonobuoy system onboard a maritime patrol aircraft (MPA). In this work environment, the MPA generally has one acoustic (sonar) operator who manages a network of distributed resources (e.g., sonobuoys) to gather sonar data that would be transformed into meaningful tactical information. This is in part an intentional system (i.e., a system driven by the intentions of its users, rules and practices) because the work environment is constrained by naval values and regulations, availability of resources, and tactical considerations. However, the system is also bound by the laws of nature, as any sonar operations would be (e.g., principles of underwater sound). The scope and complexity of this environment makes an interesting case for conducting a work domain analysis (WDA). This chapter presents the WDA from its scope and boundary to the resulting abstraction hierarchy and its means-end and causal links.

5.1 Defining the System and its Boundary

The term system here refers to an environment that not only consists of the physical machine or space that one is designing for, but also elements which the end user must interact with or manipulate. Considering the nature of the sonobuoy operator's work on a MPA, a loosely bounded system is constructed to include the sonobuoys, contacts (e.g., enemy submarines), and the natural environment in which the mission operates. Though an operator has no control of the natural environment, it is necessary to include it because the transmission of acoustic data and tactical decisions made in underwater warfare are heavily influenced by environmental factors.

Results from SME interviews identified a list of common tasks carried out by the sonar operators on a MPA (Table 5-1). By examining this list, it is evident that a sonobuoy operator has two major functions on a mission: to manage the sonobuoys, including deploying and monitoring sonobuoys at sea, and to handle and interpret sonar data in support of their tactical situation awareness. While the two functions share environmental and social constraints, and are dependent on the success and capability of each other, each of them has unique requirements and processes to fulfill. Therefore, the work domain analysis begins by defining two separate domains: the domain of sonobuoys management and the domain of tactical situation awareness.

Table 5-1: Mapping of Tasks to Work Domains

Work Domains / Tasks	Management of sonobuoys	Tactical situation awareness
Configure sonobuoys	x	
Deploy sonobuoys	x	
Maintain and track the physical locations of sonobuoys	x	
Monitor the condition of status of sonobuoys	x	
Patrol/Surveillance		x
Search/Detect potential targets		x
Track known contacts		x

Using multiple domains to describe a system has been done in various settings before. Burns and Hajdukiewicz (2004) have noted that when dealing with a large domain in which the users may not have complete control, it is easiest to break the model down into parts that reflect the distinct regions. In healthcare applications, Chow (2004) proposed two separate work domains to address patient risk management and resource management in her work on emergency ambulance dispatching. Enomoto (2006) also applied the same concept of modeling patient's own health and the medical resources available separately in her two-part WDA of decision support tools for nurses. In both studies, operators of the system have no control over the patient's condition, and the processes are affected by external factors presented in the environment. In military settings, Burns, Bryant, and Chalmers (2005) attributed naval command and control with characteristics of an open boundary system with multiple (but not shared) purposes. Their WDA on command and control in the Halifax class frigates were a three-part model of frigate, environment and contact; of all three parts only the frigate is under the control of the operator. Nonetheless, none of these parts can be entirely independent of the others.

The problem space presented in this work has obvious resemblance to that of the frigate command and control problem faced by Burns et al (2005). Adherence to naval values, rules and practices, sensor capabilities and environmental conditions are all concerns of both projects. However, the natural environment is not modeled separately, but rather becomes part of both models in the analysis to follow. This is done to emphasize that the operator has no control of the natural environment and the environment itself has no functional purposes in this work. The domain of sonobuoy management and the domain of tactical situation awareness are in fact distinguished by the nature of the tasks performed by the operators. One is to control and manipulate physical resources while the other one is to support the tactical aspect of decision making.

5.2 The Domain of Sonobuoy Management

An AH describes how a system works at functional levels (Functional Purpose, Abstract Principle, General Process, Physical Function, and Physical Form); and a part-whole hierarchy breaks the system down into subsystems and components, resulting in a decomposition hierarchy, or DH (Burns and Hajdukiewicz, 2004). The domain of sonobuoy management identifies three levels of decomposition: the system that includes the natural environment in which a mission operates and all the sonobuoys it encompasses; sonobuoys, divided up by their deployment groups (e.g., the first round of deployed group versus the second round of deployed group); and, at the finest level of decomposition, individual sonobuoys. A work domain model (WDM) combines the AH and the DH to yield a complete description of the work domain. The WDM for the domain of sonobuoy management is shown in Figure 5-1: A work domain model for the domain of sonobuoy management. This model shows the part-whole decomposition from left to right, and the abstraction hierarchy from top to bottom. The following subsection explains each abstraction level in more detail.

Work Domain Model: Domain of Sonobuoys Management

	Physical and social environment	Sonobuoys network	Individual sonobuoys
Functional Purpose	• Maximize chance of success in sonar operation • Meet naval values	• Maximize sonar signal detection ability over a given area • Minimize number of sonobuoys deployed	
Abstract Principle	• Law of Entropy • Conservation of Mass • Conservation of Energy • Military principles for tactics and intelligence • Balance and flow of authority • Balance and flow of economic values	• Specific tactics of different sonobuoy network configurations	• Balance and flow of resource (sonobuoys) • Specific tactics of different sonobuoy configurations
General Process	• Air processes • Water processes • Processes of confirming and operating within limits	• Processes of configuring sonobuoy network • Processes of positioning aircraft	• Processes of configuring individual sonobuoys • Processes of physically deploying sonobuoys • Processes of positioning aircraft
Physical Function	• Guidelines provided by ROEs • Air • Water • Ocean floor	• Description and capability of the sonobuoy network • Capabilities of different sonobuoy network configurations	• Policy/instructions provided for sensor use • Description and capability of individual sonobuoys
Physical Form	• Location of ROE boundaries • Atmospheric pressure, wind speed and direction, air temperature • Water temperature, salinity, speed, pressure, depth and current • Geographical shape and land type of ocean floor	• Location of sonobuoy network • Location of sonobuoy network with respect to aircraft	• Type, class, label, cost • Physical shape, size, color, visible marking • Location of individual sonobuoy • Location of sonobuoy w.r.t sonobuoy network • Location of sonobuoy w.r.t. aircraft • Condition (battery, signal strength) • Operational status (on/off, hot/cold, etc) • Settings (frequency, depth, etc)

Figure 5-1: A work domain model for the domain of sonobuoy management

5.2.1 The Abstraction Hierarchy

5.2.1.1 Functional Purpose

The role of sonobuoy management in a mission such as underwater warfare is to ensure that sonobuoys are configured and deployed in a way that they can be most effective in supporting the mission objectives. Simply put, the ultimate purpose in managing sonobuoys is to ensure a successful mission, hence the functional purpose: *to maximize chance of success in sonar operation*. As a deployed group of sonobuoys, how they are configured and the patterns they are deployed with strongly impact the capabilities of the sonobuoy network as a whole. Therefore, the same idea of maximizing chance of success in sonar operation is translated as: *to maximize sonar signal detection ability over the specified area* at the second level of part-whole decomposition, i.e., the sonobuoy network.

From the social-economic side of the system, *meeting naval values* is a functional purpose that encapsulates many of the principles involved. These values take into consideration economics, national and international laws, naval norms, etc., and provide important constraints to the domain. For example, if cost is not taken into account, the objective of maximizing sonar detection would lead to deploying an excessive number of sonobuoys in a given area to minimize (completely if possible) the chance of not detecting a potential contact. In reality, the cost of sonobuoys and limited storage on a MPA restricts the number of sonobuoys one can deploy. This leads to the functional purpose of *minimizing the number of sonobuoys deployed* as a countering purpose to maximizing sonar signal detection ability over the given area, at the part-whole level of sonobuoy network.

5.2.1.2 Abstract Principle

Physics principles (e.g., *conservation of mass and energy* and the *law of entropy*) apply to this work domain because a physical environment is included in the system. These principles have specific implications to how sonobuoys are expected to behave in a natural environment. The law of entropy, for example, describes the natural tendency for matters to achieve disorder or to disintegrate, which points out the fundamental need to be monitoring sonobuoys at sea.

The *balancing of resource* follows the conservation of mass principle to describe the amount of resource stored or remained on the MPA ($R_{stored} = R_{in} - R_{out}$). This restricts the use of resources and is particular important in this system because sonobuoys in general are not designed to allow recycling.

In the previous subsection, meeting naval values is stated as a functional purpose of the work domain, and an example applying *economic principles* was given to explain the need to have a purpose of minimizing the number of sonobuoys deployed. Economics principles that govern such decisions include minimizing cost with regard to a given goal, maximizing utility for a given level of cost or input, and evaluating the opportunity cost associated with applying resources for a particular situation. To continue on with the same example, the operator must decide if it is justifiable to use all sonobuoys at once to ensure success, when half the number could achieve an acceptable, but not one hundred percent certain, level of performance.

Economic values can flow from training and policy to actual military operation; it can also flow from a leader or a commander to the rest of the task force. The *flow of economic values* thus provides constraints to decisions regarding the use of resource beyond reasoning of resource availability. Furthermore, authority can be granted to or taken away from a position given the task and situation. The responsibility for each position is clear, though it may change from time to time. Commands can be given at a very high level and move through the hierarchy of personnel to be carried out. This creates a *flow of authority* that affects each specific process within the system. It is important to recognize where the authority is at in a given situation and understand that it cannot exist simultaneously at multiple positions.

Finally, military principles provide strict guidance to the actions of Canadian Forces, including when and how sensors should be deployed. Such principles make use of doctrine, geographical and environmental conditions, etc, to gather intelligence and determine appropriate tactics. At lower levels of decomposition, the domain is interested in understanding the specific tactics involved with various configurations of individual sonobuoys and the sonobuoy network.

5.2.1.3 General Process

This level explains the processes that take place within this domain, and how the laws and principles found at the AF level are fulfilled through these processes. Relating back to the physics principles are the *physical processes of air and water*, including their movements and characteristics, which often interfere with sonobuoy deployment and thus influence the configuration. Deployments are generally according to plans made prior to the mission, but are often modified on the spot due to tactical and/or environmental updates. To differentiate the use of sonobuoys individually or as a group, the *process of configuring sonobuoys* is stated twice at this abstraction level: individually to obtain best possible data, and as a group to support tactical plans. The *positioning of aircraft* is a process that directly affects how close sonobuoys are deployed to their planned and desired locations. The position of aircraft in relation to the sonobuoys may also affect how sonobuoys at sea are monitored.

On the other hand, given the strong naval values in the work environment, sonar operators are also constantly engaged in the *process of confirming and operating within limits*. These limits are social, economical constraints based on the naval principles, rules and practices. The actual limits may also shift depending on the operator's own level of authority in the mission.

5.2.1.4 Physical Function

Physical function describes the various components of the domain and their capabilities. The most obvious components in this domain are the sonobuoys. For *individual sonobuoys*, each one's *ability to sense and transmit data*, and the *conditions in which they are able to operate* are of interest. It is also important to note the distinct capabilities that different configurations allow. According to a SME, three common models of tactical sonobuoys used by the Canadian Forces are:

- DIFAR (Directional Passive) sonobuoy AN/SSQ-53D: optimized for low frequency detection, qualified for operation in Sea State Six., and offering additional operating depth for improved performance in the littoral environment.
- DICASS sonobuoys AN/SSQ-62D and AN/SSQ-62E: designed specifically for aircraft launch, and for the purposes of detecting, tracking, and localizing submarines. They both employ active sonar methods, and allow certain commands via UHF transmission from an ASW Aircraft. These sonobuoys are capable of providing both the range and bearing information of a pursued submarine. Both DICASS sonobuoys have selections available for depth and radio frequency (RF) Channel via Electronic Function Set for pre-deployment configuration. The 62E model also enables selections of depth, RF Channel, and acoustic channel via Command Function Set.

At the network level, *sonobuoy groups* also vary in their combined ability to sense, localise, and track contacts. For example, an extended, straight line of sonobuoys is often useful when the tactical information already reveals that the target of interest is heading a specific direction, and one would like to detect it before it moves past a certain point.

The patterns of sonobuoy deployments are also dependent on *the condition and capability of signal transmission (in both sea and air)* and the environment's *ability to facilitate or restrict the movement of aircraft and sonobuoys*. The ocean floor, for instance, can block the transmission of acoustic signals, as well as provide hideouts to the adversary.

The need to examine capabilities provided by the environment leads to the use of bathythermal buoys, which are deployed to measure water temperature versus depth. A bathythermal buoy relays, by VHF (very high frequency) FM radio transmissions, water temperature profile information measured by a descending probe of constant velocity. The information provided by a bathythermal buoy allows an antisubmarine sensor operator to understand the underwater acoustic environment and predict where and how an adversary submarine may be operating. While the sensors themselves are not included in the domain boundary, the information they are able to provide are captured via description of the natural environment. Finally, there are policy and instructions provided for the use of acoustic sensors and sonobuoys, and general guidelines such as *Rules of Engagement (ROEs)* that describe the capabilities and limitations of military force in different situations.

5.2.1.5 Physical Form

At the lowest level of abstraction, physical form describes the physical quality of the various components in the work domain. In the natural environment, it depicts the *characteristics of water and air, such as speed, pressure, temperature, water salinity and depth*. The *geographical shape and land type of the ocean bottom* are also included. As the physical environment for sonar operation is also bound by national and international regulations, the *physical locations of ROE boundaries* are also drawn for the given task or operation.

The physical form items pertaining to the sonobuoys are their *location, physical appearance, operational status, class, type, condition, cost and various settings*. Some of these are straightforward. For example, the class (passive/active/bathythermal) and type (specific model) of the sonobuoy are all required data that are known prior to deployment. The physical appearance of a sonobuoy can also be defined by its *shape, size, color and any other marking*.

Other variables may be more complex: locations of sonobuoys are to be sensed and relayed back from sonobuoys to the control platform. A *sonobuoy location* can be specified in multiple ways: location of sonobuoys on an individual level can be specified as an exocentric, global position, as a position relative to the sonobuoy network, or as a position relative to the aircraft. The sonobuoy network itself can be specified with a global reference or relative to the aircraft.

The *operational status* of sonobuoys should indicate whether a sonobuoy is stored, deployed and in use, or discarded. It may take 3 minutes or more for the sonobuoy to start sensing after being released into the water, and such data may also be informative to the operator. Also of relevance to operational status is the number of contacts held by the buoy at the given time. Other useful data for an operator may include *battery condition, acoustic signal strength, radio signal strength for transmission, and monetary cost*. As most sonobuoys today are equipped with settings, the choices for each setting and the current choice are available prior to deployment and during the operation. The reader may access information about functions and settings of sonobuoys from manufacturer specifications.

5.2.2 Means-End and Causal Relationships

Abstraction hierarchy is a structure that reveals the relations between adjacent levels of abstractions in the work domain. In the domain of sonobuoy management, these relationships are analysed in terms of their means-end links, as depicted in Figure 5-2. These links describe "how" or "why" a level helps achieve the other level above or below it, respectively. By going down and going up the AH via the means-end links, the how and why relationships between levels of abstraction are fairly transparent.

To give an example of how the means-end links can describe the relationships between AH levels, Figure 5-3 highlights a path that maps to a particular scenario. At the level of Physical Form, water temperature, direction and speed of current, depth, etc., affect the ability of a sonobuoy (described at the level of Physical Function) to sense data and maintain its own location. Consequently, at the level of general processes, configurations of individual sonobuoys are dependent on such information, and the processes must also follow the principles of military intelligence and tactics. Only when constrained and supported by the abstract principles can the functional purpose of maximizing chance of success in sonar operation be addressed appropriately.

Another approach to understanding the AH is to look at an abstraction level on its own: each level should be able to provide a complete description of the work domain. Causal and action links, which show how processes and flows are connected to each other within a level, are especially useful at the General Process and Abstract Principle levels (Burns and Hajdukiewicz, 2004). Figure 5-2 presents the casual and action links of this work domain at the level of General Process. What this diagram depicts is one possible set of activities when opening up a process. The model itself includes multiple processes, and within each process multiple sets of activities may be incorporated. The intention here is not to produce a task analysis, but rather to show how functions relate to the activities performed by sonar operators, directly through the work domain description. This differs from, but has similar intentions to the work of Naikar, Moylan and Pearce (2006).

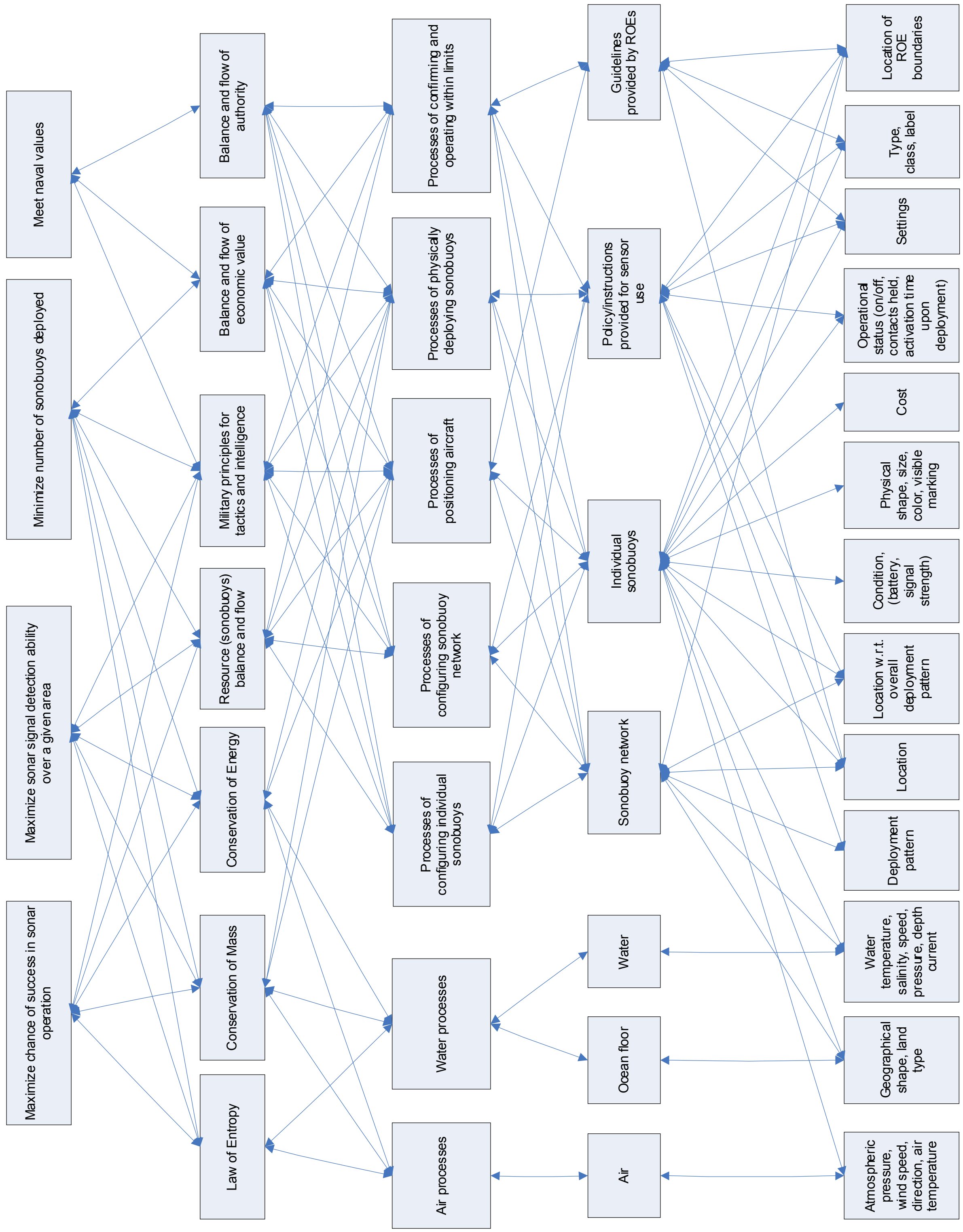


Figure 5-2: Abstraction hierarchy for the domain of sonobuoy management

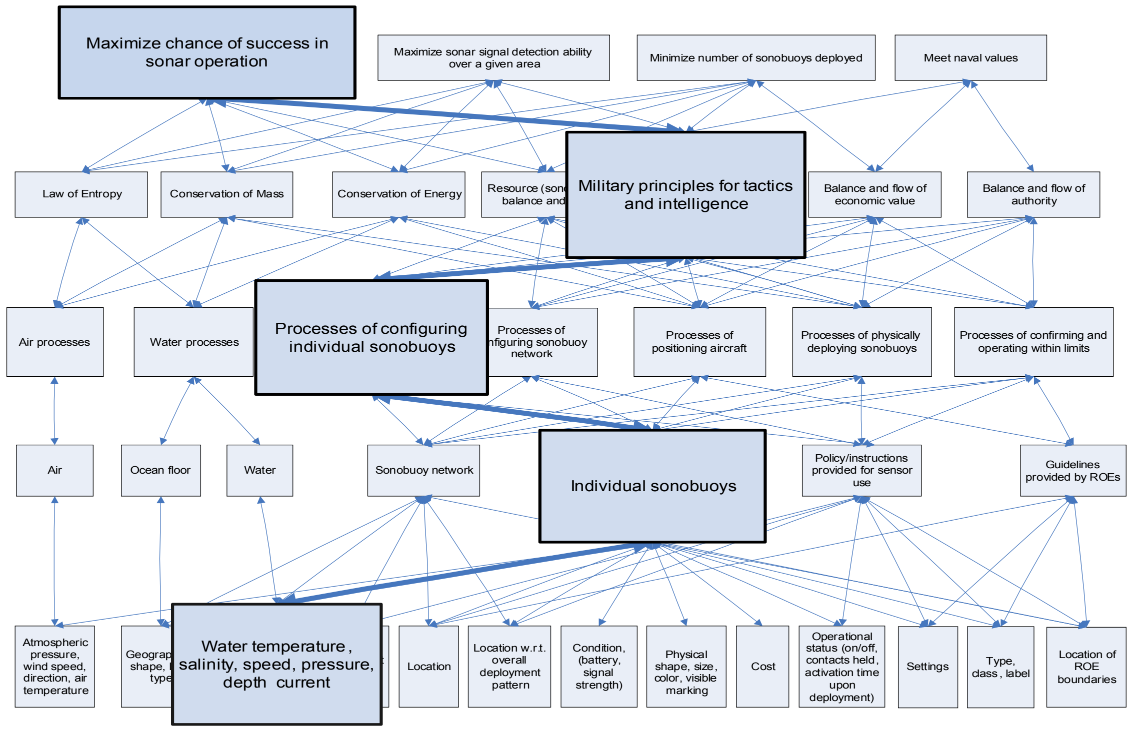


Figure 5-3: Scenario mapping example for the domain of sonobuoy management

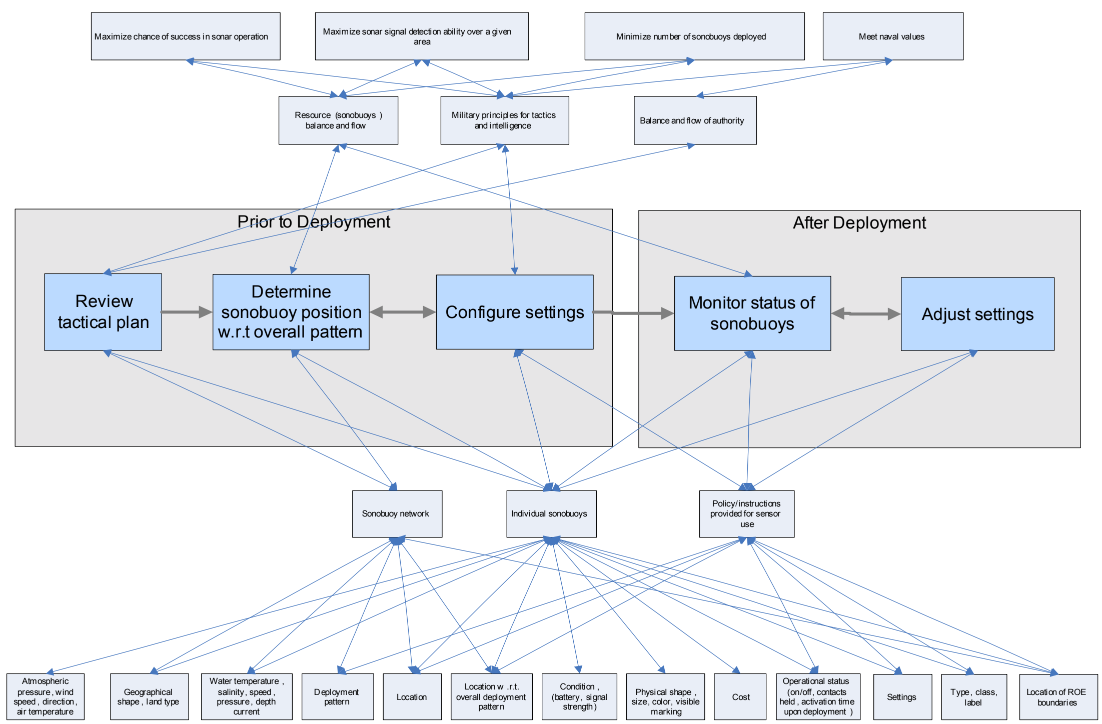


Figure 5-4: Causal links at the General Processes level in the domain of sonobuoy management

5.3 The Domain of Tactical Situation Awareness

The domain of tactical situation awareness describes how sonar operators monitor and analyse the acoustic data sensed in order to elevate their awareness of the tactical picture. Information processing is therefore a more prominent component of the domain, rather than the manipulation of physical entities as in the domain of sonobuoy management.

Once again, a WDM is created and includes a representation of the tactical picture built and the social and natural environment to which the tactical situation is closely coupled. Figure 5-5 on the next page shows the work domain model, presenting horizontally three different levels of decompositions from the overall system to the individual contacts, and vertically the five abstraction levels.

Work Domain Model: Domain of Tactical Situation Awareness

	Overall Environment	All Contacts	Individual Contact
Functional Purpose	• Meet naval values • Maximize completeness of tactical picture • Minimize time in establishing tactical information	• Maximize number of known contacts	• Maximize accuracy of individual contact information
Abstract Principle	• Conservation of Mass • Conservation of Energy • Balance and flow of authority • Probabilistic Balance of Success and Risk	• Military principles for tactics and intelligence • Principles of Geometry • Principles of Underwater Sound	
General Process	• Processes of aggregating environmental information • Processes of aggregating tactical intelligence • Processes of confirming and operating within limits	• Processes of detecting signals	• Processes of localising signal sources • Processes of tracking known signal sources
Physical Function	• Water characteristics • Ocean floor characteristics • Guidelines provided by ROEs	• Policy/instructions provided for monitoring, analysing, and recording acoustic data	• Signal source
Physical Form	• Water temperature, salinity, speed, pressure, depth and current • Geographical shape and land type of ocean floor • Location of ROE boundaries	• Locations of contacts (sources of signals)	• Main blast information • Feature data • Contact data • Track data • Time w.r.t. signal history • Classification

Figure 5-5: A WDM for the domain of tactical situation awareness

5.3.1 The Abstraction Hierarchy

5.3.1.1 Functional Purpose

Looking at the system level, the functional purposes include two countering purposes: *to maximize completeness of tactical domain*, and *to minimize time in establishing tactical information*. The first purpose refers to the primary objective of this domain, which is to create and maintain strong tactical situation awareness. However, most missions are time-critical and operators have to react to events very quickly, hence the second functional purpose. Together, these two purposes address the need to be both effective and efficient in performing relevant tasks. At the levels of subsystem (i.e., all contacts) and components (i.e., individual contacts), the functional purposes express the need *to maximize number of known contacts* and *to provide accurate tactical information about these contacts*, respectively. Additionally, the social-economic purpose of *meeting naval values* is also present to govern how operations are carried out in the given naval setting.

5.3.1.2 Abstract Principle

Since the natural and physical environment is again included in this domain, physics principles (e.g., *conservation of mass, conservation of energy,* etc.) apply here as well, revealing the impact of the environment on various processes. The *principles of underwater sound* are stated at the level of all the contacts because sonar tasks are founded on the understanding of sound transmission in the water. While the principles of underwater sound violate not the laws of conservation of mass and energy, sound can behave very differently in other mediums.

On the other side of the spectrum, the *probabilistic balance of success and risk* governs the overall domain. This is true because in any military operations, there is no guarantee of success without associate risk. For example, when invoking the use of active sonar to obtain more information about a target, the operator takes the risk of revealing own-platform location to a potential enemy. The *balance and flow of authority*, for the same reason given in the domain of sonobuoys management, hold true here. In addition, *military principles for tactics and intelligence* are thoroughly applied in sonar operations to detect, localize, and track potential and established contacts. *Mathematical principles of geometry* are extremely useful in this case for its use in localizing and tracking contacts.

5.3.1.3 General Processes

The major responsibilities of sonar operators are to carry out the *processes of detecting signals, localizing signal sources and tracking known contacts*. These processes are carried out at the level of individual contacts since such data needs to be obtained for each and every contact, if possible. To further assist in their sonar tasks, operators also *aggregate environmental information and aggregate tactical intelligence* based on information established at the level of individual contacts. As usual, all processes performed for a naval mission must be regulated and confirmed for operating within limits.

5.3.1.4 Physical function

The capabilities or strength of a *signal source* determines how difficult it is to obtain their information. The signal source's capabilities are also tightly coupled with the capabilities of *water and ocean floor*, which affect the behaviour of acoustic signals. In compliance with naval values, operators must also follow *policies and/or instructions provided for monitoring, analysing, recording and reporting acoustic data*.

5.3.1.5 Physical form

At the lowest level of abstraction hierarchy, the domain is given a physical description. This includes environmental factors such as *water temperature, salinity*, etc. The *geographical shape and location of ocean floor* are described, as well as the *location of the boundary of ROE*. To describe contacts on a high level, their *location and signal strength* are needed. Threat and contact information on signal sources of interest include *feature data, main blast information, contact data and track data*.

Features are distinct anomalous events or characteristics that produce a positive signal excess from the signal processing. They are the lowest level of data with which the operator interacts through either manual or automated tools. The main blast is the acoustic signal arriving at the sensor directly from the source, without reflection off any other surface or target. Main blast information may be used in tracking, interpretation and environmental assessments. Main blast information is similar to active feature data and in some cases could be treated as a feature but it is given its own type since its information content is handled differently. Main blast information is used to calculate possible target positions in bistatic sonar and can also be used to calculate transmission losses to help tune the sonar parameters.

When one or more features have a high probability of coming from a real object, which implies a maritime platform, a contact is formed. The designation of a contact involves a decision by an operator or automatic process (i.e., the confidence level that the source creating the features is a platform has risen above some threshold). The contact contains information on where the information originated from, unique contact identifiers, and speculation made by operators on what the target is, its status and whether it is hostile. Location estimates are also provided. The underlying features may not all be in agreement on location and the location estimate of the contact could be formed by a processing algorithm of the feature data. A sequence of features or contacts then form a track, whereby the system or operator can estimate kinematics attributes of the real world object, which can include the direction to the object, its position, its course, and/or its speed.

Acoustic data continuously arrive at a sonar operator's work space, and while all the above-mentioned data are constantly monitored, analyzed and acted on, it is important to keep track of *historical data and its given time*.

5.3.2 Means-End and Causal Relationships

The means-ends relationships between adjacent abstraction levels in the domain of tactical situation awareness are laid out in Figure 5-6. An example to map a scenario to the AH is shown in Figure 5-7. To ensure that maximum number of contacts are discovered and known, sonar operators are to carry out the signal detection task continuously. At the lower levels of abstraction, the environment plays an important role. The water characteristics, made up of temperature, layers, depth, salinity, etc., determine how sound is transmitted and detected according to the principles of underwater sound, and thus heavily influence the process of signal detection.

In particular, this scenario addresses the case of 'the afternoon effect,' the development of the diurnal thermocline resulting from a warming of the water column by the sun throughout the day. While the warming of water column leads to a focusing acoustic energy, it may also give rise to areas of acoustic 'shadow zones,' in which enemy submarine positioned in the zone would not be detectable by sonar (Urick, 1983). Given this scenario, the mapped path is able to explain this phenomenon, and ensures that proper information is provided for the sonar operator to determine if the 'afternoon effect' is influencing their performance.

Once again, as in Section 5.2.2, causal and action links between elements can be revealed by this work domain description. In Figure 5-8, the process of signal detection is expanded at the level of

General Processes, showing the work flow of an operator and the means-end links connecting each activity within the process to the abstraction levels above and below.

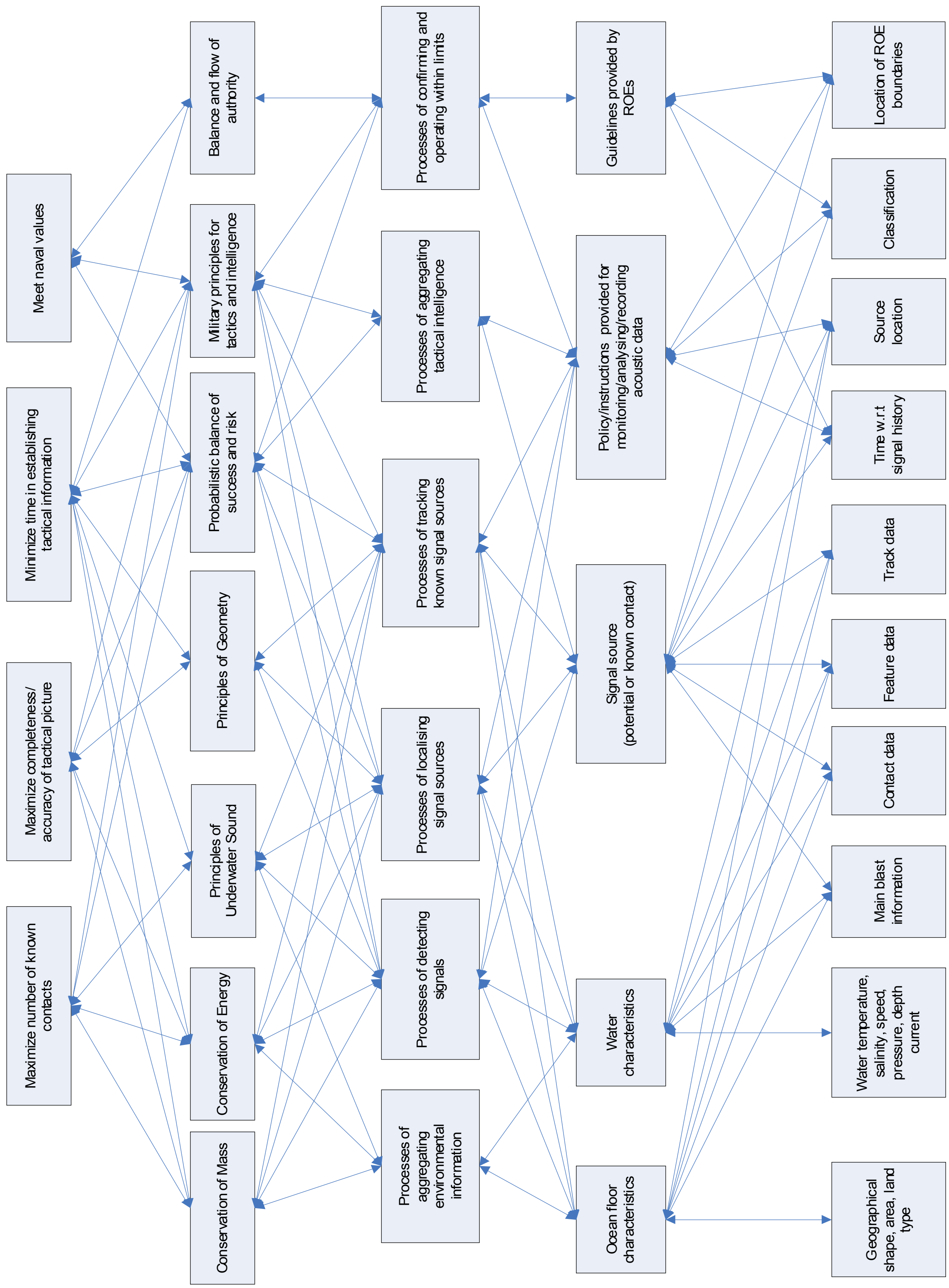


Figure 5-6: Abstraction hierarchy for the domain of tactical situation awareness

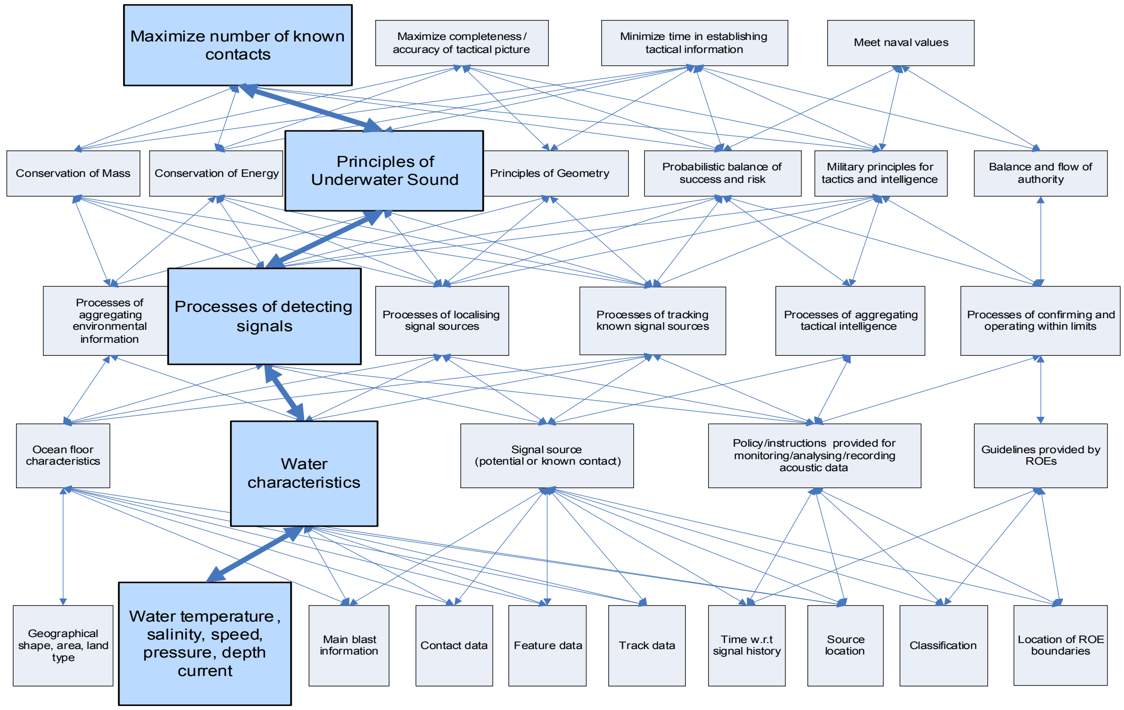


Figure 5-7: Scenario mapping in AH for the domain of tactical situation awareness

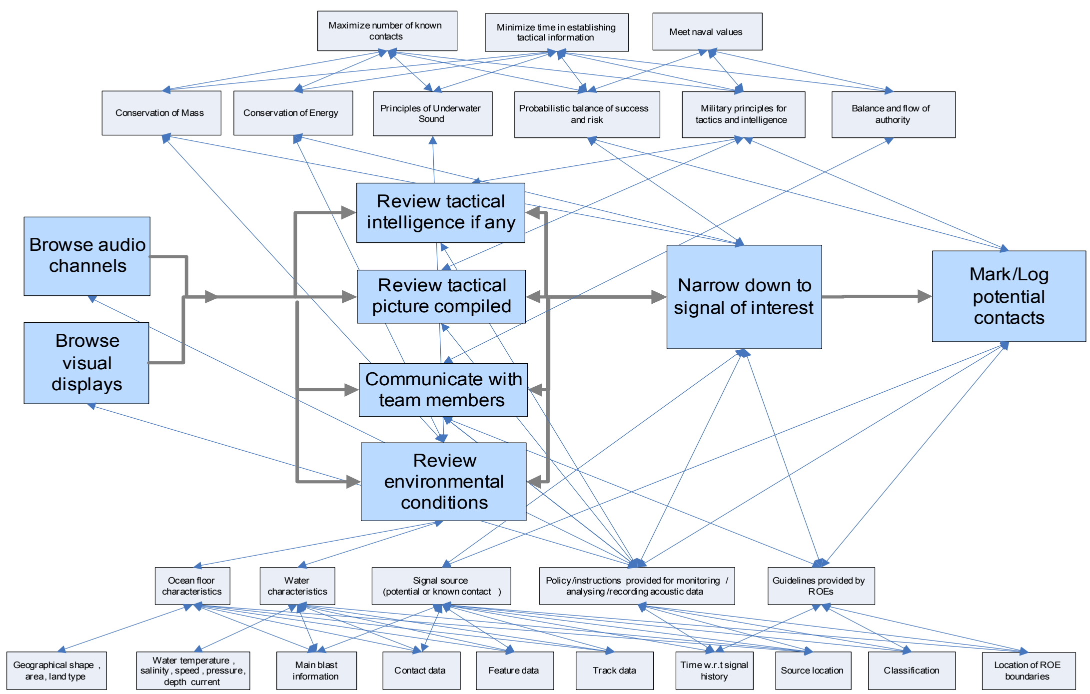


Figure 5-8: Causal links describing the process of detecting signals.

5.4 Domain Interactions

While two separate domains are defined for the problem space, the two domains have proven to be tightly coupled in carrying out sonar tasks through the sonobuoy system onboard a MPA. A typical mission may begin within the domain of sonobuoy management, where sonobuoys are to be deployed to maximize chance of success in detecting a contact. Once the sonobuoys are laid out properly, processes of sonar detection, localising and tracking may follow thereafter. However, it is possible to be applying changes of sonobuoy patterns on the spot and/or deploying additional sonobuoys due to changes in the tactical situation. Decisions formed in one domain have to support and take into consideration the elements of the other domain.

As is apparent in the two work domain models, the natural environment is shared by both domains. Information regarding weather, water characteristics and ocean floor layout are essential in determining tactics regarding sonar data collection. The behaviour of air and water directly affects the ability to detect or hide acoustic signals, and the knowledge of ocean floor geography is useful in anticipating where the adversary submarine could hide, how sound would reflect and travel in the water, etc. Therefore, the environmental condition, part of which is often sensed by the bathythermal sonobuoys, applies to sonobuoy settings and deployment pattern, as well as the actual processes of sonar information processing tasks.

A common purpose of the two domains is to meet naval values, which govern both domains through the flow of authority, flow of economic value, and other policies and procedures. Tactical information gathered prior to the mission sets the basis of sonobuoys management, which at the same time is affected by the tactical information gathered during the mission. A new update of tactical information gathered outside the realm of sonobuoys will also impact the decisions and actions regarding both domains.

It is important to recognize where the two domains overlap and how they interact with each other, because often it is amongst such interactions that unique circumstances arise that reveal important constraints on, and relationships between, the elements of the system.

Chapter 6
Ecological Interface Design for Sonobuoy System

6.1 Information Requirements

A Work Domain Analysis (WDA) provides information requirements, which lead to the generation of interface concepts. The work domain models enabled constraints, relationships between components, and means-end relationships across abstraction levels to be drawn within each domain. Table 6-1 and Table 6-2 present some of the information requirements extracted from the sonobuoy management model and the tactical situation awareness model, respectively. The requirements shown in italics are known available information sensed by the current sonobuoy system. As seen from the tables, attributes from the physical function and physical levels are more likely to be readily available. Tactical sonobuoys provide frequency vs. time information of the sonar data, and sonobuoys' own bearings and settings pre-selected by the operator. Basic environmental conditions, such as water temperature and pressure, are sensed by a special type of sonobuoys, the bathythermal sonobuoy. The other information is not directly provided by the system and demands further data processing, often in the form of a paper-based calculation or a mental assessment by the operator. At the functional purpose level, information requirements yield variables that provide potential measures of how well the system has achieved its objectives. However, an accurate assessment of the correctness of the tactical picture compiled is almost impossible to obtain during a real mission.

Information requirements and design criteria also arise from the interdependency of the two domains. On-going decisions regarding sonobuoy deployment are based on the tactical picture constructed. The need to assess the tactical value of data sensed by a particular sonobuoy, considering its capability and location, stands out as a multivariate, cross-domain relationship to be accounted for in the interface design.

Table 6-1: Information Requirements of the Sonobuoy Management Model

Abstraction Level	Information Requirement
Functional Purpose	*Number of sonobuoys deployed*. Range of possible sonar coverage by deployed sonobuoys. Chance of signal detection (density of sonobuoys in the area, high level assessment of environmental conditions).
Abstract Principle	Water mass and energy levels. Sonobuoys *storage level* and rate of deployment for each class of sonobuoys. Level of adherence to policy and procedures.
Generalized Process	Propagation level of acoustic signals, air movement processes, range and accuracy of deployment, aircraft movement, selected settings of each sonobuoy (frequency channel, depth). Pattern planned for sonobuoys deployment. Actual pattern of deployed sonobuoys.
Physical Function	*Wind speed/direction, air temperature, and atmospheric pressure.* *Water temperature and pressure profiles*. Direction and speed of current. Capabilities of deployment pattern. Anticipated battery life of sonobuoys.
Physical Form	*Sea bottom composition and contour, water temperature, salinity, and pressure, at various depths.* *Locations (bearings) of sonobuoys.* Remaining battery life, *radio signal strength, shape, size, visible (color) marking, cost, operational status, activation time, class and type of individual sonobuoys.* *Location of Rules of Engagement boundary.*

Table 6-2: Information Requirements of the Tactical Situation Awareness Model

Abstraction Level	Information Requirement
Functional Purpose	Time to establish a contact. Classification level of contacts successfully established. Number of contacts established during the mission. Percentage correction in determining a contact's location and classification. Completeness of tactical picture.
Abstract Principle	Water mass and energy levels. Propagation level of underwater sound. Level of adherence to policy and procedures. Probable regions of contact location. Assessment of contact threat.
Generalized Process	Sound speed profiles. Water movement processes. Documented acoustic signatures of known and expected contacts. Location, signal pattern, and strength of known and potential contacts. Displacement of contacts being tracked.
Physical Function	*Water temperature and pressure profiles.* Direction and speed of current. Constraints and difficulties in signal detection posed by ocean floor characteristics. Strength of signals emitted by contacts. Possible actions permitted within operational limits.
Physical Form	*Sea bottom composition and contour, water temperature, salinity, and pressure, at various depths.* *Acoustic signals sensed by sonobuoys.* Current and historical results (detection, localization, tracking, and classification details of contacts). *Location of Rules of Engagement boundary.*

6.2 Interface Concepts for the Domain of Sonobuoy Management

The purpose of EID is to provide support for decision making by having constraints and relationships visible (Burns and Hajdukiewicz, 2004). Table 6-3 below lists all the interface concepts generated for the domain of sonobuoy management, the relationships and constraints revealed by each, the level of AH addressed and the potential level of situation awareness each concept may support. In the subsections following this table, a number of these concepts are transformed into sketches, accompanied by more detailed explanations.

Table 6-3: Design Concepts for the Domain of Sonobuoy Management

Concept	Relationships revealed	Constraints revealed	Level of AH
Pie chart for inventory status (see Figure 6-2 for a concept sketch)	Buoys: stored vs. deployed Buoy types: percentage, number	Total number/ percentage of deployable buoys, and deployable buoys within each buoy type	AP - Balance and flow of resources (buoys) PForm - buoy deployment status, type
2D pattern and locations of deployed buoys (see Figure 6-1 for a concept sketch)	Buoy location: planned vs. deployed Buoy location: beginning vs. current Water current: Direction of drifting		PForm - deployment pattern, buoy location, location w.r.t. deployment pattern GP - supports of deploying buoys in the future, given all the depicted and implied drift status.
Icon for depth and frequency settings (see Figure 6-1 for a concept sketch)	Frequency setting: chosen vs. available channels depicted Depth setting: chosen vs. available depths depicted	Settings are restricted: sonic frequency (4 possible channels) deployment depth (4 possible depths)	PForm - settings (depth, frequency channel) GP - directly supports buoy configuration
Networked sonobuoys - indication of platforms	which buoy controlled by which platform	A buoy controlled by one platform cannot be manipulated by another.	GP - processes of confirming and operating within limits, and thereby supports the AP of balance and flow of authority
3D location vs. time (see Figure 6-10 for a concept sketch)	Location (bearing) vs. time of buoys (can also be contacts tracked, as discussed in Section 6.3.3)		PForm - location of buoys/contacts

6.2.1 Monitoring the Actual Sonobuoys

Information requirements from the domain of sonobuoy management reveal the need to monitor a sonobuoy's physical condition, location, and settings. Amongst numerous pieces of information available regarding the physical form and function of a sonobuoy, some data were considered priorities: frequency and depth settings which are necessary in establishing the channel for data arriving from a particular sonobuoy; the current location of a sonobuoy with respect to its location in the deployment pattern; and the anticipated battery life of each sonobuoy.

The sketches in Figure 6-1 are designed to integrate multiple pieces of data regarding the sonobuoy's conditions and settings. The deployment pattern (e.g., grids of sonobuoys with equal spacing) is shown as the underlay of the display. The actual locations over time of sonobuoys are shown on top. Deployment error can be observed by looking at the original spot of deployment, and drifting status can be monitored by looking at a track of dots generated for each sonobuoy. For each buoy, locations are recorded at a fixed interval, such that the track can show not only the direction of drifting, as well as if the drift speed is increasing or decreasing, and if it is comparable to other sonobuoy drifts. This allows a quick interpretation of how the water is affecting deployment pattern (operator should take this into consideration for further sonobuoy deployment), as well as whether or not individual sonobuoys are drifting at a speed and/or direction different from the others. The icon in the middle of the sketch is designed to complement the 2D map display by visually showing the sonic frequency and the deployment depth of each sonobuoy. Finally, the horizontal bar mimics the battery life remained for each sonobuoy, and is color coded to show design considerations for salience. The objective of showing all the relevant information through the use of icons and colors is to bring out the salience and to keep their respective meanings intuitive.

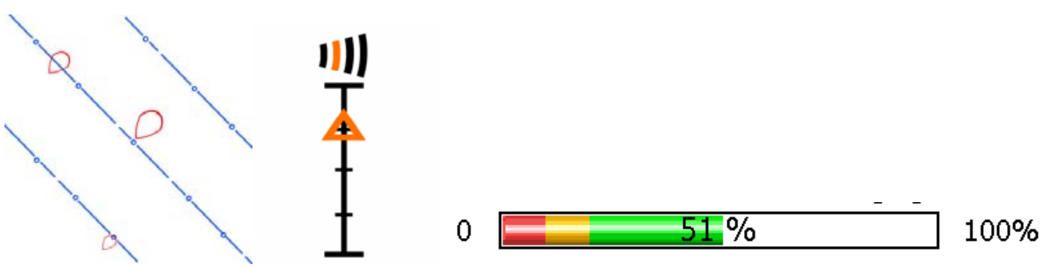


Figure 6-1: Location, interactive settings, and battery life status of deployed sonobuoys

6.2.2 Visualizing Inventory Data

An area that has received little attention in past interfaces is information regarding sonobuoy inventory and usage during a mission. A visualized inventory count would enable the operator to quickly determine the availability of their resources over time. The initial idea for this problem was to provide a pie chart (as listed in Table 6-3), which provides an overview at the level of functional purposes to sum up the current inventory status (see Figure 6-2). Following the idea of pie chart, a configural display (see Figure 6-3) was then proposed to explicitly show the expected battery life of the deployed and the to-be-deployed sonobuoys. This projection of future inventory status would be based on a deployment rate selected by the operator during the mission. A selection menu for deployment rates is also included in Figure 6-3**.** A complementary stack chart (see Figure 6-4) shows the number of sonobuoys left at given time intervals. Together, these displays address the criteria of operating within limited resources.

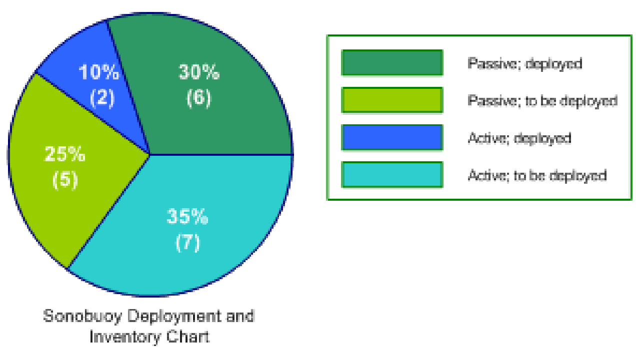


Figure 6-2: Pie Chart of Sonobuoy Inventory

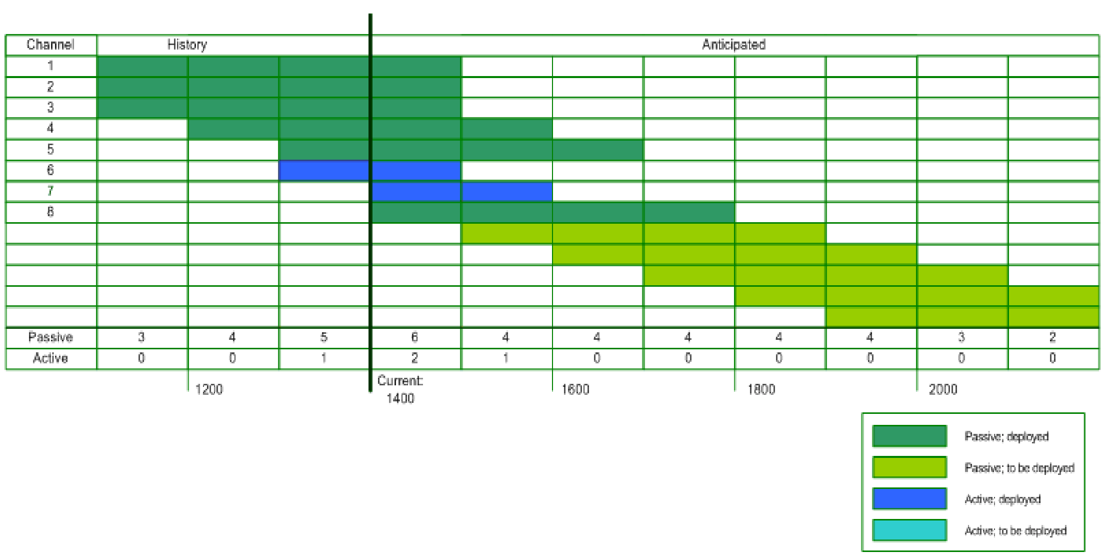


Figure 6-3: Timeline display for expected sonobuoy life

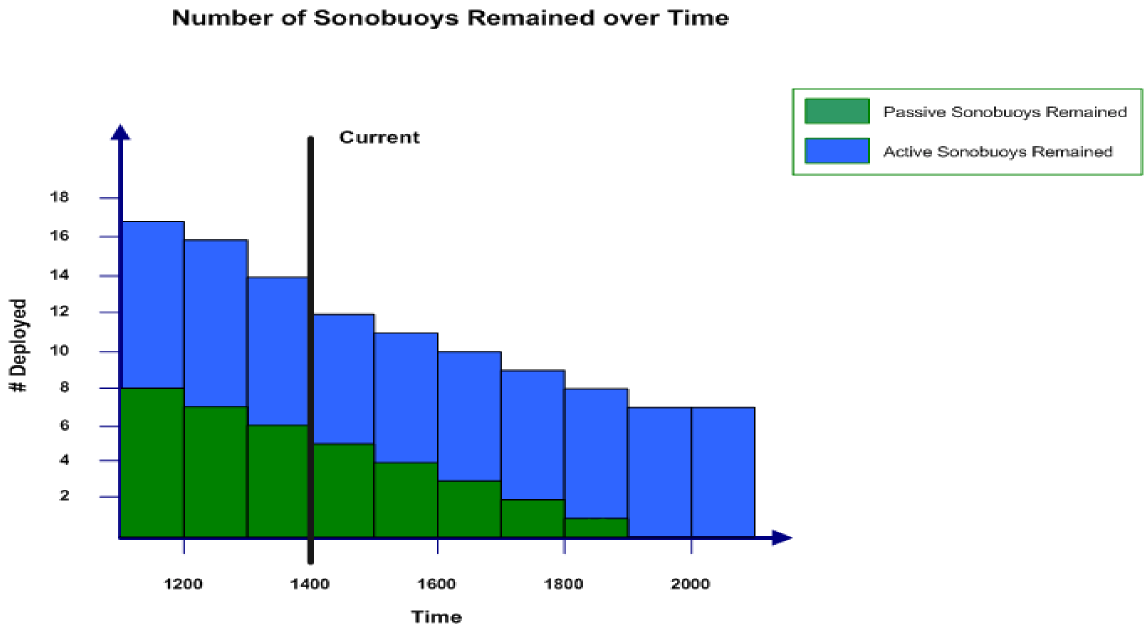


Figure 6-4: Stack bar display of remaining sonobuoy count

6.3 Interface Concepts for the Domain of Tactical Situation Awareness

A number of concepts (see Table 6-4) are developed specifically to support tactical situation awareness. Readers may be curious to see that visualization of acoustic data is not part of these designs. Lack of deep understanding in acoustics and the restricted availability of tactical data are the main limitations to designing for the actual visualization of acoustic data. Instead, design for this domain focuses on bringing out the salience of higher risk situations and providing peripheral information for increasing the accuracy and completeness of the tactical picture. The following subsections expand on a number of the concepts listed in Table 6-4 to include sketches and discussions.

Table 6-4: Design Concepts for the Domain of Tactical Situation Awareness

Concept	Relationships revealed	Constraints addressed	Level of AH
Enabled sharing of tactical pictures across platforms	The common, identified contacts and differences in pictures across platforms		GP - supports aggregation of tactical intelligence

Probable areas of targets detected by multiple buoys (see Figure 6-5 for a concept sketch)	Probabilistic relationships or contact locations	Target location is restricted to within areas of calculated probabilities	AP - supports decisions made at the level of probabilistic balance of success and risk. It also makes apparent the principles of geometry. GP - illustrates the processes of localization and tracking, making results of TMA visible. PForm - reveals information regarding location of contact.
Trends for Sound Speed Profiles (SSPs) (see Figure 6-7 for a concept sketch)	SSPs: temperature vs. depth SSP vs. time	Soft constraints of roughly what depth the layers should be at around given time/season.	PFunction - reveals influence from water characteristics PForm - directly shows water temperature and depth over time.
Linking audio channel to visual display	Audio channel is linked to its corresponding frequency vs. time display of the buoy.		GP - signal detection by operator is facilitated FP - minimize time in establishing tactical information
Hot/cold indicator display (see Figure 6-6 for a concept sketch)	Which buoys are holding contact and at what time		PForm - operational status of contacts held for each buoy GP - supports aggregating tactical intelligence and tracking signal sources
Gaze directed display for browsing channels of buoys (see Figure 6-9 for a concept sketch)	This concept stresses the relationship between eye movements and attention	A common problem is being too fixated on a given area of the display and ignoring the flashing information elsewhere	GP - supports processes of detecting signals in a way that leads to achieving FP of minimizing time in establishing tactical information
Target's sphere of influence (see Figure 6-8 for a concept sketch)	Distance between known target vs. own-platform location	The zone in which the target may have influence (in terms of sensors, weapons) on our platform/forces.	AP - Probabilistic balance of success and risk, military principles for tactics and intelligence. GP - Processes of confirming and operating within limits

6.3.1 Visualizing Relationships between Sonobuoys and Contacts

The plausible area for a target location given any two sonobuoys holding the contact can be given in an elliptical equation. With 2 or more sonobuoys these areas can be drawn out and may overlap to identify areas of higher probabilities. The idea of drawing elliptical shapes for possible target location is not new, but revealing the overlapping areas to define different levels of probability would be beneficial. This concept assumes that the sonobuoys are holding the same contact. This concept supports the general process levels of the AH, since it attempts to illustrate the processes of localization and tracking. It also utilizes the principle of geometry, and hence supports information at the abstraction principles level.

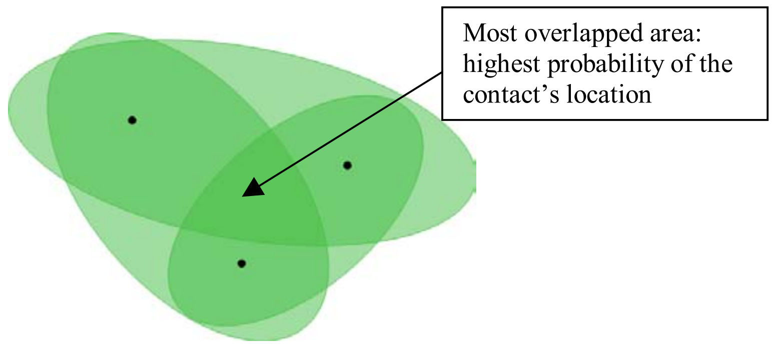


Figure 6-5: Visualization of Probable Areas Detected by Multiple Sonobuoys

Figure 6-6 is a mass data display to show which sonobuoys had or have been holding contacts over the length of a mission. Each row of data corresponds to a particular sonobuoy; the status of hot or cold at a given point of time is represented by a filled circle. When the sonobuoy is cold, a blue small circle is shown. Once the sonobuoy senses a target above its detection threshold, the circle becomes red. The size of the circle also increases relative to the intensity or certainty in sensing a contact of interest. This design provides a high level immediate feedback to which buoys have been holding contacts and in return, helps to create a sense of target movement due to the changes over time in the display. However, it has two limitations that need to be addressed. It is unable to distinguish between the multiple contacts each sonobuoy may be holding, and it relies on an ordered list of buoys, without explicitly mapping the location of sonobuoys.

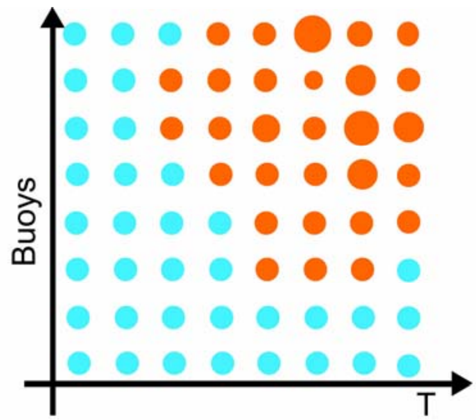


Figure 6-6: Indicator of hot/cold status over time

6.3.2 Visualizing Peripheral Data in Supporting Tactical Situation Awareness

Sonar operators utilize a wide range of knowledge in performing their tasks. They are knowledgeable in the military tactics of underwater warfare, the acoustic technology of enemy submarines, and they are constantly paying attention to environmental data, which can drastically affect the behaviour of underwater sound.

While water temperatures, pressures and salinity are sensed directly, their impact on underwater sound propagation is largely determined by a holistic view. Sound speed profiles (SSPs), for example, are heavily utilized by sonar operators to determine the current condition of underwater sound propagation. In the advanced sonar systems used today, plots of sound speed profiles may be generated automatically; however, the perceived significance of the plots, such as potential blind zones of detection and the impact of variability over time, is still dependent on an operator's experience and training in underwater acoustics and tactical intelligence. Figure 6-7 depicts a display that stresses changes in SSP over time, revealing any abnormalities in water condition that may affect sonar performance.

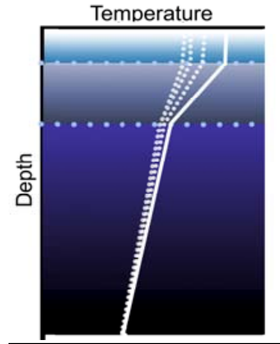


Figure 6-7: Sound Speed Profiles over time

From the tactical standpoint, sonar operators also need to perceive the potential threats their own platform is facing. Graphically presenting a target's sphere of influence (Figure 6-8) reminds the sonar operator of the zone in which the target may possess a serious threat to their own platform. This concept follows the abstraction principle that stresses the balance between success and risks. Military tactics and intelligence are necessary to provide accurate data for such representations.

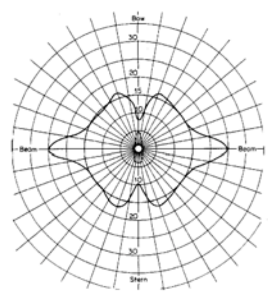


Figure 6-8: Target's Sphere of Influence

6.3.3 Maintaining Situation Awareness in a Complex Environment

Sonar operators function in a highly complex environment and receive data both aurally and visually. As pointed out in interviews with SMEs and a literature review of current technology, a major challenge is to address the segregation between aural and visual channels for sonar data. Sonobuoy interfaces, with the added numbers of channels into which data are arriving, are especially demanding in the sense that an operator must be able to switch their attention selectively but efficiently. A successful operator needs to maintain an overall tactical awareness while attending to data from a single sonobuoy.

A resulting design criterion is to provide a means to appropriately alert the operator of potentially critical data arriving from another sonobuoy. Auditory alerts are not considered because of the already noisy environment on a MPA, and because headphones are worn by operators to follow acoustic data aurally. Visual alerts (such as blinking) may be disrupting or lead to a fixation problem. A gaze-directed display or other transitional tool is therefore proposed for the effective monitoring of data arriving from multiple sources. In Figure 6-9, the white boxes on the left represent a slightly minimized list of channels revealing the latest acoustic data from different sonobuoys. The bigger white box on the left represents the one channel that the operator has chosen to examine in more details. The red frames pair the sonobuoy channel currently selected for browsing with the list on the right. When an important event arises, such as a new contact detection, the yellow gradient appears from the main window and extends to the channel of interest in the list on the right. This way, the operator is visually guided to where their attention should be, without being interrupted from their current task.

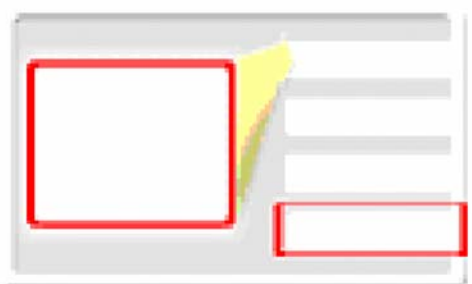


Figure 6-9: Concept of Gaze-direct Display

Finally, to track known contacts and their movements, a three-dimensional (3D) map of location versus time is proposed (Figure 6-10). Contacts are marked on a regular bearing map, with history over time added on to give depth to the 2D map. The resulting cylindrical representation should allow rotation on its z axis such that it is possible to arrive at a 2D bearing view, where the most current locations are marked as bigger circles, and its historical movement would appear on the map as dots of decreasing sizes. The same graphical representation can also be applied to the domain of sonobuoy management for showing the location of sonobuoys over time (included in Table 6-3).

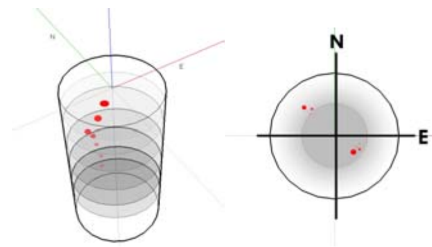


Figure 6-10: Contact (or Sonobuoy) Location vs. Time

6.4 Integration of Concepts

The final stage of EID is to integrate display components into a meaningful interface. Design concepts from both domains are integrated into the display, placed according to their respective abstraction level. Burns and Hajdukiewicz (2004) suggested that users should monitor at the highest level of WDM, i.e., at Functional Purpose, and explore other levels only when problems arise. Therefore, graphic components that provide high level information should be presented in the most visually accessible space of the interface, which researchers have considered to be the top and/or left portion of the visual space (Wickens & Hollands, 2000). Depending on the space availability of the display, concepts corresponding to lower level of abstraction can be placed either close to the bottom of the display, or if space is limited, on a second layer of display. Multiple displays, if possible, would also provide extra space for large amount of data without reducing space for the higher level data.

Attempts were made to lay out concepts with graphical components onto a display assumed to be a regular computer monitor. Figure 6-11 organizes the components according to the AH; it is, however, by no means what the actual implementation should look like. While graphical components are salient and communicate data efficiently, it is best to provide data in text, especially data that have quantitative values. The background colour of the interface should be grey, because it is a neutral, comfortable and less distracting colour for operators to use over long periods of time. The visual designs also do not address the interactive functionalities, and the recommendation of integrating audio and visual interfaces for the acoustic data. A prototype based on some of the concepts presented so far is detailed in the next chapter.

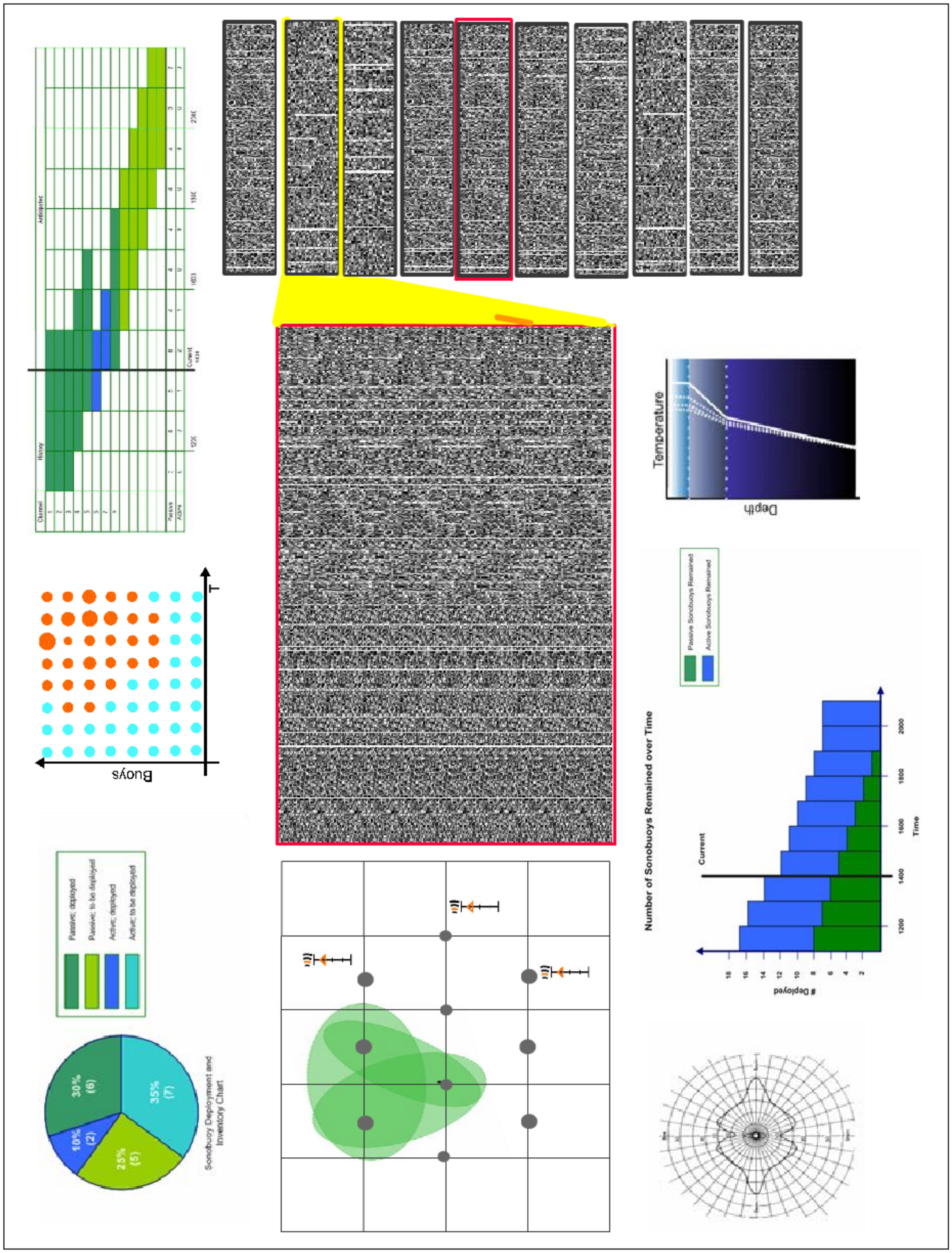


Figure 6-11: Mapping design concepts on to a display space

Chapter 7
Display Prototype

To prepare for user testing, a functional prototype was developed using Macromedia Flash. A number of earlier concepts have been modified. Some were modified as improvements to the original concepts, and some were modified to overcome implementation difficulties. This chapter presents the final display designs that are included in the prototype, and include screenshots of the integrated display.

7.1 Individual Display Components

7.1.1 Pie Chart for Inventory

The original concept of pie chart for the inventory remains the same. Here, passive sonobuoys are represented in green and active sonobuoys in blue. Undeployed sonobuoys are represented using a lighter shade of colour than deployed sonobuoys. When the user rolls over a segment of the pie with their mouse, more information about the selected group of sonobuoy shows up underneath the chart.

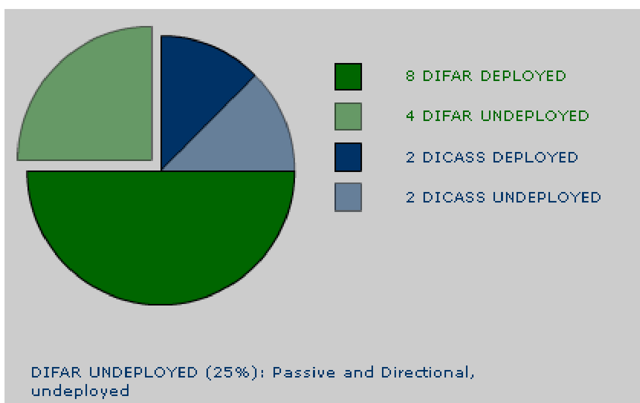


Figure 7-1: Pie chart for inventory

7.1.2 Individual Sonobuoy Details

The original designs of settings and conditions of sonobuoys are significantly changed. Multiple pieces of information are now integrated to eliminate the need to have multiple graphical items for each sonobuoy. In Figure 7-2: Sonobuoy icon, each circle represents a sonobuoy and a square around a circle indicates that it is an active sonobuoy. The background map, scaled and labelled, allows one to interpret the location of a sonobuoy, and reveals the pattern of deployment for a group of sonobuoys.

The size of the circle indicates the depth of the sonobuoy (four depth settings are available): a larger circle means a more shallow deployment. The proportion of the circle that is filled with a dark grey color is proportional to the percentage of battery remaining for this sonobuoy. The blue line attached to the circle icon reveals the movement (drifting) of a sonobuoy since its deployment. When a sonobuoy has made detection, the icon turns red and stays red while it is making detection. A yellow, semi-transparent area containing the sonobuoy icon in the middle reveals the area in which the sonobuoy is able to detect contacts, and thus indicate the possible region in which a contact may lie. The indication of signal strength does not appear until the sonobuoy turns red (i.e., has made detection) to avoid cluttering of the display space. Due to implementation issues, it has been simplified into the shape of a circle when in reality it resembles an ellipse. When two or more nearby sonobuoys are hot, the yellow areas overlap, resulting in an area with a more solid shade of yellow. There is no indication of the diminishing signal strength in areas further away from the sonobuoy.

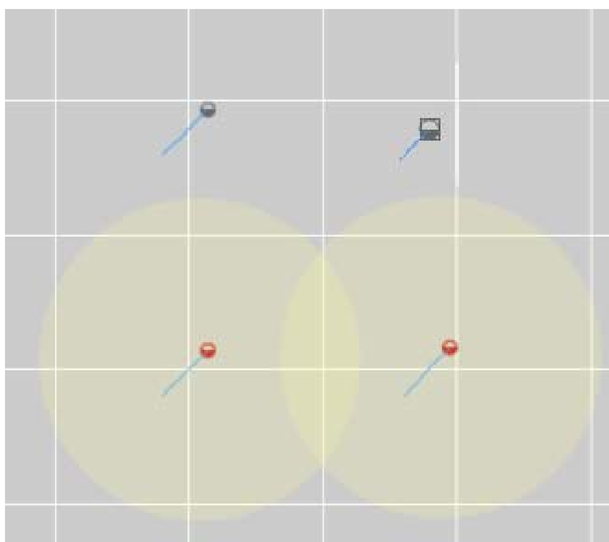


Figure 7-2: Sonobuoy icon

7.1.3 Historical Hot vs. Cold Information for All Sonobuoys Deployed

The initial design to give a high level view of sonobuoys' status over time faces a major limitation: it is difficult to map data from a particular sonobuoy on this display to its actual location. Location is usually visualized in at least 2 dimensions, and thus adds much complexity to be presented along with time and status (hot/cold) variables. This problem is overcome by the realization that maintaining the detail and linearity of time is not critical; instead, the real design challenge is to reveal the location of sonobuoys holding contacts over time. Therefore, in the new design, sonobuoys and their status (hot/cold) are taken as snapshots periodically and all the snapshots are then collapsed onto a 2D map.

A blue circle represents a sonobuoy that is/was cold at a certain hour and a red circle represents a sonobuoy that is/was hot. Each actual sonobuoy is represented here by multiple circles, the number depending on how many hours it has been (or was) deployed. No effort is made to distinguish between sonobuoys, but the user is expected to interpolate the information from the locations of the circles. The transparency level of each circle indicates the time the 'snapshot' was taken. The strongest, most solid color represents the current hour. The lightest, most transparent circles represent sonobuoys at the start of the mission. This view is meant to give a high level overview of tactical history captured by the sonobuoys. The figure below contains three examples of this design. From the left to right:

- Detection has been made since the second hour of the mission by three sonobuoys at different hours. Possibly a single contact has moved diagonally up from the bottom left corner.
- Detection has been made throughout the mission by one sonobuoy only. A contact may be present at the top right corner or further up from the space shown on the map.
- Same as the previous example, except two sonobuoys at the bottom have just made detection during the latest hour. It is possible that a new contact has arrived.

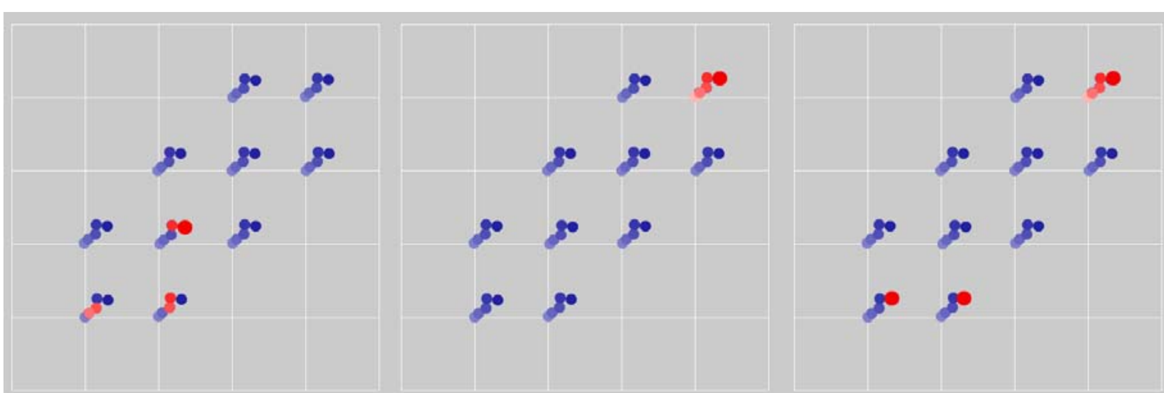
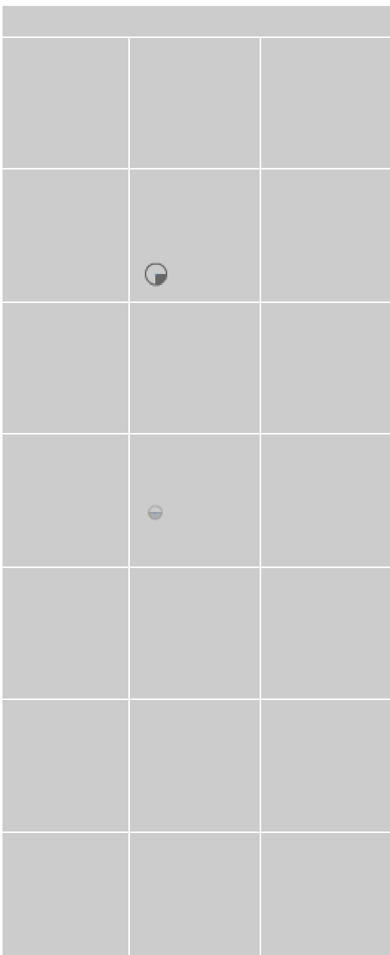


Figure 7-3: Three examples of historical hot/cold status display

7.1.4 Detailed Data for Sonobuoys Deployed

This design addresses the need to supplement graphical forms with actual data (numbers and text). Attributes with real time values are presented for the deployed sonobuoy under clear headings. To facilitate visual mapping between the graphical representation and the actual data, user interaction is implemented to allow highlighting of corresponding view by either clicking on the data or on the sonobuoy icon on the map. When the user has clicked or rolled over a mouse to focus on a particular sonobuoy and its data, all other sonobuoy icons are masked, and type and capability information of the selected sonobuoy appears at the bottom of the data view.



Channel	Type	Depth	Deployed	Battery	Long	Lat
0	P	120	15:30	0:59	119:39:27 W	33:08:33 N
1	P	120	15:30	0:59	119:39:54 W	33:08:6 N
2	P	120	15:30	0:59	119:40:21 W	33:07:39 N
3	P	120	15:30	0:59	119:40:41 W	33:07:2 N
4	P	30	16:30	1:59	119:39:54 W	33:08:33 N
5	P	30	16:30	1:59	119:39:27 W	33:08:6 N
6	P	30	16:30	1:59	119:40:48 W	33:07:39 N
7	P	30	16:30	1:59	119:40:21 W	33:07:12 N
8	A	120	17:30	0:59	119:40:21 W	33:08:6 N
9	A	120	18:30	1:59	119:39:54 W	33:07:39 N

DIFAR ANSSQ 53D
PASSIVE,
DIRECTIONAL
CAPABLE OF: SEARCH, LOCALIZATION, SURVEILLANCE

Figure 7-4: Detailed data for the sonobuoys deployed

7.1.5 Chart of Sonobuoy's Time of Deployment and Battery Life and Chart Showing Remaining Sonobuoys on the MPA

The two concepts for visualizing inventory data are implemented as designed. A drop-down menu is implemented to demonstrate how the user may select the rates for future deployment of active and passive sonobuoys. The future deployment according to the selection (and subject to inventory constraints) shows up in both charts in a transparent color for the blocks representing sonobuoys.

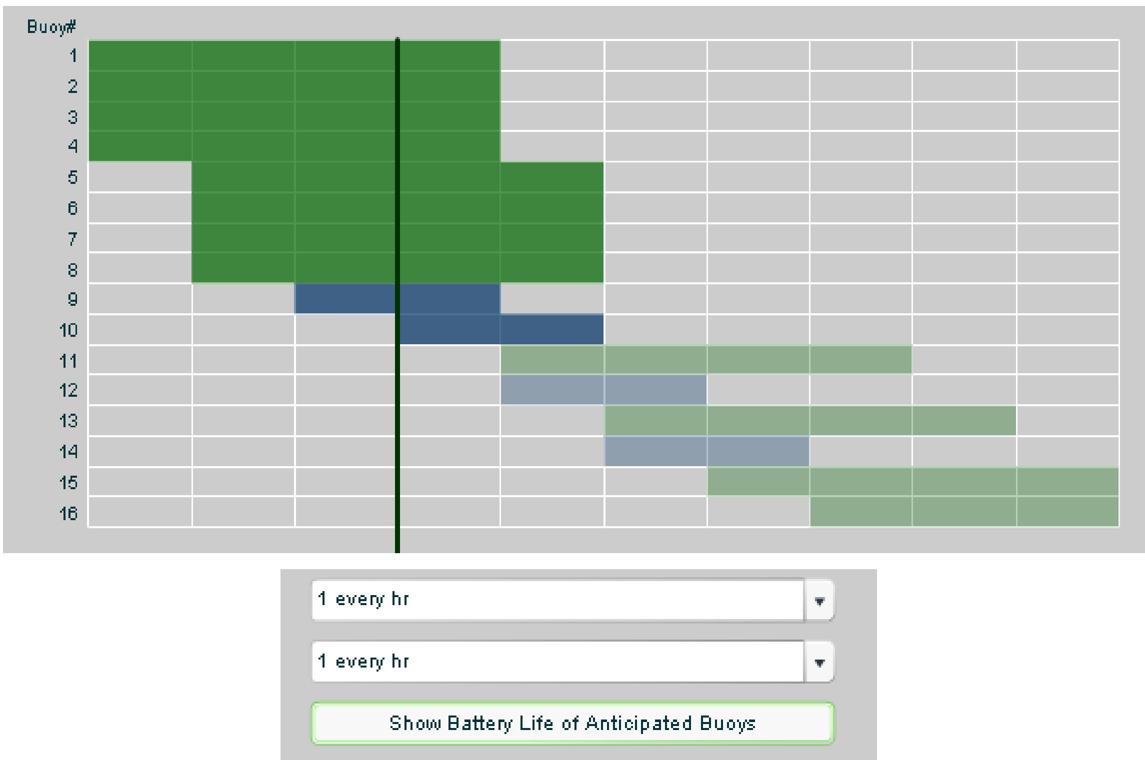


Figure 7-5: Chart of time of deployment and battery life of sonobuoys and a selection menu for future deployment rates

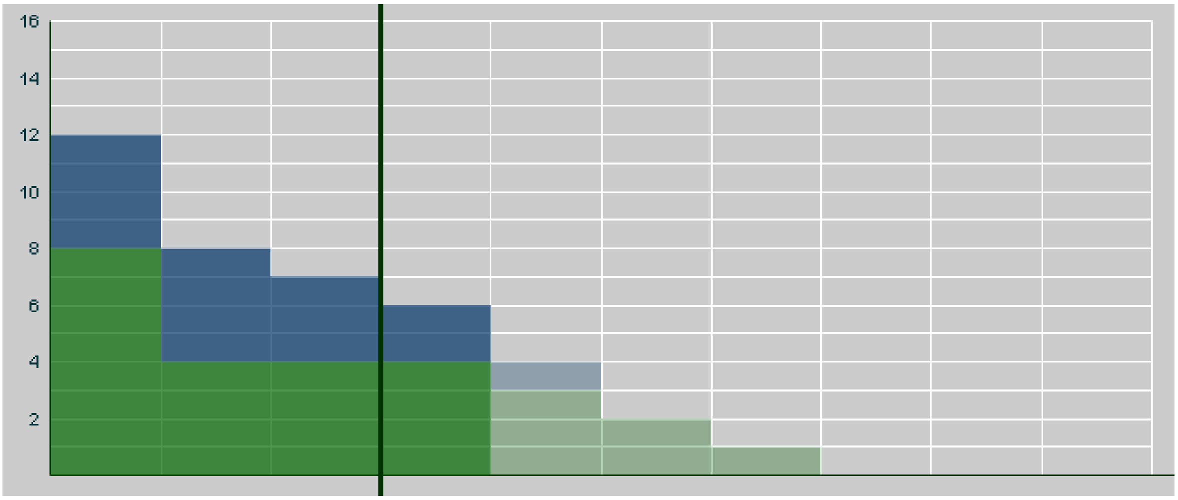


Figure 7-6: Inventory chart of sonobuoys remaining on board

7.2 Information Layout on the Prototype Display

The final prototype for testing purposes assembled the components described in the previous section. Organizing the display components resulted in three groups of information, each given a separate display space and is accessible through the labelled tabs at the top of the display screen. The front page of the prototype is an overview display, containing only high level information at the FP and AF levels. A user may view more detailed information on processes, capabilities, and physical forms in two other pages accessible through the tabs on top of the screen. This second level of information is organized into two pages: one contains information pertaining to the operational status and condition of the sonobuoys, and the other contains information about the current and projected status of the sonobuoys. Screenshots of the three display pages are included in the following pages.

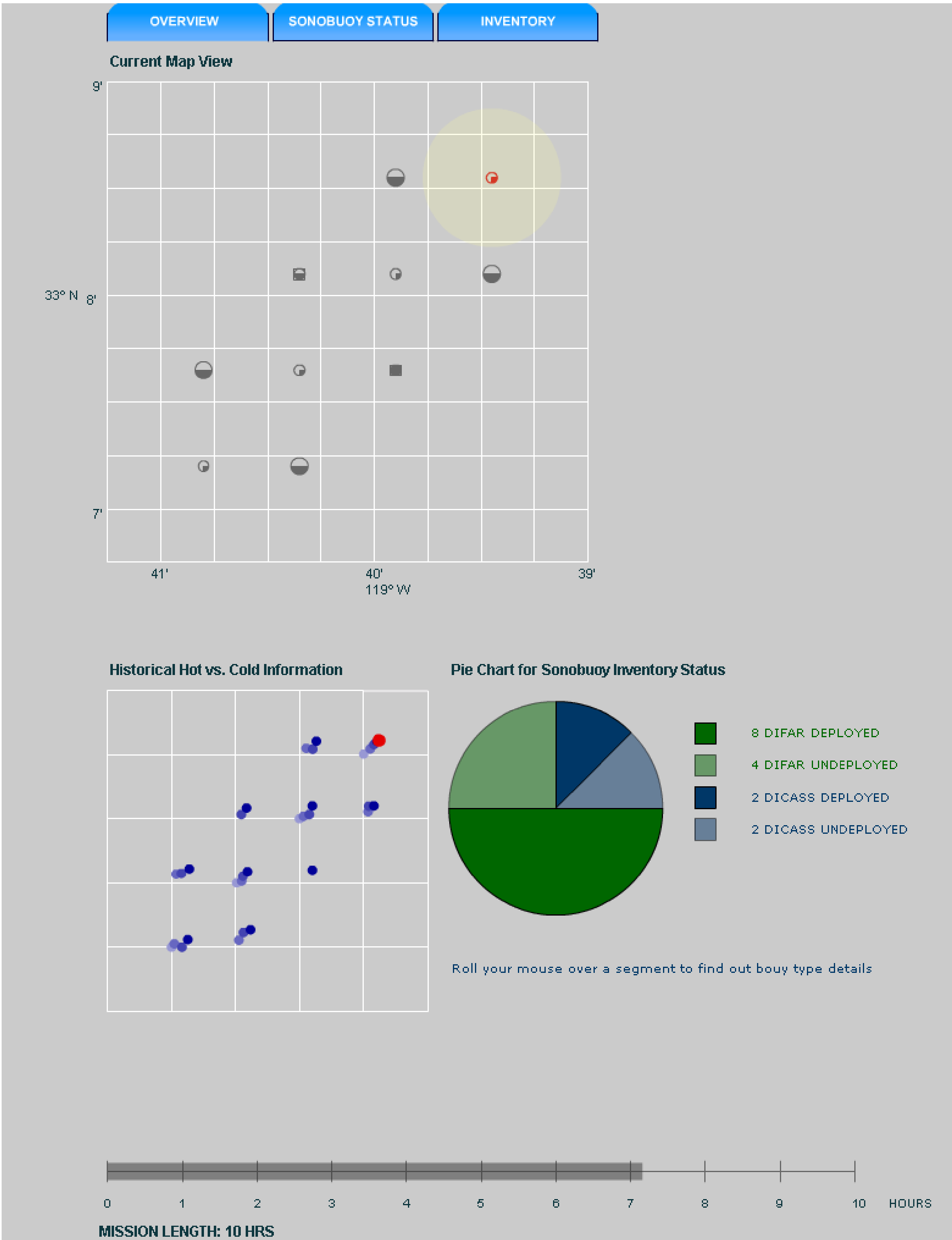


Figure 7-7: Prototype screenshot – overview

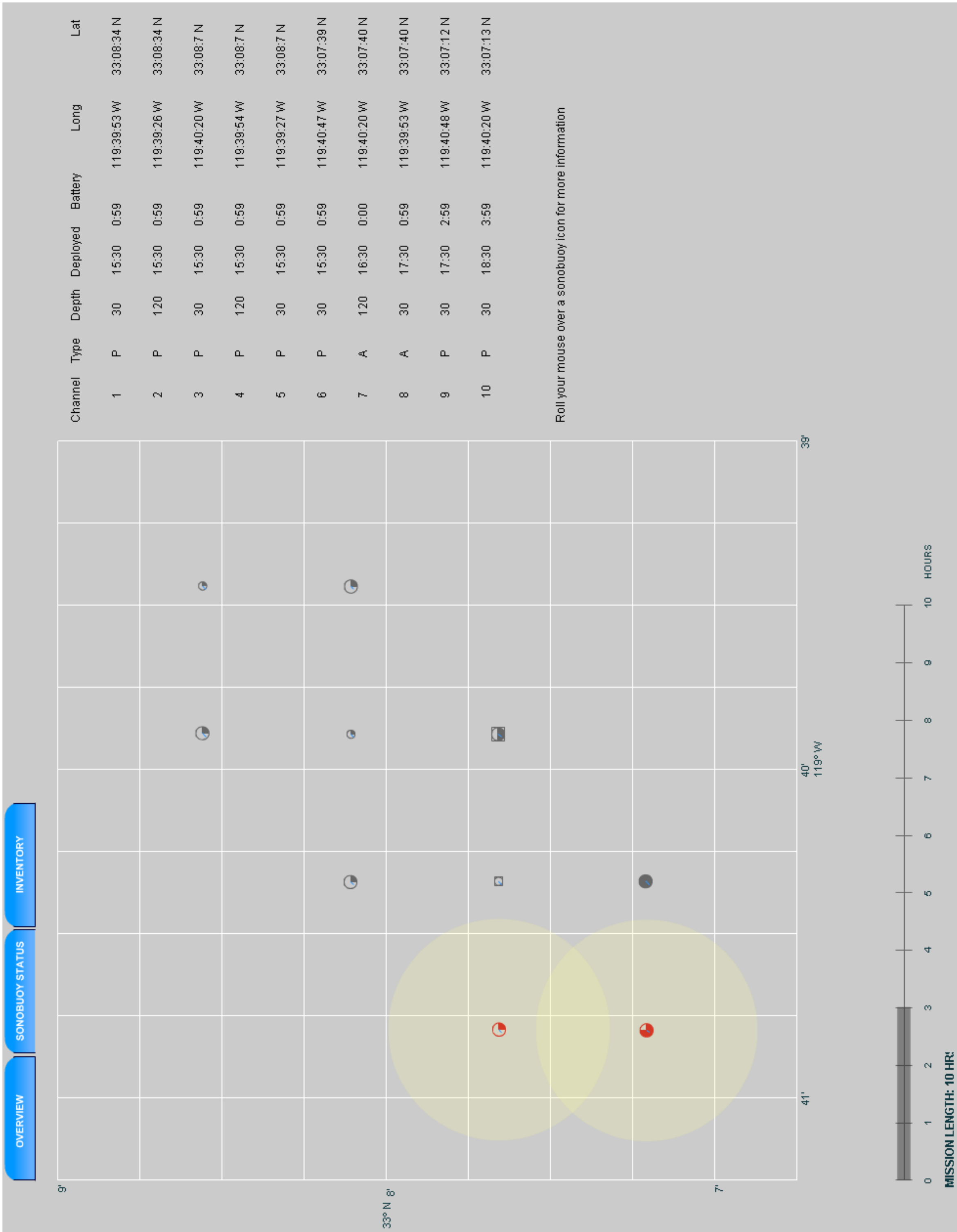


Figure 7-8: Prototype screenshot - sonobuoy status

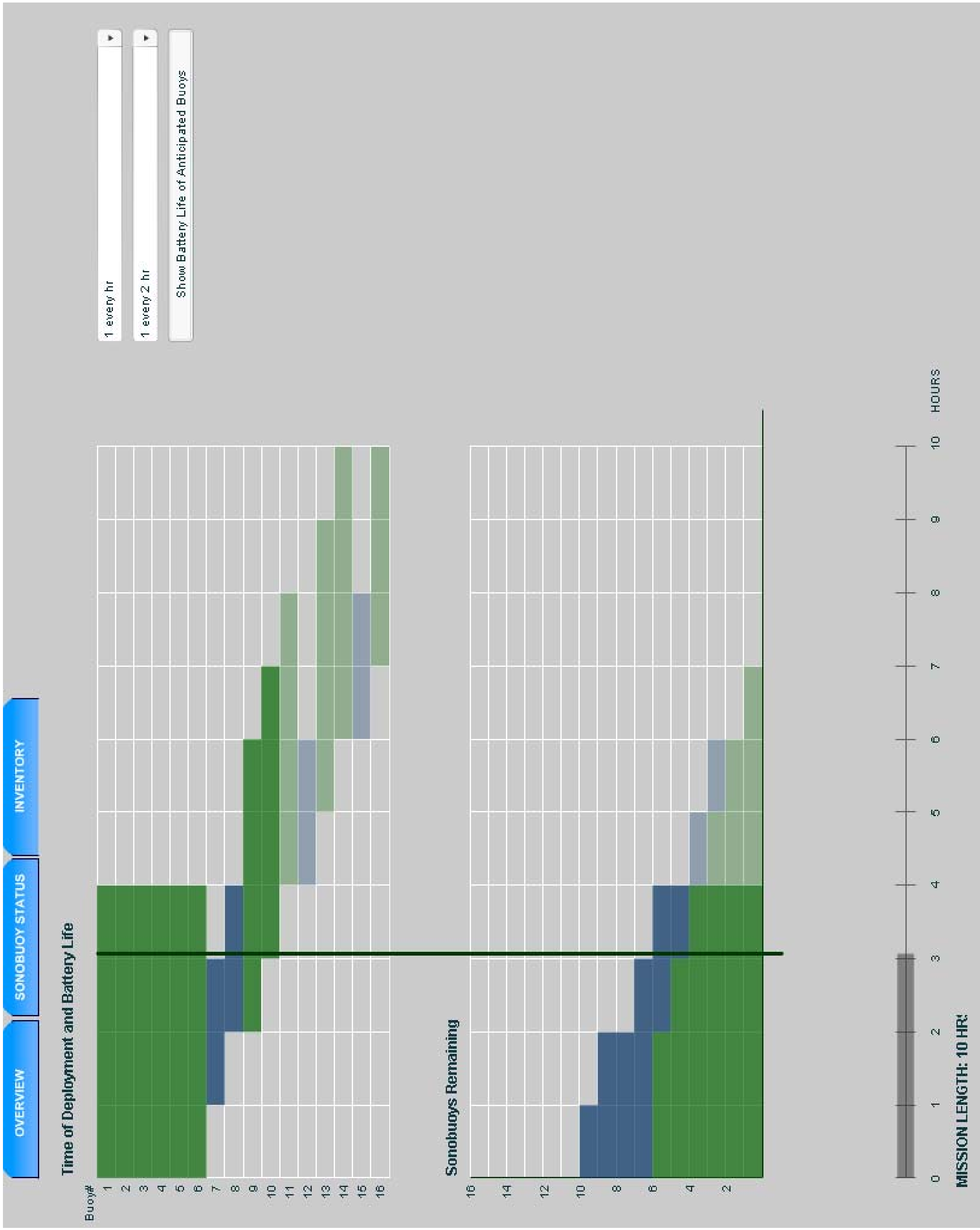


Figure 7-9: Prototype screenshot - inventory

Chapter 8
User Testing

Because there are no alternative systems available with which to compare the design concepts in question, this study adopts the user testing framework to evaluate the effectiveness of the interface concepts. In a nutshell, user testing is a systematic approach to evaluating user performance with the product or system in question in order to inform and improve usability design (Preece, Rogers, and Sharp, 2002). The primary focus of the user testing was to collect meaningful data, both quantitative and qualitative, for assessing how well the interface concepts achieve the design goals. This chapter describes the user testing method and results. All materials related to the study are included in Appendix C.

8.1 Objectives

The objective of user testing is to assess the effectiveness of the resulting interface concepts, along with the organization of the integrated display, in supporting the decision making of users in both sonobuoy management and tactical situation awareness. The specific goals of the study are: to determine which concepts enable users to determine relevant information quickly and accurately; to find design flaws in concepts that confuse users or prevent users from understanding the data presented; and to understand any difficulties users may have in locating the information that they need.

8.2 Prototype Setup

The prototype described in the earlier chapter allowed the design concepts to be tested in a logical manner for the users. Three scenarios were constructed in the Flash prototype for the purpose of user testing. Each of them simulated a tactical environment, containing information such as sonobuoys deployment time and pattern, sonobuoys' conditions, and tactical events that require a user's attention and response. The first scenario was fairly straightforward, primarily testing if the user was able to perceive changes on the display and recognize what the changes signify. The tactical situation simulated in the second and third scenarios was more complicated. Users were asked to describe the overall situation by interpolating from the dynamic events they spotted on display. The third scenario introduced additional complexity by providing a complicated history of deployment that may not be obvious at first glance. The layout and key events for each scenario are listed in Appendix C.

8.2.1 Limitations and Assumptions

Restrictions to access of actual tactical and sonar data limit the ability to construct realistic sonar data displays. For this reason, several interface concepts were left out in the prototype construction. In addition, several assumptions were made to simplify the prototype:

- A sonobuoy has only two states of detection, "hot" and "cold."
- Equal signal-sensing strength throughout the range of detection of a sonobuoy.

8.3 Method

8.3.1 Participants

Ideally, participants for this study should be sonar operators, such as the SMEs interviewed in the beginning of the project. However, due to geographic limitations, evaluations by SMEs were done remotely in the form of predictive review of the prototype. Details about the SME reviews are discussed in the next chapter. In this study, participants recruited were players of sonar-related PC games. These games generally involve anti-submarine missions and contain components of sonar systems in a tactical environment. Participants with such gaming experience are familiar with the notion of building a tactical picture, and the use of sonar in underwater warfare. Three participants who all rated themselves as intermediate level players of antisubmarine games were recruited for the study.

8.3.2 Procedures

Each participant was given an information letter about the study and a consent form to sign before the study began. They were also required to fill out a background questionnaire. The administrator then gave an orientation presentation about the project and the prototype, familiarizing the participant with individual concepts. The presentation ended with an explanation of the user testing procedures and what they could expect to see.

Three separate scenarios were played in the study. Each scenario modeled a different tactical situation. Participants were asked to recognize what was going on in each scenario, and to be aware of the sonobuoy inventory and the overall tactical picture. During each scenario, the administrator asked scripted questions to probe the participant's awareness of the situation. The participant could browse the displays as they answered these questions. Furthermore, participants were encouraged to explore the displays freely, using the mouse to roll over and click on various components. They were asked to think aloud as they browsed the displays and/or looked for particular information. At the end of each scenario, a short questionnaire was prepared for them to answer specific questions relating to the scenario. There was no time limit in either running the scenarios or filling out questionnaires.

8.3.3 Data Collection and Measures

The user testing study adopted two major forms of data collection: paper-based questionnaires after each scenario and online questions administered verbally during each scenario. A pre-test questionnaire for gathering background information on the participant revealed the participant's level of expertise, which may affect their results. Three questionnaires specific to each of the three scenarios were designed to probe the participant's understanding of the concepts, as well as finding their preferences and their perceived ease of use. Participants' verbal responses to online questions were measured against a set of metrics (see Appendix D) developed to assign scores based on the completeness and correctness of the responses. Furthermore, the thinking aloud protocol was used during the study: participants were asked to vocalize their thoughts, feelings, and opinions while interacting with the interface. This protocol allows the observer to understand how the participant approaches the interface and what considerations the user maintains when using the interface. Data recorded from the thinking aloud protocol were organized and added on to results from the online questions.

8.4 Results

8.4.1 Questionnaire Responses

Table 8-1 to Table 8-3 summarize the questionnaire responses in three categories: participants' perceived effectiveness of the displays, perceived level of difficulty in understanding and utilizing the displays, and the participants' level of understanding of the displays. For each multiple choice question in the questionnaire, responses were combined into an overall score by assigning each tick made by the participant a point. When participants made two choices or more for a question that required only one choice, the mark was divided equally amongst the choices (e.g., 2 choices would give 0.5 point for each choice). In rating questions, participants were given a numerical range from 1 to 5, where 1 was very easy and 5 was very difficult. Overall scores for these questions were simply derived from adding up each participant's ratings. Consequently, the lowest overall rating possible for each item would result in 3 (3 participants all gave a rating of 1) and the highest possible rating would be 15 (3 participants all gave a rating of 5).

Table 8-1: Summarized Questionnaire Results: Participant Perceived Effectiveness of Displays

Questions on the Participant Perceived Effectiveness of Displays	Vote
The best picture for the current sonobuoy inventory	
Pie Chart for Inventory	**1**
Detailed Data View on the 'Sonobuoy Status' Screen	**0.5**
Chart for Sonobuoy's Time of Deployment and Battery Life	**0**
Chart for Showing Remaining Sonobuoys on the MPA	**1.5**
The most useful in determining a sonobuoy's battery status	
Sonobuoy Icon (partially filled circle presented on the map views)	**1**
Detailed Data View on the 'Sonobuoy Status' Screen	**1**
Chart for Sonobuoy's Time of Deployment and Battery Life	**1**
The most effective items for informing that a sonobuoy is low on battery	
Sonobuoy Icon (partially filled circle presented on the map views)	**3**
Detailed Data View on the 'Sonobuoy Status' Screen	**0**
Chart for Sonobuoy's Time of Deployment and Battery Life	**0**
Use of the "Inventory" Screen (the 3rd tab)	
To find out a deployed sonobuoy's battery status	**1**
To find out when the current sonobuoys will expire	**2**
To deploy more sonobuoy(s)	**1**
To determine future deployment rate	**3**

Table 8-2: Summarized Questionnaire Results: Perceived Level of Difficulty in Understanding and Utilizing the Displays

Questions on Perceived Level of Difficulty in Understanding/Using the Displays	Total

	Rati ng
Please rate the level of difficulty to perform the following tasks, based on this demonstration.	
To detect that a sonobuoy is HOT	**3**
To visualize the extent of a sonobuoy's coverage	**4**
To anticipate movement of a held contact	**7**
Please rate the level of difficulty to perform the following tasks, based on this demonstration.	
• To find out the location of a sonobuoy	**5**
• To find out the battery remained for a sonobuoy	**5**
• To find out the depth of a sonobuoy	**6**
• To distinguish between a passive and an active sonobuoy	**7**
• To detect a malfunctioning sonobuoy	**10**
Please rate the level of difficulty to understand and interpret data from the following displays.	**Total Rating**
Map View with grids and long/lat labels	**4**
Historical Hot vs. Cold Information	**3**
Pie Chart for Sonobuoy Inventory Status	**11**
Sonobuoy icon and the pieces of information revealed	**5**
Blue line showing a sonobuoy's movement	**4**
Lines of data and highlighting of corresponding sonobuoys	**6**
Chart: Time of Deployment and Battery Life	**7**
Chart: Sonobuoys Remaining	**6**
Use of selecting rate of future deployment	**6**

Table 8-3: Summarized Questionnaire Results: Effectiveness of Displays in Creating an Accurate Awareness of the Situation for the Participants

Questions on the Effectiveness of Displays in Creating Accurate Situational Awareness	Vote
On the 'Historical Cold vs. Hot Information' view, a red and semi-transparent circle indicates:	
A contact was held at some point in the past (correct).	**2.5**
The exact location of a contact in the past (incorrect).	**0**
The length of time a sonobuoy has been HOT (incorrect).	**0.5**

A sonobuoy has been running low on battery (incorrect).	**0**
Information possibly drawn from the 'Historical Cold vs. Hot Information' view alone:	
Most up-to-date information about the presence of a held contact (incorrect).	**1**
Significant regions in which contact had been present or moved about (correct).	**3**
Significant time periods when contact had been present or moved about (correct).	**3**
Speculated past movement of a held contact (correct).	**3**
Anticipated movement of a held contact (correct, and shows high level of Situation Awareness).	**1**
Conclusions when multiple nearby sonobuoys are HOT (the 'big circles' appear around the sonobuoy icons)	
No more than the fact that these sonobuoys are sensing something (correct, but incomplete).	**1**
The overall area bounded by the 'big circles' most likely contains the contact (correct).	**1**
The region with the most overlapping of big circles is where the contact most likely would be in (correct, and most meaningful).	**2**
The situation is inconclusive (Incorrect).	**0**

8.4.2 Online Question Responses

Results of the online questions were transformed into numerical scores based on predetermined metrics. Table 8-4 to Table 8-6 present the results categorized by each question's associated work domain: the domain of sonobuoy management, the domain of tactical situation awareness, and concepts that fall into the interaction of both domains. The metrics assign a score to each response for its accuracy while recognizing the diversity of sources for information retrieved. A total score across participants for each response is shown, as well as totalling scores for each participant to give a quantifiable performance measure.

Table 8-4: Online Question Response: Sonobuoy Management

Question	Metrics and Corresponding Score		#1	#2	#3	Total
How many DIFAR sonobuoys are left on the screen?	Correct	1	x	x	x	3
	Incorrect	0				0
Point to an active sonobuoy: is this a passive or active sonobuoy?	Correct	1	x	x	x	3
	Incorrect	0				0
Point to a random sonobuoy: can you tell me its location?	Correct answer of exact long/lat	1	x		x	2
	Correct answer of approx. on map	1		x		1
	Incorrect answer of exact long/lat	0				0
	Incorrect answer of approx. on map	0				0

	Don't know	0				0
For the same sonobuoy, how much battery is left?	Correct answer given both exact time and %	1	x	x		2
	Correct answer of % remained	1			x	1
	Correct answer of exact time	1				0
	Incorrect answer	0				0
	Don't know	0				0
How many active sonobuoys will remain on board at the beginning of the 8th hour, if you were to deploy an active sonobuoy every hour from now on?	Correct, using the charts and selection menu on the inventory page.	1	x		x	2
	Correct, without using the charts and selection menu.	1		x		1
If new reports come in and lead you to suspect that there may be a contact showing up near the end of the mission, how would you plan your deployment? (Think about buoy types and rates).	Complete, logical answer, e.g., active buoys should be deployed later in the mission /when contact appears.	1	x	x	x	3
	Logical answer, but not as complete	0.5				0
	Answers which are not reasonable.	0				0
Do they notice the sonobuoy with depleted battery? If not, ask them to look at sonobuoys conditions	Notice quickly.	1			x	1
	Needed more time and/or probing.	0.5	x			0.5
	Did not notice at all.	0		x		0
Can you find out the capability or function of the DIFAR sonobuoy?	They roll over the pie chart to find out details about DIFAR sonobuoys.	1			x	1
	They look at Screen2 and roll over the sonobuoy (takes longer).	1				0
	Don't know.	0	x	x		0
When will you run out of all the current buoys?	Correct	1	x	x	x	3
	Incorrect	0				0
How many passive sonobuoys will still be sensing in the ocean at the end of this mission, if you were to deploy passive sonobuoy 1/ hr from now on?	Correct	1	x	x	x	3
	Incorrect	0				0
Give an exact long lat location of a sonobuoy.	Correct answer of exact long/lat	1	x		x	2
	Correct answer but approx. on map	0.5		x		0.5
	Incorrect answer/Don't know	0				0
How many sonobuoys are deployed at the shallow level, and how shallow would that be?	Correct	1	x	x	x	3
	Incorrect/Don't know	0				0
Ask them when the Sonobuoys were deployed.	Correct	1	x	x	x	3
	Incorrect/Don't know	0				0
How many passive sonobuoys are left right now?	Correct	1	x	x	x	3
	Incorrect / Don't know	0				0
How many active sonobuoys are left right now?	Correct	1	x	x	x	3
	Incorrect / Don't know	0				0

What do you notice about the current condition of the sonobuoys (do they notice the icon without a blue tail)? Probe if they don't notice quickly.	Quickly noticed	1				0
	They did not notice right away until further probing.	0.5	x	x		1
	Never noticed	0			x	0
Give an explanation	They gave a plausible reason: (physically) stuck; and/or malfunctioning.	1	x	x		2
	Cannot give a plausible reason	0				3
Now, if I were to ask you to replace this sonobuoy so that the new one will be at this location (point to it), where would you deploy it?	They considered water direction and gave a plausible answer: e.g., SE of the location, since Water Direction is NW.	1	x	x	x	0
	They did not consider water direction, but gave a plausible answer.	0.5				0
	They did not consider water direction and did not give any plausible answer.	0				0
How long do you think the sonobuoys have been deployed?	Correct	1	x	x	x	3
	Incorrect / Don’t know	0				0
Looking at the historical hot/cold view, please describe what the closely packed groups of circles represent? (do they notice and interpret the small gap between the groups)	Explain: some were the same buoys but at different times, and the gaps are due to expired sonobuoys.	1	x	x	x	3
	Represent the same sonobuoy but at different times.	0.5				0
	Incorrect/Don’t know	0				0
Individual Total		**20**	**18**	**17**	**18**	

Table 8-5: Online Question Response: Tactical Situation Awareness

Question	Metrics and Corresponding Score		#1	#2	#3	Total
Assuming that there has been no big surprise of your contacts' movement for the rest of your mission, what would you anticipate next?	Anything plausible, e.g., sonobuoys continue to be hot, or contact may move forward, or near the current region.	1	x	x	x	3
	Anything implausible / Don't know	0				0
Have any of these sonobuoys detected a contact in the last 3 hours?	Correct (NO, from Historical Hot vs. Cold view)	1	x	x	x	3
	Incorrect (YES) / Don't know	0				0
Now, if I were to ask you to replace this sonobuoy so that the new one will be at this location (point to it), where would you deploy it?	They considered water direction and gave a plausible answer: e.g., SE of the location, since Water Direction is NW.	1	x	x	x	3
	They did not consider water direction, but gave a plausible answer.	0.5				0
	They did not consider water direction and did not give any plausible answer.	0				0
Can you tell if any of these sonobuoys have detected a contact since the beginning of the mission?	Correct: 3 sonobuoys (that are still HOT and have been for 3 hours)	1	x	x	x	3
	Incorrect.	0				0
	Don't know.	0				0
If they have noticed the sonobuoys are HOT initially, ask them where would they suspect the contact(s) to be located?	Correct. Point to the region of overlapping circles.	1	x	x	x	3
	Correct. Point to the overall region of all circles	0.5				0
	Incorrect. Point to anywhere else.	0				0
	Don't know.	0				0
See if they notice that one sonobuoy is no longer HOT. Observe what they say about that.	Notice quickly.	1	x	x	x	3
	Needed more time and/or probing.	0.5				0
	Did not notice at all.	0				0
See if they notice that the final two sonobuoys are no longer HOT.	Notice quickly.	1		x	x	2
	Needed more time and/or probing.	0.5	0.5			0.5
	Did not notice at all.	0				0
Observe what they say about that. Ask them to explain their rationale for it.	They gave a complete and plausible rationale	1	x	x	x	3
	They gave an incoherent rationale	0.5				0
	They couldn't interpret it.	0				0
See if they notice the sonobuoy that is initially HOT right away.	Notice quickly.	1	x	x	x	3
	Needed more time and/or probing.	0.5				0
	Did not notice at all.	0				0
What do you think is happening with this sonobuoy? (the HOT one)	It's HOT for a while/ the last 8 hours.	1	x	x	x	3
	It's HOT.	0.5				0
	Don't know	0				0

Do they notice the two sonobuoys turn HOT?	Notice quickly.	1	x	x	x	3
	Needed more time and/or probing.	0.5				0
	Did not notice at all.	0				0
Ask them what they think is happening.	A contact has moved into the detection ranges of these sonobuoys.	0.5				0
	Most likely location is in the overlapping regions.	1	x	x	x	3
Individual Total		**12**	**11.5**	**12**	**12**	

Table 8-6: Online Question Response: Overlapping Domains

Question	**Metrics and Corresponding Score**		**#1**	**#2**	**#3**	**Total**
How would you deploy your sonobuoys (rate, and where) for the rest of the mission in order to maintain as much tactical picture as possible?	Plausible: deploying near the known/past contacts; deploying 1 or 2 at each hour, etc	1	x	x	x	3
	Anything implausible / Don't know	0				0
What do you think is the current time, approximately?	Correct time into mission	1	x		x	2
	Correct time by some mental calculation	1		x		1
	Incorrect time/ Don't know	0				0
Total		**2**	**2**	**2**	**2**	

8.5 Discussion

As stated earlier, the objectives of user testing are to determine the strengths and weaknesses of the designs in providing the necessary information efficiently and effectively. Good designs should increase the operator's situation awareness, and thus it is important to determine from user testing results how well the participant was able to comprehend the situation and its events. The degree of their awareness is reflected in their responses to a number of online questions, and also through observations made during the user testing trials.

Although the study had a limited number of participants, valuable insights were gained from the participants' feedback, which were surprisingly similar in their criticisms and suggestions. Overall, participants made very few mistakes on questions regarding their understanding of the display components. Besides a few exceptions discussed later in this section, participants showed adequate awareness of key events regarding the tactical situation and the sonobuoy inventory. Furthermore, they demonstrated some degree of higher level situation awareness, as shown by their ability to comprehend the current situation holistically, and their ability to anticipate future events based on past and current information.

The following sections discuss key findings of the results, incorporating observations and comments from participants. These findings include specific issues regarding the effectiveness of designs and those regarding the usability of the prototype (i.e., specific to the prototype implementation rather than the design concepts).

8.5.1 Pie Chart, Horizontal Bar Graph, and Stack Chart for Resource Management

All participants made frequent use of the visualization tools for sonobuoy inventory. Of the three visualizations, two people preferred the stack chart showing the number of remaining sonobuoys over time, and one preferred the pie chart for a quick account of inventory status. One participant particularly emphasized the usefulness of the bar graph showing deployment time and battery life and the stack chart showing numbers of remaining sonobuoys over time. These two displays clearly visualize constraints associated with battery life and sonobuoys availability. This allows users to quickly assess the current inventory availability and anticipate future availability through the choice of future deployment rates provided by the selection menu tool.

Weaknesses and potential problems in design and implementation were also identified:

- Two participants pointed out that using a pie chart to represent inventory status is inappropriate. The numerical range involved is small (e.g., 16 sonobuoys in total) and providing percentages does not add much value to inventory information. Furthermore, it is difficult to derive an actual number from the size of a pie slice: participants resorted to the numerical figures included in the legend for information.
- One participant also commented that there is little need for showing the numbers of expired sonobuoys in the pie chart, which is supposed to give an overview of the current situation.
- Some confusion was noted by one participant in differentiating between the bar graph of deployment time and battery life and the stack chart of remaining sonobuoys over time. This confusion may be due to the close proximity and similar appearances of the two graphs.
- The button included in the selection menu to update the two charts on the inventory page is not necessary. All participants expected to see changes appear in the views when a choice is

selected on the dropdown menu box. They all needed instructions to click on the button for an actual update. This problem was identified as an easily fixed usability issue.

- Some participants were concerned about the use of space in the bar graph and the stack chart. Specifically, they wondered if space would run out if mission length were significantly longer.

8.5.2 Map View and the Sonobuoy Icon

The idea of representing location on a 2D map is in no way foreign to the participants and they all liked it. The main advantage for which the sonobuoy icon was designed was the integration of several importance pieces of data: type, battery life, depth, hot/cold status, range of sonobuoy's ability to sense, and whether it is functioning (receiving and transmitting signals) properly. User testing showed that these attributes were presented very effectively for the most part (see Table 8-1, Table 8-2 and Table 8-4). Participants found the ideas of filled circle for showing remaining battery life and changes in size showing depth intuitive and useful. They also commented on how helpful it was to have the area of possible contact location shown (i.e., the possible detection range covered by a 'hot' sonobuoy). In fact, two of them asked for the detection range to be shown similarly for the 'cold' sonobuoys. However, it should be also noted that the original design included only the 'hot' sonobuoys for the reason to not clutter the space. Additional issues are as follows:

- The salience of alert is not strong enough in the event of a sonobuoy's battery depletion. Alerts should appear in the brief period leading to expected depletion, and in the actual expiry of the sonobuoy should be very obvious. Similarly, the complementary data view continues to display data for the expired sonobuoy and, besides a '00:00' value in the field of battery life remained, failed to show in anyway an important event (i.e., the battery depletion) had occurred.

- The percentage fill of a sonobuoy icon (circle), which indicates percentage remained of battery life, starts at the 3 o'clock position, which has no specific meaning in any conventions of quadrant space. This was pointed out by a participant to be slightly confusing.

- There is no observed adherence to naval symbology in the use of graphical icons. Two participants pointed out that this may be a source of confusion for real operators.

- The stuck sonobuoy (without a blue line of trail attached) was not picked up by one of the participants throughout the entire trial. Another participant also commented that it was not very salient. However, given the stuck sonobuoy, none of the participants had any difficulty in interpreting the potential causes.
- One participant pointed out the possibility of an event in which the potential signal detection areas of sonobuoys overlap on the map, but in fact covering areas at a different depth. A contact that goes undetected by a nearby sonobuoy could then be due to it locating in a different oceanic layer.
- Two participants found the extra description for the sonobuoy's capability and function unnecessary.

The actual data (in text and numbers) presented in grid space were rarely ever the first source of information that participants consulted. This revealed users' natural inclination to graphical visualizations. However, the participants commented that it was nice to be able to refer to the actual data for confirmation and, in some cases, specifics such as the exact minutes left in battery life, and the longitude and latitude of the sonobuoy's location. Participants were impressed that by the controls (mouse-over and clicking) that allowed a two way link between the sonobuoy icon and its corresponding line of data. However, several usability problems were discovered regarding this interaction:

- On the overview screen, clicking on a sonobuoy icon on the minimized map takes the screen to the 'sonobuoy status' page (i.e., the second tab). This has proven to be a source of confusion as some participants expected to see corresponding highlight of data appeared on the sonobuoy they had selected (and subsequently clicked on).
- Participants showed some difficulty in establishing a successful roll-over and/or clicks on a sonobuoy icon due to the small size of the icon and the movement of the icon on screen.
- The masking (or shadowing) of the other sonobuoys when a particular one was selected (i.e., rolled over or clicked on) was not very noticeable.

8.5.3 Hot vs. Cold Information Display

This design was very well received by the study participants. One participant observed that "it would be very useful when an operator has to take over a shift." Indeed, participants had no trouble identifying the tactical history held by sonobuoys. When inquired about the level of difficulty to comprehend multiple circles representing one single sonobuoy, none of them found it confusing. Still, some shortcomings of the design were consistently noted by the participants:

- While the display serves as an overview, participants felt the need to have more details in this display. For example, data provided were updated hourly, which the participants thought was not often enough. A particularly confusing event was when a sonobuoy just lost its contact and no longer appeared to be 'hot' on the map view, but remained hot (red) on the historical view (due to the fact that it was hot at some point over the most recent hour).
- If a sonobuoy drifted very slowly, the heavy overlapping of data points (i.e., the red and blue circles) may hinder the participant's perception of the sonobuoy's past information.

8.5.4 Layout of Display

The organization and layout of information on a display plays an important role in its overall effectiveness. The layout of the display prototype was evaluated based on the following criteria:

- Pros and cons of having three pages, navigated via tabs;
- If the display components were categorized meaningfully (under the three headings), and
- If the sizes and locations of graphical components were appropriate for the page.

Reponses regarding the layout of the pages were varied. One participant thought "the tabs were pretty straightforward under the headings," while another participant found it tedious to be navigating back and forth between pages. In general, they would prefer to have all the information on the same screen, provided that there is enough space.

One participant questioned the need of having two map views, a mini one on the overview page, and the elaborated one on the sonobuoy status page. The same participant claimed that the 'blue line of trail' was redundant as one could observe drifting in the historical hot vs. cold information display. Some participants suggest that there should be a toggle for switching between current and historical information to reduce the amount of graphical components presented simultaneously. This would consequently provide space for an enlarged display of historical hot vs. cold information.

Finally, the study also discovered that multiple pages of information would be likely to decrease the user's situation awareness, since events appearing in only one of the pages would be missed if the user were viewing another page at the time.

Chapter 9
Subject Matter Experts Feedback

This chapter describes the feedback obtained from subject matter experts (SMEs). The SMEs contacted consisted of sonar operators from the Canadian Forces and acoustic engineers experienced in building sonobuoy systems.

9.1 Methods

The process of obtaining SME feedback was done remotely. Three demonstrations were created from the same scenarios that were used in user testing, and supported viewing the simulated activities of contacts on the screen. Feedback was obtained using questionnaires, which focused on subjective ratings in the concepts' effectiveness, level of difficulty, and potential value in an actual mission.

A review package was sent electronically to a number of subject matter experts. The review package contained a number of files:

- An information letter, clearly describing the use and purpose of the review package.
- A PowerPoint presentation that introduces the designs implemented in the prototype.
- A document that describes the three demonstrations in detail (i.e., the tactical situation, events, and limitations).
- Three Flash files containing the three demonstrations
- Three questionnaires, each one specific to a particular demonstration, for the SME to complete.
- Another questionnaire to obtain an overall evaluation of the prototype and provide background information about the SME.

9.2 Results

Four responses were obtained. Two SMEs were experienced acoustic operators from the Canadian Forces and the other two were acoustic engineers who were involved in the IMPACT project. All of them have ten years or more of experience with air-borne sonobuoy receiving systems, and some have additional experience with other types of sonar systems.

9.2.1 Effectiveness of Display Concepts

The effectiveness of concepts was examined by asking about the participant's preference of display concepts in a number of situations. Table 9-1 summarizes results in this category. The most favourably received concept in each of the first three questions is highlighted for saliency.

Table 9-1: Questionnaire Results - Effectiveness of Concepts

Questions	Votes
Which of the following views gives you the best picture of your current sonobuoy inventory?	
Pie Chart for Inventory	**3**
Detailed Data View on the 'Sonobuoy Status' Screen	**0**
Chart for Sonobuoy's Time of Deployment and Battery Life	**0**
Chart for Showing Remaining Sonobuoys on the MPA	**1**
All of the above are equally effective	**0**
None of the above is effective	**0**
Which of the following views would you rely most on to determine a sonobuoy's battery status?	
Sonobuoy Icon (partially filled circle presented on the map views)	**3**
Detailed Data View on the 'Sonobuoy Status' Screen	**0**
Chart for Sonobuoy's Time of Deployment and Battery Life	**0**
All of the above are equally useful	**1**
None of the above is useful	**0**
Which of the following views would you rely on to inform you of a sonobuoy with low battery?	
Sonobuoy Icon (partially filled circle presented on the map views)	**3**
Detailed Data View on the 'Sonobuoy Status' Screen	**0**
Chart for Sonobuoy's Time of Deployment and Battery Life	**0**
All of the above are equally useful.	**1**
None of the above is useful	**0**
In what situation(s) would you want to consult the "Inventory" page? Check all that apply.	
When I need to find out a deployed sonobuoy's battery status	**0**
When I need to find out when the current sonobuoys will expire	**0**
When I need to deploy more sonobuoys	**2**
When I need to determine future deployment rate	**1**
None of the above	**1**

9.2.2 Situation Awareness Supported by Display Concepts

As some concepts were designed to provide support for an operator's situation awareness, the questionnaires included several questions to determine if the prototype was able to achieve some level of situation awareness. Table 9-1 presents the relevant results. A total score for each row is listed in the last column, and an overall score for each participant is provided on the last row. Every correct answer is assigned a score of one. For answers that only demonstrate a low level of awareness, a score of 0.5 is assigned. The maximum score obtained by answering every question correctly and completely is 12.

Table 9-2: Questionnaire Results: Situation Awareness Supported by the Concepts

Questions / Choices	**Score**	**SMEs' Choice**				**Vote**
Direction of the water current that was moving in demo 1:						
North-West (Incorrect)	0					**0**
North-East (Correct)	1	x	x	x	x	**4**
South-East (Incorrect)	0					**0**
There was no indication of the water moving. (Incorrect)	0					**0**
Data possibly drawn from the 'Historical Cold vs. Hot Information' view alone:						
Most up-to-date information about the presence of a held contact. (Incorrect)	0		x	x	x	**3**
Significant regions in which contact had been present or moved about. (Correct)	1	x	x	x	x	**4**
Significant time periods when contact had been present or moved about. (Correct)	1		x	x	x	**3**
Speculated past movement of a held contact. (Correct)	1	x			x	**2**
Anticipated movement of a held contact. (Correct and with high level of SA)	1				x	**1**
Conclusion when multiple nearby sonobuoys are HOT (the 'big circles' appear around the sonobuoy icons)						
No more than the fact that these sonobuoys are sensing something. (Correct, but conservative)	1			x		**1**
The overall area bounded by the 'big circles' is where the contact most likely in. (Correct)	1	x				**1**
The region with the most overlapping of big circles is where the contact most likely is.(Correct, and most meaningful)	1		x		x	**2**
The situation is inconclusive. (Incorrect)	0					**0**
Did you notice the sonobuoy icon without a blue tail, and their interpretation:						
No, I didn't notice at all.	0		x			**1**
Yes, the sonobuoy did not appear to be moving.	0.5	x			x	**2**
Yes, the sonobuoy appeared to be (physically) stuck.	1					**0**

Yes, the sonobuoy appeared to be malfunctioning.	1					**0**
Yes, for other reason. Please describe:	1			x		**1**
Were you aware of the time frame in a scenario, i.e., time with respect to mission length:						
No, not at all.	0					**0**
Yes, but only in the beginning.	0.5		x			**1**
Yes, most of the time.	1	x		x	x	**3**
Yes, constantly.	1					**0**
In demo 3, check any unreasonable action(s) in the case of all sonobuoys deployed have expired:						
Deploy an active sonobuoy near the location of a previously hot sonobuoy. (Incorrect)	0					**0**
Deploy a passive sonobuoy near the location of a previously hot sonobuoy. (Correct)	1	x	x	x	x	**4**
Deploy an active sonobuoy at a rate of 1 every 2 hours. (Incorrect)	0	x				**1**
Deploy a passive sonobuoy at a rate of 1 every hour. (Correct)	1	x	x	x		**3**
All of the above are reasonable actions. (Incorrect)	0					**0**
In demo 3, what would they <u>not</u> expect to see in the near future? Check all that apply:						
Sonobuoy linked to channel 1 indicates HOT. (Incorrect)	0					**0**
Sonobuoy linked to channel 3 indicates HOT. (Correct)	1	x	x	x		**3**
Sonobuoy linked to channel 8 indicates HOT. (Correct)	1		x	x		**2**
Sonobuoy linked to channel 9 indicates COLD (Incorrect)	0				x	**1**
I am not sure what to expect.	0					**0**
Total Score for each Participant	**12**	**8.5**	**8.5**	**10**	**8.5**	

9.2.3 Ease of Use

SMEs were asked to identify any display concepts they had trouble understanding. The responses indicated that none of them had trouble understanding any of the concepts (see Table 9-3). They were then asked to rate the difficulty of performing several different tasks. They were also asked to rate how difficult they would expect it to be to recognize certain tactical events, if there were no visualization of contacts' activities on the map views. Scales provided in all rating questions were from 1 to 5, with 1 being very easy and 5 being very difficult. Table 9-4 summarizes the responses by giving a total rating, for each concept or task, across all subjects. As a result, 4 is the lowest possible score (1*4 SMEs) and 20 is the highest possible score (5*4 SMEs).

Table 9-3: Questionnaire Results: Identification of Concepts that are Difficult to Understand

Did the SME have trouble understanding how any of the following components work?	Votes
Historical Hot vs. Cold Information	**0**
Pie Chart for Sonobuoy Inventory Status	**0**
Sonobuoy icon and the pieces of information revealed	**0**
Blue line showing a sonobuoy's movement	**0**
Chart: Time of Deployment and Battery Life	**0**
Chart: Sonobuoys Remained	**0**
Use of selecting rate of future deployment	**0**

Table 9-4: Questionnaire Results: Easy of Use

Questions	Total Score
Please rate the level of difficulty to perform the following tasks in Demo 1.	
To find out the location of a sonobuoy	**6**
To find out the battery remaining for a sonobuoy	**6**
To find out the depth of a sonobuoy	**6**
To distinguish between a passive and an active sonobuoy	**6**
To detect a malfunctioning sonobuoy	**12**
Please rate the level of difficulty to perform the following tasks in Demo 2.	
To detect that a sonobuoy is HOT	**4**
To visualize the extent of a sonobuoy's coverage	**8**
To anticipate movement of a held contact	**14**
Please rate the expected level of difficulty to recognize the following events in a scenario with no marked contacts (Demo 2):	
The presence of a contact	**6**
A contact moves into the detection range of sonobuoy(s)	**6**
A contact moves away from the detection range of sonobuoy(s)	**8**
Please rate the expected level of difficulty to recognize the following events in a scenario with no marked contacts (Demo 3):	
To detect that a sonobuoy is now HOT	**5**
To visualize the extent of a sonobuoy's coverage	**7**
To hypothesize possible areas of a contact location	**8**
To find out how long a sonobuoy has been HOT	**8**
To speculate movements of a held contact	**10**
To anticipate movement of a held contact	**11**

9.2.4 Potential Values

Finally, the SMEs were asked to rate the potential value of implementing these concepts in real sonobuoy systems to be used in naval missions. They were asked to rate each concept on a scale of 1 to 5, with 1 being not useful at all and 5 being very useful. The responses are summarized in Table 9-5. For each concept, the total score summed over all SMEs is listed.

Table 9-5: Questionnaire Results: Potential Values of Concepts in a Naval Mission

Please rate the level of usefulness the following components may address in a real mission.	Total Score
Overview	
Map View with grids and long/lat labels	**18**
Historical Hot vs. Cold Information	**16**
Pie Chart for Sonobuoy Inventory Status	**18**
Sonobuoy Status	
Sonobuoy icon and the pieces of information revealed	**17**
Blue line showing a sonobuoy's movement	**16**
Lines of data and highlighting of corresponding sonobuoys	**15**
Inventory	
Chart: Time of Deployment and Battery Life	**9**
Chart: Sonobuoys Remaining	**12**
Use of selecting rate of future deployment	**10**

9.3 Discussion

The results indicate that the SMEs had no trouble understanding the display concepts and the information they provide. The responses relating to situation awareness reveal that the SMEs, while interpreting the data conservatively, are aware of the tactical and inventory situation in the demos. In many cases, they were also able to demonstrate anticipation of the location and movement of contacts. Overall, concepts were found to be useful and show potential for further development and implementation in sonobuoy systems used in underwater warfare. A detailed analysis of display components is performed in the following subsections.

9.3.1 Pie Chart, Horizontal Bar Graph, and Stack Chart for Resource Management

In contrast to the user testing results, the pie chart for inventory received 3 out of 4 votes for being the best display in conveying inventory status. One SME commented, "The pie chart for inventory is useful as an overview and far exceeds what is currently available." However, since the SMEs were not questioned during the demos, it is not clear if they found the percentage information revealed by the pie chart particularly useful, or if they would use the numeric inventory count in the legend.

Reactions to the horizontal bar graph and the stack chart for inventory varied. The two acoustic engineers liked the stack chart, with one stating that the tools "make for a great usage planning tool." However, the two acoustic operators from the Canadian Forces held an opposing view. One sonobuoy operator went into great detail in his comments on the reasons why these tools are not particularly useful.

- In an actual mission, the rate of sonobuoy expenditure is not based on an hourly consumption rate. Rather, it is based on the detection range of the target, the target's speed and manoeuvres, and the number of sonobuoys an operator wants to have in contact for tracking (usually two or more).
- The deployment of sonobuoys increases at a somewhat unpredictable rate when a submarine begins evasive manoeuvres. Therefore the charts, as they are seen on this prototype, are not very useful in an operational sense.

It is also noted that as an experienced operator from the Canadian Forces, this particular SME was more conservative in his interpretation and usage of the display concepts. The two military operators were more concerned with the practical aspects of the prototype than the engineers on the development side, who were probably more experienced in evaluating proof-of-concept prototypes.

The same sonobuoy operator provided extensive suggestions for what tools should be included in future prototypes. The operator wanted a tool that allows him to enter detection range and desired number of sonobuoys in contact, and calculate a mean line of advance for a target based on the current and past track parameters (i.e., current speed, average speed in last 0.5-1 hour, number of heading changes in last 0.5-1 hour, and magnitude of heading changes). This data could then be used to forecast sonobuoy expenditure. All of the data required to calculate a mean line of advance for a target can be captured by the original work domain model under contact and track information, and the calculated mean line of advance could have been a measurement for the purpose of 'mmaximize accuracy of individual contact information' in the domain of tactical situation awareness. It is interesting to see that another information requirement was identified here, and this particular calculation demonstrated again the overlapping nature of the two work domains. Curiously, the SME also expressed interest in seeing the expenditure forecasted in a condensed message rather than in chart formats. This may be because he simply dislikes the charts on the inventory page, or perhaps because he is habituated to the text messages used in the current display.

9.3.2 Map View and the Sonobuoy Icon

All SMEs were fond of the map view revealing the location of a sonobuoy's current and past positions. They also found the sonobuoy icon effective in conveying multiple pieces of data. The battery status component, presented as an empty, partially filled, or filled circle was well received by the SMEs (as seen in Table 9-1). In determining a sonobuoy's battery life remaining, most SMEs would choose to examine the sonobuoy icon rather than use the numeric data on the side or the horizontal bar graph for inventory. One SME noted that the sonobuoy icon is particularly useful because the icon provides other information, such as the sonobuoy's hot or cold status, that may imply actions that should be taken (e.g., to deploy another sonobuoy about the same position and at the same depth).

Detecting a malfunctioning sonobuoy, i.e., one that has no blue tail while the other sonobuoys have a tail, is considered the most difficult task, with a total rating of 12 across subjects. This is probably because the lack of a blue tail is not very salient. In comprehending the operational hot or cold status of sonobuoys, SMEs found it very easy to detect a sonobuoy that is hot (total score: 4) and more difficult, but not excessively so, to anticipate the movements of a held contact. In Demo 2, SMEs rated the anticipation of a held contact as a total score of 14 out of 20 (averaged at 3.5 out of 5). In Demo 3, a tactically more complicated situation, SMEs were asked to rate the difficulty of anticipating a held contact if the contact visualization were to be removed from the display. The sum of the ratings was 11 out of 20 (average: 2.75 out of 5). These numbers show that the SMEs did reveal some confidence in the ability of the display concepts to support their situation awareness.

One of the most useful pieces of SME feedback was their association of the design concepts with existing or currently developing technology. This provides an indication of how useful the concepts could be if integrated into existing systems. For example, one of the SMEs, who found the visualized detection range around a hot sonobuoy very effective, also pointed out that this range may be calculated by an acoustic range prediction tool that determines the initial range of detection and provides continuous updates of this range information.

9.3.3 Hot vs. Cold Information Display

Consistent with findings from user testing trials, SMEs also suggested shorter time intervals to accommodate contacts that are only present for a short duration. In the demos, when a sonobuoy went from ‘hot’ to ‘cold’, the corresponding circles on the Hot vs. Cold Information Display stayed red, because they were designed to display any ‘hot’ information over the most recent hour. However, this was confusing for both the SMEs and the participants of the user testing study. As a result, the SMEs thought that “information possibly drawn from the ‘Historical Cold vs. Hot Information’ display” included the “most up-to-date information about the presence of a held contact.” This was an incorrect response.

9.3.4 Other Comments

One SME commented that the concepts were intuitive and have potential. A challenge observed by the SMEs is to integrate the graphical forms and symbology in the designs with existing standards. However, they were quite hopeful that it could be done. The SMEs also pointed out a minor mistake: latitude should always come before longitude on displays.

9.4 Noticeable Differences between User Testing Results and SMEs Feedback

There are some noticeable differences found in the results obtained from user testing and from the feedback of SMEs. These differences include their preferences (e.g., SMEs liked the pie chart while user testing participants did not), as well as the type of comments they gave (e.g., user testing participants were interested in colours and control modes, while (tactical) SMEs were interested in the accuracy achieved). Several factors may account for the difference in opinions:

- SMEs are particularly concerned with the practical use of displays, regardless of the prototype’s limitation in functionality and realistic tactical data.
- Participants of user testing have extensive PC gaming experience. PC games typically contain state-of-the-art graphical components and interactive functionality. The user testing participants are therefore more familiar with the possibilities for data visualization and

usability. Similar differences are also noted between the SMEs from the tactical, operational side, and those from the research and development side.

Chapter 10
Conclusions and Recommendations

10.1 Limitations

Several limitations exist throughout the study. They are listed as follows:

- Data availability: Due to the sensitive nature of tactical data, it is difficult to obtain acoustic and tactical data from training or post-mission analysis. Information on anti-submarine tactics is also limited. A lot of the information and data that would have been helpful for designing and implementing displays is classified information.
- Access to SMEs: SMEs for this study are the sonar/sonobuoy operators from the Canadian Navy and sonobuoy operators from a Canadian Air Force MPA. Limited funding prevented in-person user testing to be run with the SMEs, who are based at the Canadian Forces Base in Halifax, Nova Scotia. Feedback was obtained through an online demonstration of prototype and questionnaires. This removed the opportunity to directly observe experts using the prototype, and the potential feedback such observation could have provided. The number of SMEs the evaluation study was able to obtain feedback from was also limited. Conclusions are drawn from the responses of four SMEs, who may not represent the sonobuoy operator population very well.
- User testing as a means of evaluation: The scale of the project did not allow design concepts to be implemented into a testbed such as IMPACT. In addition, it is impossible to implement the design concept on existing sonobuoy systems. As a result, user testing and SME feedbacks were chosen as evaluation means to point out design weaknesses and usability issues. Due to the subjective nature of these evaluation methods, biases may be present in the user testing results. Users with extensive pc gaming background may be more inclined to prefer good graphics instead of assessing the practical use of certain elements. On the other hand, sonar operators may be overly concerned with how proof-of-concept test cases mimic real situations and thus are negatively biased towards certain concepts. Finally, without a basis (i.e., an existing interface for the system) for comparison, conclusions on

how the new concepts are able to improve operator's performance and situation awareness cannot be drawn.

10.2 Contributions

This thesis contributes to the existing literature in EID. The design process delineated in Burns and Hajdukiewicz (2004) was adapted successfully to a dynamic, loosely bounded system that involves a natural environment, in the military domain. The WDA presented in Chapter 5 describes the resulting WDM that contains two separate but interacting domains, which share an underlying environmental component. Information requirements extracted from the WDM accounted for much of the concept generation of interface concepts. This proves an interesting case of EID in a work domain, or a system, that has significant intentional components and a natural environment that has no purposes of its own.

In the process of understanding the sonobuoy system's operating environment and the nature of the tasks involved, this thesis also examines and summarizes a sonar operator's decision making processes, and the contributing factors from the environment.

Practical contributions were also made through the design concepts resulting from the EID approach. As seen in Section 2.3.3, literature review yields no examples of sonobuoy interface design that consider the management of sonobuoys as physical resources. This project, by drawing a separate work domain model around the management of sonobuoys, has come up with information requirements that were not previously identified. Design concepts were also generated to address the management of sonobuoys as physical entities that may deplete or malfunction, and provide forecasting tools for sonobuoys' expenditure. On the other hand, display concepts for building high level tactical situation awareness were proposed. These concepts are unique to previous research in sonar displays because they attempt to bring out the saliency of high level tactical events, instead of analyzing and visualizing raw sonar data. By providing visualization tools to view the operational status within the geographical context, operators are enabled to connect the information from sonar data to the overall tactical picture and the physical environment they operate in. Tools for providing historical information of sonobuoys and the contacts they (have) held also augment the tactical picture for operators. Finally, the two separate and interacting domains constructed facilitated the design of concepts to fall into two separate domains without disconnecting them. The resulting concepts were able to come together at the end to provide an integrated display.

Evaluation of design concepts was also made possible by the integration of concepts into a Flash prototype. The positive feedback obtained from this evaluation provides a valuable starting point for future interface design for sonobuoy systems, on MPAs as well as on ships. In addition, some of the concepts based on managing sonobuoys can be easily extended to resource management applications.

10.3 Proposed Improvements and Design Recommendations

Results from the user testing study and questionnaires for SMEs show that, in general, the display concepts achieve their intended purposes and are relatively easy to use. The graphical forms are also able to convey the data effectively in most cases. This section summarizes the recommended changes to display designs and implementation, based on the problematic areas described in the user testing results and questionnaire responses by SMEs.

10.3.1 Inventory Visualizing Tools

- Replace the pie-chart with a stack chart that shows the number of remaining and deployed sonobuoys for each type of sonobuoy. The first layer (bottom stack) should represent the number of remaining sonobuoys, since that is the most important information, and the bottom stack is the most salient layer in a stacked chart. The number showing the count of sonobuoys remaining and deployed should be kept in the display. In addition, because the SMEs liked the pie chart, a small study should be run with SMEs to compare the use of pie chart versus the use of a stack chart.
- To clearly differentiate between the bar graph of deployment time and battery life and the stack chart of remaining sonobuoys over time, the following is proposed:
    - Use different textures to shade the blocks found on the two graphs.
    - Provide training or allow more time for users to familiarise themselves with the concepts. This may be sufficient to eliminate confusion between the two graphs.
- Since the user is operating on a real-time basis, it makes more sense if the interface moves forward in time. Therefore, the pointer to current time, which can be found on the timelines and the inventory graphs, should be fixed on the screen: history can grow to the left and interpolation of data for the future can continue to be projected on the right. A horizontal scroll bar can be implemented for access to historical data.

10.3.2 Sonobuoy Status and Condition

- Low battery is a critical piece of information and should be given more salience. Alerts, such as change of colours in the filling, should occur in the period leading up to its depletion, and another alert, such as flashing, when it has just run out of battery. The expired sonobuoy should be removed from screen after a short period of time.
- One participant asked for the visualization of the signal strength on hot sonobuoys. This could be integrated into the icon as the thickness of the icon's border. Stronger signals would generate thicker borders.
- Include a toggle option for turning the detection region on and off for cold sonobuoys. There are times when an operator may want to see the detection range of a cold sonobuoy in order to narrow down the possible locations of a contact held by the hot sonobuoy(s) and spot any gaps in coverage.
- Include an option to switch between showing both shallow and deep detection regions, showing only shallow regions, or showing only deep regions.
- Distinguish between the hot sonobuoys, based on the depth of deployment. This may change the likelihood of contacts in regions that appear to overlap, if the apparently overlapping sonobuoys are deployed at different depths.
- Provide more salience for the stationary sonobuoy without a blue line of trail attached. However, this alert should not be confused with tactical alerts (i.e., a sonobuoy turns hot). Preferably, the interface should be able to use data about the sonobuoy to tell if the sonobuoy is stuck, malfunctioning, or has lost communication with the platform. For the case of malfunctioning or lost signals, one possibility is to grey out the sonobuoy and the region it is supposed to be sensing. This highlight the area that is no longer covered, which is especially important if a contact is being held by sonobuoys in the vicinity.
- While still using a completely filled circle to represent a fully charged sonobuoy, the fill of a circle should begin decreasing from the 12 o'clock position. The current version begins decreasing at the 3 o'clock position, which has no meaning in quadrant space.

10.3.3 Hot vs. Cold Information Display

The overall comments received about this display are that it is intuitive and useful, but it would be better if it had the ability to provide more details about the situation. Based on the suggestions made by user testing participants and the SMEs who provided feedback, here are a list of proposed features and changes:

- Smaller initial time steps, e.g., 15 minutes.
- Adjustable settings for user to change the time steps.
- Allow zooming in on a particular circle to show a breakdown of time history.
- Use rings instead of filled circles, or use smaller dots. This would allow access to historical information even if there has been minimal drifting of the sonobuoys.
- Employ the concept of 'tool tips' to show additional information about each circle.

10.3.4 Layout of Display and other Comments

The use of three tabs was found to obstruct the overall situation awareness as certain information was missing when a user was on a particular view. This work proposes adopting dual monitors, one for the overview, and the other for toggling between details on the sonobuoys and the inventory. If a large display space is available, it is also possible to integrate all three layers into a single screen. Organization of display space would then have to be restructured to map the AH (Abstraction Hierarchy) and DH (Decomposition Hierarchy) space. In such a display, the minimized map on the overview would be redundant and could be removed.

Additional suggestions for the usability controls of the current display are as follows:

- Clicking on the sonobuoy icon on the minimized map of the 'overview' screen should take the user to the detailed screen (as is currently implemented), and also highlight the same sonobuoy icon and the corresponding text and data on the detailed screen. Another solution would be to show tool tip information on the minimized map, instead of redirecting the user to another screen.
- Allow users to select multiple sonobuoys in the map view, therefore highlighting the corresponding text and data of the selected sonobuoys.

- In general, combine all information onto a single screen, provided that there is enough display space.
- Ensure consistency and differentiation in colours. For example, the use of blue to represent 'cold' in the historical information display conflicts with the use of blue to represent active sonobuoys in inventory tools.

10.4 Future Work

The results and conclusions from this study provide a sound basis for future research and development in designing interfaces for sonobuoy systems. A larger evaluation study can be run in the future to test the current prototype and an improved prototype based on the proposed changes described in the previous section. Concepts initially proposed but not implemented due to the technical difficulty and other limitations should be considered for implementation in any revised prototype. For example, the use of a gaze-directed display to alert users without disrupting their visual space may be very useful when monitoring stacked waterfall displays for multiple sonobuoys.

A standardization with naval symbology will also be required to permit the integration of these new interface concepts into real sonobuoy systems. This standardization may include integrating existing symbology with the graphical forms in the new designs, or generating graphical forms that are significantly different from existing naval symbology to eliminate any source of confusion.

Another important area to explore is the use of auditory interfaces in the work of sonobuoy operators. One concept initially proposed was to link the navigation of auditory channels to navigation of the visual channels. This means that the operator would be able to automatically see the visual sonar displays for the sonobuoy to which they are listening. The superior ability of humans to detect signals aurally should be exploited in an auditory interface that supplements its visual counterpart effectively.

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Appendix A

Subject Matter Experts (SMEs) Interview Questions

A1. Interview 1: SCS from Ship

Background

1. As a SCS, what do you consider is your primary role in sonar tasks? (e.g., to confirm/verify 'hot'; to facilitate communication, etc)
2. From my understanding, the sonar system on a frigate includes CANTASS, HMS, and SPS (confirm). Would you say you spend equal time and effort supervising the sonar operators working on these three stations?
   - If not, can you give the order from the most to the least time spent?
   - Do you spend the most time on (e.g., CANTASS) because the information it provides is most useful, or because it is the hardest to work with?
3. When an operation begins, what relevant information is already available before the acoustic operators start their tasks? (e.g., weather, oceanographic, etc)
   How are these information presented to you, and how are they integrated into your displays?
4. On my visit to *Charlottetown,* I noticed white boards with data fields such as drawing in temp/sound velocity, equipment status, etc. In what ways is such information used, and how important do you consider them to be? Is TMA usually done automatically by the system or manually?
5. As a SCS, how do you connect (mentally, or if the technology allows) the sonar information with the overall tactical picture from CCS?

Decision Making:

1. As an acoustic sensor operator, what cues you to the presence of potential targets?
2. When you note a suspicious target, do you (and at what point) make any assumptions about the potential contact? (e.g., the type of vessel, a possible source, etc). *This is to find relationships between the detection and classification tasks - are they really sequential, or does a more experienced operator combine the two tasks mentally?*
3. Do you tend to look for information to confirm, or to reject your hypothesis?
4. When do you decide to call a 'hot'?
5. What information do you look for once you suspect there is a contact of interest? Are you usually able to obtain this information quickly? How is this information presented to you?
6. What is the most demanding aspect of your job, in terms of mental workload? Why?

Mental Model / Situation Awareness:

1. Do you formulate a mental picture of the situation in mind (e.g., known vessels location, actions, directions of possible contacts, etc)?

2. If yes, is there any reference to your current understanding of the tactical picture (something that may be affected by current or anticipated events in the area)

Team Communication

1. Could you describe the level of communication with the other sonar operator(s) in your team?
2. Do the sonar operators you supervise contribute to your decision beside noting and reporting to you any changes or unknown sound source?
3. Is it possible or common to have a discussion going on between the entire group of sonar operators?
4. Could you describe the level of communication with the other non-acoustic operators on your ship?
5. How effective do you feel the communications are, in terms of how they help your performance and understanding of the situation?
6. Giving the Navy's focus on building a NUW environment for the UWW, do you think your tasks may be affected? In what ways?

Evaluation

1. What feedback do you get concerning how well you are performing your detection/classification/localization/tracking task?
2. Do you receive any evaluations or comments by your supervisor? If so, what criteria is used to evaluate your performance?
3. Are you generally confident about your calls on detection/classification? What factors may influence that confidence level?

Expertise:

1. What makes a detection/classification/localization task difficult?
    a. Nature of the target
    b. A particular underwater environment
    c. The physical work environment
    d. Team members, communication
    e. Time pressure, etc
2. What would you call a 'bad day' at work?
3. Can you recall and describe a difficult situation you faced as a sonar operator?
4. Do you have strategies for handling these situations? Please describe them. Are they routine?
5. In a more general sense, what would you consider as the toughest problem in the tasks of a sonar operator?
6. What differences do you find between a novice and an experienced sonar operator? (coming from personal experience or by observing other sonar operators)
7. What makes a sonar operator particularly successful?

Training/Experience:

1. Since graduating from the navy school, have you gone through anymore training sessions?
2. What did you find particularly useful from trainings?
3. Did they help advance your knowledge of the tasks?

4. Were they directly relevant to the tasks you perform?
5. Did they enable you to become an expert of the job?
6. What has your experience provided you with that training didn't?

Interface Modality:

1. Can you give a rough estimate what percent of your sonar task is done in the audio mode?
2. Do you prefer one modality over the other (visual vs. audio)? Which one and why?
3. Do you usually start with the visual display? At what point do you switch to the other modality?
4. While using the audio component, do you continue to use the visual display simultaneously?
1. Does the audio system interfere with your communication with other team members? How?

Ideas for Interface Design

In any design ideas, watch for negative response concerning complexity, workload, etc.

1. What are the interactive components of the current interface you are using? (e.g., point and click, drag and drop)
2. What else do you see can be made interactive?
3. What do you think can be the benefits of having a more interactive display? What are the cons? (can probe and compare with more automation as well)
4. How can a screen be designed to suite your needs better? (add another screen, color coded if not already in use, etc)
5. We talked about audio modality of sonar interface. How may the visual and audio components interact to achieve better information presentation?
6. Would an immersive environment be helpful? For example, audio interface that mimics the direction and range of the sound source.

A2. Interview 2: Acoustic Operator from Aurora (MPA)

1. From my understanding, sonobuoys are the only sonar sensors employed by Aurora, and they are all passive. Is that true?
   - If not, what other sensors are there? How are they being used?
   - Are there any other types of sonobuoys besides the vertical line sonobuoys?
2. When an operation begins, what relevant information is already available before the deployment of sonobuoys start?
3. When do you deploy sonobuoys?
4. What information is required (and what is good to have) before deploying sonobuoys?
5. How do you determine the pattern of sonobuoys to be deployed? (These questions may be the task of the NAV TAC, but see if the acoustic operators are involved in the process as well)
   - What routines, procedures may be employed, or is it more knowledge- based, utilizing experience and training?
   - What patterns are used (grid, array form, circular, etc)? Operators are not likely to comment because it may be classified. Need to find out from other sources
6. How does the current process localize a contact of interest (requiring two sonobuoys as I understand it)?
   - Is it done by creating a mental picture, or the system does it for them (then to what extent and how the final information is presented)?

7. Besides sonar data, what other information is useful for you? e.g., sound speed profiles (SSPs), environmental and geographical conditions, etc.
   MPA seems to deploy their own bathythemography sonobuoys, explore and discuss how these information and fused with the sonar data

Decision Making:

1. At what point do you establish your hypothesis (i.e., a contact of interest is present/ what the contact of interest is)?
2. Do you tend to look for information to confirm, or to reject your hypothesis?
3. At what point do you decide a target is established?
4. When do you report this finding?

Expertise:

1. Is there any particular sequence you use going about the task?
2. When you note a suspicious target, do you (and at what point) make any assumptions about the potential contact? (e.g., the type of vessel, a possible source, etc). *This is to find relationships between the detection and classification tasks - are they really sequential, or does a more experienced operator combine the two tasks mentally?*
3. What cues you to the presence of potential targets?
4. What information do you look for once you suspect there is a contact of interest? Are you usually able to obtain this information quickly? How is this information presented to you?
5. Which task do you find most demanding in terms of mental workload? Why?
6. What makes a detection/classification/localization task difficult?
   f. Nature of the target
   g. A particular underwater environment
   h. The physical work environment
   i. Team members, communication
   j. Time pressure, etc
7. What would you call a 'bad day' at work?
   Can you recall and describe a difficult situation you faced as a sonar operator?
8. Do you have strategies for handling these situations? Please describe them. Are they routine?
9. In a more general sense, what would you consider as the toughest problem in the tasks of a sonar operator?
10. What differences do you find between a novice and an experienced sonar operator? (coming from personal experience or by observing other sonar operators)
11. What makes a sonar operator particularly successful?

Mental Model / Situation Awareness:

1. Do you formulate a mental picture of the situation in mind (e.g., known vessels location, actions, directions of possible contacts, etc)?
2. If yes, is there any reference to your current understanding of the tactical picture (something that may be affected by current or anticipated events in the area)

Team Communication

1. Could you describe the level of communication with the other sonar operator(s) in your team?
2. Could you describe the level of communication with the other non-acoustic operators on your ship?
3. How effective do you feel the communications are, in terms of how they help your performance and understanding of the situation?
4. Giving the Navy's focus on building a NUW environment for the UWW, do you think your tasks may be affected? In what ways?

Evaluation

4. What feedback do you get concerning how well you are performing your detection/classification/localization/tracking task?
5. Do you receive any evaluations or comments by your supervisor? If so, what criteria is used to evaluate your performance?
6. Are you generally confident about your calls on detection/classification? What factors may influence that confidence level?

Expertise:

3. What makes a detection/classification/localization task difficult?
   k. Nature of the target
   l. A particular underwater environment
   m. The physical work environment
   n. Team members, communication
   o. Time pressure, etc
4. What would you call a 'bad day' at work?
5. Can you recall and describe a difficult situation you faced as a sonar operator?
6. Do you have strategies for handling these situations? Please describe them. Are they routine?
7. In a more general sense, what would you consider as the toughest problem in the tasks of a sonar operator?
8. What differences do you find between a novice and an experienced sonar operator? (coming from personal experience or by observing other sonar operators)
9. What makes a sonar operator particularly successful?

Training/Experience:

1. Since graduating from the navy school, have you gone through anymore training sessions?
2. What did you find particularly useful from trainings?
3. Did they help advance your knowledge of the tasks?
4. Were they directly relevant to the tasks you perform?
5. Did they enable you to become an expert of the job?
6. What has your experience provided you with that training didn't?

Interface Modality:

1. Can you give a rough estimate what percent of your sonar task is done in the audio mode?
2. Do you prefer one modality over the other (visual vs. audio)? Which one and why?

3. Do you usually start with the visual display? At what point do you switch to the other modality?
4. While using the audio component, do you continue to use the visual display simultaneously?
7. Does the audio system interfere with your communication with other team members? How?

Ideas for Interface Design

In any design ideas, also watch for negative response concerning complexity, workload, etc.

1. What are the interactive components of the current interface you are using? (e.g., point and click, drag and drop)
2. What else do you see can be made interactive?
3. What do you think can be the benefits of having a more interactive display? What are the cons? (can probe and compare with more automation as well)
4. How can a screen be designed to suite your needs better? (add another screen, color coded if not already in use, etc)
5. We talked about audio modality of sonar interface. How may the visual and audio components interact to achieve better information presentation?
6. Would an immersive environment be helpful? For example, audio interface that mimics the direction and range of the sound source.

Appendix B

Experimental Material

B1. Ethics Application

ORE OFFICE USE ONLY

ORE #______________

APPLICATION FOR ETHICS REVIEW OF RESEARCH INVOLVING HUMAN PARTICIPANTS

Please remember to PRINT AND SIGN the form, and forward TWO copies to the Office of Research Ethics, Needles Hall, Room 1024, with all attachments.

A. GENERAL INFORMATION

1. Title of Project: Evaluation of Interface Concepts Developed for a Sonobuoy system

2. a) Principal and Co-Investigator(s)

Name	Department	Ext:	e-mail:

2. b) Collaborator(s)

Name	Department	Ext:	e-mail:

3. Faculty Supervisor(s)

Name	Department	Ext:	e-mail:
Catherine M. Burns	Systems Design Engineering	84904	c4burns@uwaterloo.ca

4. Student Investigator(s)

Name	Department	Ext:	e-mail:	Local Phone #:
Huei Yen Winnie Chen	Systems Design Engineering	84904	hwchen@uwaterloo.ca	

5. Level of Project: MASc **Specify Course:**

Research Project/Course Status :

6. Funding Status:

Is this project currently funded? Yes

- If Yes, provide Name of Sponsor: NSERC
- If No, is funding being sought OR if Yes, is additional funding being sought? Not Answered
- Period of Funding: 2 years

7. Is this research a multi-center study? No
If Yes, what other institutions are involved:

8. Has this proposal been submitted to any other Research Ethics Board/Institutional Review Board? No

9. For Undergraduate and Graduate Research:

Has this proposal received approval of a Department Committee? Yes

- If Yes or Approval Pending, provide approval date: 10/1/2006

Approval Date: 10/1/2006

B. SUMMARY OF PROPOSED RESEARCH

1. Purpose and Rationale for Proposed Research

a. Briefly describe the purpose (objectives) and rationale of the proposed project and include any hypothesis(es)/research questions to be investigated. Where available, provide a copy of a research proposal:

The purpose of the proposed research is to evaluate a set of interface concepts uniquely developed for the sonobuoy system on board a maritime patrol aircraft. Both the development and the evaluation of interface concepts are objectives of a thesis project at the MASc level. The interface concepts should enable human operators to interpret sonar data quickly and accurately in order to maintain an awareness of their current situation and the manner in which the situational context will evolve in the near to medium-term future. The concepts should address the need to manage multiple sonobuoys and to provide integrated information of data sensed by multiple sonobuoys. Given these design goals, the proposed research intend to investigate how successful these concepts are through qualitative measurements of how study participants navigate and respond to events in a computer-based software implementation of the interface concepts.

b. In lay language, provide a one paragraph (approximately 100 words) summary of the project including purpose and basic methods:

The proposed research aims to evaluate a set of interface concepts uniquely developed for the sonobuoy system on board a maritime patrol aircraft. The concepts are designed to facilitate operators in managing multiple sonobuoys and augmenting their own tactical situation awareness. The concepts have been implemented in the Macromedia Flash environment as an integrated prototype. Three scenarios will be setup for study participants to explore the capability of the concepts; their response to events will be captured by the computer and an investigator on the set. Results of this study would establish the potential value of these concepts and provide direction for future development.

C. DETAILS OF STUDY

1. Methodology/Procedures

a. Which of the following procedures will be used? Provide a copy of all materials to be used in this study.

Survey(s) or questionnaire(s) (in person) All are standardized.
Computer-administered task(s) or survey(s) All are standardized.
Unobtrusive observations

b. Provide a brief, sequential description of the procedures to be used in this study:

1. Greet the Participant.

2. Provide the participant with the Information Letter, and go through it with the participant answering any question he or she may have.

3. Ask the participant to complete the consent letter.

4. Ask the participant to complete the Background Questionnaire.

5. Give the participant a power point presentation to introduce the project and the prototype, explaining how individual concepts work. Answer any questions he or she may have.

6. Explain what they have to do for the study. See script below:

> You will be given three separate trials, each of them models a different tactical situation. Your goal is to recognize what is going on and be aware of the inventory status and tactical pictures. You may explore the displays freely, using the mouse to roll over and click on various components. You are encouraged to speak out loud any thoughts going through your mind. You will be asked several questions during each scenario, and you may answer them with the displays in front of you. At the end of each scenario, you will be given a short questionnaire, asking specific questions relating back to the scenario. When you have complete all three trials, you will be giving an exit questionnaire, which asks you for more feedback and comments on the overall prototype. You can take as much time as you like to browse the displays during each scenario and to answer the questionnaires. Do you have any question before we start the practice trials?

7. Run Scenario 1 (a Flash Movie based interface), during which:

- Ask them a set of pre-determined questions at pre-determined times.
- Encourage them to think-out-loud.
- Observe their navigation and response to events.
- Ask them to complete a short questionnaire at the end of the demo.

8. Repeat 5. for Scenario 2 and Scenario 3.

9. Provide the feedback letter and thank the participant.

c. Will this study involve the administration of any drugs? No

2. Participants Involved in the Study

a. Indicate who will be recruited as potential participants in this study.
UW Participants:
Undergraduate students
Graduate students

Non-UW Participants:
Adults

b. Describe the potential participants in this study including group affiliation, gender, age range and any other special characteristics. If only one gender is to be recruited, provide a justification for this:

Potential participants include sonar simulation enthusiasts and naval combat game players.

c. How many participants are expected to be involved in this study? 5 to 8 participants are expected to be involved in this study, depending on the number of responses to recruitment.

3. Recruitment Process and Study Location

a. From what source(s) will the potential participants be recruited?
UW undergraduate or graduate classes
Businesses, industries

b. Describe how and by whom the potential participants will be recruited. Provide a copy of any materials to be used for recruitment (e.g. posters(s), flyers, advertisement(s), letter(s), telephone script):
The recruitment process will be run by the student investigator of this research: Huei-Yen Winnie Chen. The recruitment process will rely on in-class recruitments, posters and letters.

c. Where will the study take place? On campus: E2-1303N Off campus: Participant's place of work

4. Compensation of Participants
Will participants receive compensation (financial or otherwise) for participation? Yes
If Yes, provide details:
$10 per hour (expected completion time is one hour).

5. Feedback to Participants

Briefly describe the plans for provision of feedback. Where feasible, a letter of appreciation should be provided to participants. This also should include details about the purpose and predictions of the study, and if possible, an executive summary of the study outcomes. Provide a copy of the feedback letter to be used.

A feedback letter will be provided to study participants at the end of the study, when results of the study are finalized. A copy of the feedback letter is attached in this application.

D. POTENTIAL BENEFITS FROM THE STUDY

1. Identify and describe any known or anticipated direct benefits to the participants from their involvement in the project:

Participants will learn about the use of sonobuoys, human factors research, usability issues, and interface design.

2. Identify and describe any known or anticipated benefits to the scientific community/society from this study:

The results of this study will provide meaningful feedback and recommendations to the design of sonobuoy systems' interface. The results will contribute to the continuous research effort in sonar displays, especially for the sonobuoy system used in the Canadian Navy.

E. POTENTIAL RISKS TO PARTICIPANTS FROM THE STUDY

1. For each procedure used in this study, describe any known or anticipated risks/stressors to the participants. Consider physiological, psychological, emotional, social etc. risks/stressors.

No known or anticipated risks

This study is meant to be a usability evaluation of a simple computer-based graphical interface; it has no known or anticipated risks.

2. Describe the procedures or safeguards in place to protect the physical and psychological health of the participants in light of the risks/stresses identified in E1:

There are no known or anticipated risks in this study, and hence no necessary procedures for protection of participants.

F. INFORMED CONSENT PROCESS

Researchers are advised to review the Sample Materials section of the ORE website

1. What process will be used to inform the potential participants about the study details and to obtain

their consent for participation?

Information letter with written consent form

2. If written consent cannot/will not be obtained from the potential participants, provide a justification for this.

3. Does this study involve persons who cannot give their own consent (e.g. minors)? No

G. ANONYMITY OF PARTICIPANTS AND CONFIDENTIALITY OF DATA

1. Describe the procedures to be used to ensure anonymity of participants and confidentiality of data both during the research and in the release of the findings.

During the experimental session, a number will be assigned as a participant ID in the record. The name of the participant, or any other identifying information, will not be part of the data collection. All information collected from participants in this study will be aggregated. Individual names will not appear in any report, publication or presentation resulting from this study.

2. Describe the procedures for securing written records, video/audio tapes, questionnaires and recordings.
Written records will be locked up in a secured location (E2-1303N) where only investigators of the project have access to. The use of these records will be conducted in the same location only, in the presence of investigators of the project only.

3. Indicate how long the data will be securely stored and the method to be used for final disposition of the data.
Paper Records
Confidential shredding after 5 year(s).
Electronic Data
Erasing of electronic data after 5 year(s).
Location: E2-1303N

4. Are there conditions under which anonymity of participants or confidentiality of data cannot be guaranteed? No

---

H. DECEPTION

1. Will this study involve the use of deception? No

Researchers must ensure that all supporting materials/documentation for their applications are submitted with the signed, hard copies of the ORE form 101/101A. Note that materials shown below in bold are required as part of the ORE application package. The inclusion of other materials depends on the specific type of projects.

Researchers are advised to review the Sample Materials section of the ORE web site:
http://www.research.uwaterloo.ca/ethics/human/informed_consent.asp

Please **check** below all appendices that are attached as part of your application package:

- Recruitment Materials: A copy of any poster(s), flyer(s), advertisement(s), letter(s), telephone or other verbal script(s) used to recruit/gain access to participants.
- Information Letter and Consent Form(s)*. Used in studies involving interaction with participants (e.g. interviews, testing, etc.)
- Feedback letter *

* Refer to requirements for content under Elements for Information Letters and Consent Forms, including suggested wording:
http://www.research.uwaterloo.ca/ethics/human/samples/ElementsInfoLtrConsentForm1.htm

Please note the submission of incomplete packages may result in delays in receiving full ethics clearance.
We suggest reviewing your application with the Checklist For Ethics Review of Human Research Applications
to minimize any required revisions and avoid common errors/omissions.
http://www.research.uwaterloo.ca/ethics/form101/checklist.htm

INVESTIGATORS' AGREEMENT

I have read the Office of Research Ethics Guidelines for Research with Human Participants and agree to comply with the conditions outlined in the Guidelines. In the case of student research, as Faculty Supervisor, my signature indicates that I have read and approved the application and proposal and deem the project to be valid and worthwhile, and agree to provide the necessary supervision of the student.

Signature of Faculty Investigator/Supervisor	**Date**
Signature of Student Investigator	**Date**

FOR OFFICE OF RESEARCH ETHICS USE ONLY:

Susan E. Sykes, Ph.D., C. Psych. **Director, Office of Research Ethics** ***OR*** ***Susanne Santi, M.Math*** ***Manager, Office of Research Ethics***	**Date**

ORE 101
Revised August 2003

A. Recruitment Flyer

University of Waterloo
Advanced Interface Design Lab

PARTICIPANTS NEEDED FOR RESEARCH
in Interface Design for Sonobuoy Systems

Department of Systems Design Engineering
University of Waterloo

We are looking for volunteers with pc gaming experience **in sonar-related, or submarine games** to take part in a study of assessing interface concepts for monitoring and managing multiple sonobuoys.

A participant of this study would be asked to engage in a set of scenarios that simulate the tasks of monitoring and managing sonobuoys via a computer-based graphical interface. The participant would be asked to respond to events pertaining the status and condition of sonobuoys in a simulated tactical situation.

The study would take approximately an hour of your time. In appreciation for your time, you will receive $10 as compensation.

For more information about this study, or to volunteer for this study, please contact:
Winnie Chen
Systems Design Engineering
at
519-888-4567 Ext. 34904 or
Email: *hwchen@engmail.uwaterloo.ca*

This study has been reviewed by, and received ethics clearance through, the Office of Research Ethics, University of Waterloo.

B. Recruitment Letter

Dear Sir/Madam:

I am a 2nd year Master's student in the Department of Systems Design Engineering at the University of Waterloo, conducting research under the supervision of Professor Catherine M. Burns on designing innovative display concepts to interface the sonobuoy system on board a maritime patrol aircraft. Sonobuoys are expendable sonar devices that can be dropped by aircrafts in an underwater warfare mission. A sonobuoy system allows the aircraft crew to deploy sonobuoys, and to receive and process acoustic data sensed by the deployed sonobuoys. We are now at the stage of assessing the concepts that have been developed for this particular research. If you have experience with naval combat games or sonar simulations, your opinions on our display concepts may be important to this study. I would appreciate the opportunity for you to come participate in a usability study with our prototype.

As a participant in this study, you would be asked to engage in a set of scenarios that simulate the tasks of monitoring and managing sonobuoys via a computer-based graphical interface. You would be asked to respond to events pertaining the status and condition of sonobuoys in a simulated tactical situation. Your involvement in this study is entirely voluntary and there are no known or anticipated risks to participation in this study. If you agree to participate, the study should not take more than about an hour, and you will be compensated at $10. You may also withdraw from the study at any time and receive remuneration prorated at $10/hour. All information you provide will be considered confidential and will be grouped with responses from other participants. Further, you will not be identified by name in any thesis, report or publication resulting from this study. The data collected will be kept for 5 years in my supervisor's lab at the University of Waterloo.

I plan to conduct this study in our lab space at the University of Waterloo between now and July 13th. You are welcome to choose a date and time that you prefer. I would also be happy to arrange for the study to take place at a location more convenient for you.

If after receiving this letter, you have any questions about this study, or would like additional information to assist you in reaching a decision about participation, please feel free to contact Professor Burns or myself at 519-888-4567, Ext. 34904.

I would like to assure you that this study has been reviewed and received ethics clearance through the Office of Research Ethics. However, the final decision about participation is yours. Should you have comments or concerns resulting from your participation in this study, please contact Dr. Susan Sykes in the Office of Research Ethics at 519-888-4567, Ext. 36005.

Thank you in advance for your interest in this project.

Yours sincerely,

Huei-Yen Winnie Chen
Advanced Interface Design Lab
Systems Design Engineering,
University of Waterloo
519-888-4567, Ext. 34904
hwchen@uwaterloo.ca

C. Information Letter and Consent Form

University of Waterloo

Date

Title of Project: Ecological Interface Design for a Sonobuoy System

Principal Investigator: Dr. Catherine M. Burns
University of Waterloo, Department of **Systems Design Engineering**
519-884-4567 Ext. **84904**

Student Investigator: Huei-Yen Winnie Chen
University of Waterloo, Department of **Systems Design Engineering**
519-884-4567 Ext. **84904**

You are invited to participate in a study that concerns the assessment of new interface concepts for monitoring and managing multiple sonobuoys on board a maritime patrol aircraft. Sonobuoys are expendable sonar devices that can be dropped by aircrafts in an underwater warfare mission. A sonobuoy system enables the aircraft crew to deploy sonobuoys, and to receive and process acoustic data sensed by the deployed sonobuoys. As a participant in this study, you will be asked to engage in three scenarios that simulate the tasks of monitoring and managing multiple sonobuoys via a computer-based graphical interface. For each set of scenario, you will be given a simulated tactical situation in which events pertaining to the status and condition of sonobuoys would require your response. You will be asked several questions during each scenario regarding the simulated events. At the end of each scenario, you will be asked to complete a short questionnaire for you to rate the display components on their level of difficulty and to capture your preferences. You will also be asked during the experiment to verbalize your perception of the situation and the rationale of your response.

Participation in this study is voluntary, and will take approximately one hour of your time. By volunteering for this study, you will learn about human factors research in general and the topic of this study in particular. In addition, you will receive 10 dollars in appreciation of your time. You may decline to answer any questions presented during the study if you so wish. Further, you may decide to withdraw from this study at any time by advising the researcher, and will be remunerated on a prorated basis of $10/hour. All information you provide is considered completely confidential; indeed, your name will not be included or in any other way associated, with the data collected in the study. With your permission, anonymous quotations from the "thinking aloud" may be used in the thesis or any publications. Paper record and electronic data collected during this study will be retained for 5 years. Paper record will be stored in a locked office to which only researchers associated with this study have access. Electronic data will be encrypted with password-only access and stored in a password-protected computer accessible only to researchers associated with this study. There are no known or anticipated risks associated to participation in this study.

I would like to assure you that this study has been reviewed and received ethics clearance through the Office of Research Ethics at the University of Waterloo. However, the final decision about participation is yours. If you have any comments or concerns resulting from your participation in this study, please contact Dr. Susan Sykes at this office at (-519-888-4567 Ext. 36005.

Thank you for your assistance in this project.

CONSENT FORM

I have read the information presented in the information letter about a study being conducted by Dr. Catherine M. Burns and Huei-Yen Winnie Chen of the Department of Systems Design Engineering at the University of Waterloo. I have had the opportunity to ask any questions related to this study, to receive satisfactory answers to my questions, and any additional details I wanted.

I am aware that excerpts from my thinking aloud may be included in the thesis and/or publications to come from this research, with the understanding that the quotations will be anonymous.

I was informed that I may withdraw my consent at any time without penalty by advising the researcher.

This project has been reviewed by, and received ethics clearance through, the Office of Research Ethics at the University of Waterloo. I was informed that if I have any comments or concerns resulting from my participation in this study, I may contact the Director, Office of Research Ethics at 519-888-4567 ext. 36005.

With full knowledge of all foregoing, I agree, of my own free will, to participate in this study.

☐YES ☐NO

I agree to the use of anonymous quotations in any thesis or publication that comes of this research.

☐YES ☐NO

Participant Name: ____________________________ (Please print)

Participant Signature: ____________________________

Witness Name: ________________________________ (Please print)

Witness Signature: ______________________________

Date: ____________________________

D. On-line Questions

Scenario 1 On-line Questions:

Screen	Question
1	Looking at this screen, how many DIFAR sonobuoys are left?
1	Point to an active sonobuoy: is this a passive or active sonobuoy?
1	Can you tell if any of these sonobuoys have detected a contact in the last 3 hours?
2	Point to a random sonobuoy: can you tell me its location?
2	How much battery is left?
2	What can you tell me about the current conditions of the sonobuoys?
2	Now, if I were to ask you to replace this sonobuoy so that the new one will be at this location (point to it), where would you deploy it?
3	How many active sonobuoys will remain on board at the beginning of the 8th hour, if you were to deploy an active sonobuoy every hour from now on?
3	So if new information comes in that leads you to suspect that there may be a contact showing up near the end of the mission. How would you organize your deployment of sonobuoys? (Think about buoy types and rates).

Scenario 2 On-line Questions:

Screen	Question
1	See if participant notice the sonobuoy with depleted battery. If not, ask them to look at sonobuoys conditions
1	Can you tell if any of these sonobuoys have detected a contact since the beginning of the mission?
1	If they have noticed the sonobuoys are HOT initially, ask them where would they suspect the contact (s) to be located?
1	Can you find out the capability or function of the DIFAR sonobuoy?
2	See if they notice that one sonobuoy is no longer HOT. Observe what they say about that.
2	See if they notice that the final two sonobuoys are no longer HOT. Observe what they say about that.
2	See if they notice that the final two sonobuoys are no longer HOT. Observe what they say about that.
2	If they have noticed but didn't comment much. Ask them to explain their rationale for it.
2	Ask them, if they were to deploy more sonobuoys now, where would they consider placing them?
3	When will you run out of all the current buoys?
3	How many passive sonobuoys will still be sensing in the ocean at the end of this mission, if you were to deploy passive sonobuoy 1/ hr from now on?

Scenario 3 On-line Questions:

Screen	Question
1	See if participant notice the sonobuoy that is initially HOT right away.
1	What do you think is happening with this sonobuoy? (the HOT one)
1 or 2	How long do you think the sonobuoys have been deployed?
1	Looking at this view (Historical Information), can you describe what the closely packed groups of circles represent? (can they understand why there's a small gap between the groups)
1 or 2	See if they notice the two sonobuoys that turn HOT. Ask them what they think is happening.
2	Ask them to give an exact long lat location of a sonobuoy.
2	Ask them how many sonobuoys are deployed at the shallow level, and how shallow would that be.
2	Ask them when the Sonobuoys were deployed.
1 or 2	While they are looking at either of the map views, ask them: Assuming that there has been no big surprise of your contacts' movement for the rest of your mission, what would you anticipate next?
lor 3	How many passive sonobuoys are left right now?
1 or 3	How many active sonobuoys are left right now?
3	How would you deploy your sonobuoys (rate, and where) for the rest of the mission in order to maintain as much tactical picture as possible?
Overall	What do you think is the current time, approximately?

E. Questionnaires

Background Questionnaire

The following questions are necessary to maximize the usefulness of your survey responses. Because there may be varying types and levels of expertise from participants, understanding your experience will help us perform more accurate analysis.

1. **What computer game(s) and/or SONAR simulations do you have experience with?**
   - ☐ Computer game(s). Please specify: ______________________________
   - ☐ SONAR simulation(s). Please specify: ______________________________
2. **For the experience(s) listed above, would you consider yourself as:**
   - ☐ Novice
   - ☐ Intermediate
   - ☐ Expert
   - ☐ Undecided
3. **Are you familiar with the use and working of sonobuoys?**
   - ☐ I have no idea what they are.
   - ☐ Yes, I know what they are.
   - ☐ Yes, I know what they are and how they work.
   - ☐ Yes, they are part of the game/simulation/systems I have experience with.
4. **How interested are you in topics regarding naval combat and technology?**
   - ☐ Not interested at all.
   - ☐ Indifferent to such topics.
   - ☐ I enjoy reading about them on the news or in journal papers that I come across.
   - ☐ I am very enthusiastic about such topics; I actively seek information on relevant issues.

Questions for Scenario 1

1. **Which of the following views gives you the best picture of your current sonobuoy inventory?**
   - ☐ Pie Chart for Inventory
   - ☐ Detailed Data View on the 'Sonobuoy Status' Screen
   - ☐ Chart for Sonobuoy's Time of Deployment and Battery Life
   - ☐ Chart for Showing Remaining Sonobuoys on the MPA
   - ☐ All of the above are equally effective
   - ☐ None of the above is effective
2. **Which of the following views would you rely mostly on to determine a sonobuoy's battery status?**
   - ☐ Sonobuoy Icon (partially filled circle presented on the map views)
   - ☐ Detailed Data View on the 'Sonobuoy Status' Screen
   - ☐ Chart for Sonobuoy's Time of Deployment and Battery Life
   - ☐ All of the above are equally useful
   - ☐ None of the above is useful
3. **Please rate the level of difficulty to perform the following tasks, based on this demonstration.**

	Very Easy				Very Difficult
To find out the location of a sonobuoy	1	2	3	4	5
To find out the battery remained for a sonobuoy	1	2	3	4	5
To find out the depth of a sonobuoy	1	2	3	4	5
To distinguish between a passive and an active sonobuoy	1	2	3	4	5
To detect a malfunctioning sonobuoy	1	2	3	4	5

Questions for Scenario 2

1. **Which of the following views would you rely on to inform you of a sonobuoy with low battery?**
   - ❑ Sonobuoy Icon (partially filled circle presented on the map views)
   - ❑ Detailed Data View on the 'Sonobuoy Status' Screen
   - ❑ Chart for Sonobuoy's Time of Deployment and Battery Life
   - ❑ All of the above are equally useful.
   - ❑ None of the above is useful

2. **On the 'Historical Cold vs. Hot Information' view, a red and semi-transparent circle indicates:**
   - ❑ A contact was held at some point in the past.
   - ❑ The exact location of a contact in the past.
   - ❑ The length of time a sonobuoy has been HOT.
   - ❑ A sonobuoy is has been running low on battery.

3. **In this demo, what information could you draw from the 'Historical Cold vs. Hot Information' view alone? Please check all that apply.**
   - ❑ Most up-to-date information about the presence of a held contact.
   - ❑ Significant regions in which contact had been present or moved about.
   - ❑ Significant time periods when contact had been present or moved about.
   - ❑ Speculated past movement of a held contact.
   - ❑ Anticipated movement of a held contact

4. **Given the situation where multiple nearby sonobuoys are HOT (the 'big circles' appear around the sonobuoy icons), which of the following statement do you agree with the most?**
   - ❑ No more than the fact that these sonobuoys are sensing something.
   - ❑ The overall area bounded by the 'big circles' is where the contact most likely would be in.
   - ❑ The region with the most overlapping of big circles is where the contact most likely would be in.
   - ❑ The situation is inconclusive.

5. **Please rate the level of difficulty to perform the following tasks, based on this demonstration.**

	Very Easy				Very Difficult
To detect that a sonobuoy is HOT	1	2	3	4	5
To visualize the extent of a sonobuoy's coverage	1	2	3	4	5
To anticipate movement of a held contact	1	2	3	4	5

Questions for Scenario 3

1. **In what situation(s) would you want to consult the "Inventory" Screen (the 3rd tab)? Please check all that apply.**
   - ❑ When I need to find out a deployed sonobuoy's battery status
   - ❑ When I need to find out when the current sonobuoys will expire
   - ❑ When I need to deploy more sonobuoy(s)
   - ❑ When I need to determine future deployment rate
   - ❑ None of the above

Please rate the level of difficulty to understand and interpret data from the following displays.

	Very Easy				Very Hard
OVERVIEW					
Map View with grids and long/lat labels	1	2	3	4	5
Historical Hot vs. Cold Information	1	2	3	4	5
Pie Chart for Sonobuoy Inventory Status	1	2	3	4	5
SONOBUOY STATUS					
Sonobuoy icon and the pieces of information revealed	1	2	3	4	5
Blue line showing a sonobuoy's movement	1	2	3	4	5
Lines of data and highlighting of corresponding sonobuoys	1	2	3	4	5
INVENTORY					
Chart: Time of Deployment and Battery Life	1	2	3	4	5
Chart: Sonobuoys Remaining	1	2	3	4	5
Use of selecting rate of future deployment	1	2	3	4	5

What do you think about our display concepts? Please list here any other comments or suggestions you have:

F. Feedback Letter

University of Waterloo

Date

Dear

I would like to thank you for your participation in this study. As a reminder, the purpose of this study is to provide feedback for a set of interface concepts developed for monitoring and managing a sonobuoy system on board a maritime patrol aircraft.

The data collected during the session will contribute to a better understanding of the potential value of the concepts in question and identify areas of concerns necessary for future development and implementation of an effective interface for the sonobuoy system.

Please remember that any data pertaining to you as an individual participant will be kept confidential. Once all the data are collected and analyzed for this project, I plan on sharing this information with the research community through seminars, conferences, presentations, and journal articles. If you are interested in receiving more information regarding the results of this study, or if you have any questions or concerns, please contact me at either the phone number or email address listed at the bottom of the page. If you would like a summary of the results, please let me know now by providing me with your email address. When the study is completed, I will send it to you. The study is expected to be completed by August 31st, 2007.

As with all University of Waterloo projects involving human participants, this project was reviewed by, and received ethics clearance through, the Office of Research Ethics at the University of Waterloo. Should you have any comments or concerns resulting from your participation in this study, please contact Dr. Susan Sykes in the Office of Research Ethics at 519-888-4567, Ext., 36005.

Sincerely,

Huei-Yen Winnie Chen

University of Waterloo
Systems Design Engineering
Contact Telephone Number
519 888 4567 x 34904
hwchen@engmail.uwaterloo.ca

G. Scenario Cases

Scenario 1

Time: Scenario begins on the 4th hour of a 10 hr long mission.

Deployment:

- Passive Sonobuoys were deployed at the beginning of the 1st hour. Deployed in a straight line (seen diagonal across the map views). Deployed all at the depth of 120 feet.
- Passive sonobuoys were deployed at the beginning of the 2nd hour. (2 to each side of the original straight line). Deployed all at the depth of 30 feet.
- 1 Active sonobuoy was deployed at the beginning of the 3rd hr. (Approx. W119° 40' 21", N33° 8' 60"). Deployed at the depth of 120 feet.
- 1 Active sonobuoy was deployed at the beginning of the 4th hr. (Approx. W119° 39' 54", N33° 7' 39"). Deployed at the depth of 120 feet.

Total number of sonobuoys originally loaded onto the MPA:

- 12 Passive sonobuoys (DIFAR)
- Active sonobuoys (DICASS)

Key Events:

- About 50 seconds into the scenario, a sonobuoy ("Channel 0") becomes hot.
- All the sonobuoys are drifting in the same direction except one ("Channel 3"). This could be due to malfunctioning of the sonobuoy.
- At the end of the 4th hour, 5 of the current sonobuoys will expire.
- At the end of the 5th hour, all of the current sonobuoys will expire.
- By selecting various rate of deployment of sonobuoys, several conclusions can be drawn:
- If deploying a passive sonobuoy every hour, there will be no more passive sonobuoys to be deployed by the 7th hour of the mission.
- If deploying an active sonobuoy every hour, there will be no more active sonobuoys to be deployed by the 5th hour of the mission.
- If deploying an active sonobuoy every 2 hour, there will be no more active sonobuoys to be deployed by the 6th hour of the mission.

Scenario 2

Time: Scenario begins on the 4^{th} hour of a 10 hr long mission.

Deployment:

- 6 Passive Sonobuoys were deployed at the beginning of the 1st hour. Deployed all at the depth of 30 ft.
- 1 Active sonobuoy was deployed at the beginning of the 2nd hr.
- 1 Active sonobuoy and 1 passive sonobuoy were deployed at the beginning of the 3rd hr.
- 1 Passive sonobuoy was deployed at the beginning of the 4th hour

Total number of sonobuoys originally loaded onto the MPA:

- 12 Passive sonobuoys (DIFAR)
- Active sonobuoys (DICASS)

Key Events:

- Sonobuoys are hot since the beginning of this demo.
- The contact held (represented by the red square) starts to move away.
- The contact moved out of range of one of the three sonobuoys that were hot.
- The contact moved out of range of all sonobuoys.
- One sonobuoy ("Channel 6") shows that its battery has depleted.
- All sonobuoys are drifting in the same direction.
- At the end of the 4th hour, 7 of the current sonobuoys will expire.
- At the end of the 6th hour, another sonobuoy will expire, leaving 1 sonobuoy left that will expire at the end of the 7th hr.
- By selecting various rate of deployment of sonobuoys, several conclusions can be drawn:
- If deploying a passive sonobuoy every hour, there will be no more passive sonobuoys to be deployed by the 7th hour of the mission.
- If deploying an active sonobuoy every hour, there will be no more active sonobuoys to be deployed by the 5th hour of the mission.
- If deploying an active sonobuoy every 2 hour, there will be no more active sonobuoys to be deployed by the 6th hour of the mission.

Scenario 3

Time: Scenario begins on the 7th hour of a 10 hr long mission.
Deployment:

- 10 passive sonobuoys were deployed at the beginning of the mission. All 10 sonobuoys were discarded at the end of the 4th hour due to depleted battery life.
- 10 passive sonobuoys were deployed at the beginning of the 5th hr to replace the previous 10.

Total number of sonobuoys originally loaded onto the MPA:

- 20 Passive sonobuoys (DIFAR)
- 5 Active sonobuoys (DICASS)

Key Events:

- 1 sonobuoy has been hot since the beginning of the mission. The contact held by this sonobuoy is shown on screen to never move throughout the demo.
- A 2nd contact appears at the bottom of the map view as the demo starts. The contact (represented by the red square) starts to move towards the sonobuoys.
- The second contact moves into range of two sonobuoys ("Channel 8 and 9").
- All sonobuoys are drifting in the same direction.

- At the end of the 8th hour, all 10 current sonobuoys will expire, and there are no more passive sonobuoys left to replace them. .
- By selecting various rate of deployment of sonobuoys, several conclusions can be drawn:
- Only 5 active sonobuoys are left. There will not be enough sonobuoys after the 8th hour to continue the current deployment pattern.
- There will be active sonobuoys left in the inventory, if only one were to be deployed at either the rate of every hour or every 2 hour.

Appendix C

Metrics for User Testing Online Questions

Scenario 1 On-line Questions:

#	Question	Metrics	Score
1	**Looking at this screen, how many DIFAR sonobuoys are left?**	**Correct** **Incorrect**	**1** **0**
2	**Point to an active sonobuoy: is this a passive or active sonobuoy?**	**Correct** **Incorrect**	**1** **0**
3	**Have any of these sonobuoys detected a contact in the last 3 hours?**	**Correct (NO, by Historical Hot vs. Cold view)** **Incorrect (YES) / Don't know**	**1** **0**
4	**Point to a random sonobuoy: can you tell me its location?**	**Correct answer of exact long/lat** **Correct answer of approx. on map** **Incorrect answer of exact long/lat** **Incorrect answer of approx. on map** **Don't know**	**1** **1** **0** **0** **0**
5	**How much battery is left?**	**Correct answer of exact time** **Correct answer of % remained** **Incorrect answer of exact time** **Incorrect answer of % remained** **Don't know**	**1** **1** **0** **0** **0**
6	**What can you tell me about the current conditions of the sonobuoys?**	**They notice the sonobuoy icon with no blue tail and gave a plausible reason: (physically) stuck; and/or malfunctioning.** **They notice but could not interpret.** **They did not notice right away until further probing.** **They did not notice at all.**	**3** **2** **1** **0**

7	**Now, if I were to ask you to replace this sonobuoy so that the new one will be at this location (point to it), where would you deploy it?**	**They considered water direction and gave a plausible answer: e.g., SE of the location, since Water Direction is NW.** **They did not consider water direction, but gave a plausible answer.** **They did not consider water direction and did not give any plausible answer.**	**2** **1** **0**
8	**How many active sonobuoys will remain on board at the beginning of the 8th hour, if you were to deploy an active sonobuoy every hour from now on?**	**Correct, using the charts and selection menu on the inventory page.** **Correct, without using the charts and selection menu.** **Incorrect, using the charts and selection menu.** **Incorrect, without using the charts and selection menu.**	**1** **1** **0** **0**
9	**So if new information comes in that leads you to suspect that there may be a contact showing up near the end of the mission. How would you organize your deployment of sonobuoys? (Think about buoy types and rates).**	**Any logical answer, as long as they address that active sonobuoys should not be deployed until later in the mission (or when the contact appears).** **Answers that are not reasonable.**	**2** **1** **0**

Scenario 2 On-line Questions:

#	Question	Correct/Potential Answers	Score
1	**See if participant notice the sonobuoy with depleted battery. If not, ask them to look at sonobuoys conditions**	**Notice quickly.** **Needed more time and/or probing.** **Did not notice at all.**	**2** **1** **0**
2	**Can you tell if any of these sonobuoys have detected a contact since the beginning of the mission?**	**Correct: 3 sonobuoys (that are still HOT and have been for 3 hours)** **Incorrect.** **Don't know.**	**1** **0** **0**

3	**If they have noticed the sonobuoys are HOT initially, ask them where would they suspect the contact (s) to be located?**	**Correct. Point to the region of overlapping circles.** **Correct. Point to the overall region of all circles** **Incorrect. Point to anywhere else.** **Don't know.**	**2** **1** **0** **0**
4	**Can you find out the capability or function of the DIFAR sonobuoy?**	**They roll over the pie chart to find out details about DIFAR sonobuoys.** **They look at Screen2 and roll over the sonobuoy (but this takes longer as they won't know which sonobuoy is a DIFAR to start with.)** **Don't know.**	**1** **1** **0**
5	**See if they notice that one sonobuoy is no longer HOT. Observe what they say about that.**	**Notice quickly.** **Needed more time and/or probing.** **Did not notice at all.**	**2** **1** **0**
6	**See if they notice that the final two sonobuoys are no longer HOT. Observe what they say about that.**	**Notice quickly.** **Needed more time and/or probing.** **Did not notice at all.**	**2** **1** **0**
7	**Observe what they say about that. Ask them to explain their rationale for it.**	**They gave a complete and plausible rationale** **They gave an incoherent rationale** **They couldn't interpret it.**	**2** **1** **0**
8	**Ask them, if they were to deploy more sonobuoys now, where would they consider placing them?**	**They gave a solution coherent with the rationale they have about the situation.** **They gave a solution incoherent with the rationale they gave.** **They don't know where to place them/place them randomly.**	**2** **1** **0**
9	**When will you run out of all the current buoys?**	**Correct** **Incorrect**	**1** **0**
10	**How many passive sonobuoys will still be sensing in the ocean at the end of this mission, if you were to deploy passive sonobuoy 1/ hr from now on?**	**Correct** **Incorrect**	**1** **0**

Scenario 3 On-line Questions:

#	Question	Correct/Potential Answers	Score
1	**See if participant notice the sonobuoy that is initially HOT right away.**	**Notice quickly.** **Needed more time and/or probing.** **Did not notice at all.**	**2** **1** **0**
2	**What do you think is happening with this sonobuoy? (the HOT one)**	**It's HOT for a while/ It's Hot for the last 8 hours.** **It's HOT.** **Don't know**	**2** **1** **0**
3	**How long do you think the sonobuoys have been deployed?**	**Correct** **Incorrect / Don't know**	**1** **0**
4	**Looking at the historical hot/cold view, please describe what the closely packed groups of circles represent? (do they notice and interpret the small gap between the groups)**	**Explain that some of them were the same buoys but at different times, and that the close gap is due to expired sonobuoys.** **Represent the same sonobuoy but at different times.** **Incorrect/Don't know**	**2** **1** **0**
5	**See if they notice the two sonobuoys that turn HOT.** **5b) Ask them what they think is happening.**	**Notice quickly.** **Needed more time and/or probing.** **Did not notice at all.** **A contact has moved into the detection ranges of these sonobuoys.** **Most likely location is in the overlapping regions.**	**2** **1** **0** **1** **2**
6	**Ask them to give an exact long lat location of a sonobuoy.**	**Correct answer of exact long/lat** **Correct answer but approx. on map** **Incorrect answer/Don't know**	**2** **1** **0**
7	**Ask them how many sonobuoys are deployed at the shallow level, and how shallow would that be.**	**Correct** **Incorrect/Don't know**	**1** **0**
8	**Ask them when the Sonobuoys were deployed.**	**Correct** **Incorrect/Don't know**	**1** **0**

9	**Assuming that there has been no big surprise of your contacts' movement for the rest of your mission, what would you anticipate next?**	**Anything plausible, e.g., sonobuoys continue to be hot, or contact may move forward, or near the current region.** **Anything implausible / Don't know**	**1** **0**
10	**How many passive sonobuoys are left right now?**	**Correct** **Incorrect / Don't know**	**1** **0**
11	**How many active sonobuoys are left right now?**	**Correct** **Incorrect / Don't know**	**1** **0**
12	**How would you deploy your sonobuoys (rate, and where) for the rest of the mission in order to maintain as much tactical picture as possible?**	**Anything plausible: deploying near the known/past contacts; deploying 1 or 2 at each hour; deploying a few at once to form a line, etc.** **Anything implausible / Don't know**	**1** **0**
13	**What do you think is the current time, approximately?**	**Correct time into mission** **Correct time by some mental calculation** **Incorrect time/ Don't know**	**1** **1** **0**

Appendix D
Questionnaires for SME Feedback

Questionnaire for Demo 1

1. Which of the following views gives you the best picture of your current sonobuoy inventory?
- ☐ Pie Chart for Inventory
- ☐ Detailed Data View on the 'Sonobuoy Status' Screen
- ☐ Chart for Sonobuoy's Time of Deployment and Battery Life
- ☐ Chart for Showing Remaining Sonobuoys on the MPA
- ☐ All of the above are equally effective
- ☐ None of the above is effective

2. Which of the following views would you rely mostly on to determine a sonobuoy's battery status?
- ☐ Sonobuoy Icon (partially filled circle presented on the map views)
- ☐ Detailed Data View on the 'Sonobuoy Status' Screen
- ☐ Chart for Sonobuoy's Time of Deployment and Battery Life
- ☐ All of the above are equally useful
- ☐ None of the above is useful

3. On the "Sonobuoy Status" screen, did you notice a sonobuoy icon had no blue tail, while all the other ones did? If yes, what was your first interpretation?
- ☐ No, I didn't notice at all.
- ☐ Yes, the sonobuoy did not appear to be moving.
- ☐ Yes, the sonobuoy appeared to be (physically) stuck.
- ☐ Yes, the sonobuoy appeared to be malfunctioning.
- ☐ Other. Please describe: ____

4. Which direction do you think the water current was moving in this demo?
- ☐ North-West
- ☐ North-East
- ☐ South-East
- ☐ There was no indication of the water moving.

5. Please rate the level of difficulty to perform the following tasks, based on this demonstration.

	Very Easy				Very Difficult
To find out the location of a sonobuoy	1	2	3	4	5
To find out the battery remained for a sonobuoy	1	2	3	4	5
To find out the depth of a sonobuoy	1	2	3	4	5
To distinguish between a passive and an active sonobuoy	1	2	3	4	5
To detect a malfunctioning sonobuoy	1	2	3	4	5

Questionnaire for Demo 2

1. **Which of the following views would you rely on to inform you of a sonobuoy with low battery?**
   - ❑ Sonobuoy Icon (partially filled circle presented on the map views)
   - ❑ Detailed Data View on the 'Sonobuoy Status' Screen
   - ❑ Chart for Sonobuoy's Time of Deployment and Battery Life
   - ❑ All of the above are equally useful.
   - ❑ None of the above is useful

2. **On the 'Historical Cold vs. Hot Information' view, a red and semi-transparent circle indicates:**
   - ❑ A contact was held at some point in the past.
   - ❑ The exact location of a contact in the past.
   - ❑ The length of time a sonobuoy has been HOT.
   - ❑ A sonobuoy is has been running low on battery.

3. **In this demo, what information could you draw from the 'Historical Cold vs. Hot Information' view alone? Please check all that apply.**
   - ❑ Most up-to-date information about the presence of a held contact.
   - ❑ Significant regions in which contact had been present or moved about.
   - ❑ Significant time periods when contact had been present or moved about.
   - ❑ Speculated past movement of a held contact.
   - ❑ Anticipated movement of a held contact

4. **Given the situation where multiple nearby sonobuoys are HOT (the 'big circles' appear around the sonobuoy icons), which of the following statement do you agree with the most?**
   - ❑ No more than the fact that these sonobuoys are sensing something.
   - ❑ The overall area bounded by the 'big circles' is where the contact most likely would be in.
   - ❑ The region with the most overlapping of big circles is where the contact most likely would be in.
   - ❑ The situation is inconclusive.

5. **Please rate the level of difficulty to perform the following tasks, based on this demonstration.**

	Very Easy				Very Difficult
To detect that a sonobuoy is HOT	1	2	3	4	5
To visualize the extent of a sonobuoy's coverage	1	2	3	4	5
To anticipate movement of a held contact	1	2	3	4	5

6. **In this demo, the presence of a contact was marked by a red square on the map. Had there been no such marks, would you be able to interpret the situations based on the displays? Please rate the expected level of difficulty to recognize the following events in a scenario with no marked contacts.**

	Very Easy				Very Difficult
The presence of a contact	1	2	3	4	5
A contact moves into the detection range of sonobuoy(s)	1	2	3	4	5
A contact moves away from the detection range of sonobuoy(s)	1	2	3	4	5

Questionnaire for Demo 3

1. **During the demo, were you aware of the scenario's time frame (e.g. mission was at its 4th hour over a total of 10)?**
   - ❑ No, not at all.
   - ❑ Yes, but only in the beginning.
   - ❑ Yes, most of the time.
   - ❑ Yes, constantly.

2. **In what situation(s) would you want to consult the "Inventory" Screen (the 3rd tab)? Please check all that apply.**
   - ❑ When I need to find out a deployed sonobuoy's battery status
   - ❑ When I need to find out when the current sonobuoys will expire
   - ❑ When I need to deploy more sonobuoy(s)
   - ❑ When I need to determine future deployment rate
   - ❑ None of the above

3. **By the end of the 8th hour, all of the sonobuoys deployed would have expired. Which of the following action is not reasonable? Please check all that apply.**
   - ❑ Deploy an active sonobuoy near the location of a previously hot sonobuoy.
   - ❑ Deploy a passive sonobuoy near the location of a previously hot sonobuoy.
   - ❑ Deploy an active sonobuoy at a rate of 1 every 2 hours.
   - ❑ Deploy a passive sonobuoy at a rate of 1 every hour.
   - ❑ All of the above are reasonable actions.

4. **Assuming that there has been no dramatic change of your contact's movement for an hour, what would you <u>not</u> expect to see (and possibly alert you) in the next hour? Please check all that apply.**
   - ❑ Sonobuoy linked to channel 1 (top right corner) indicates HOT.
   - ❑ Sonobuoy linked to channel 3 (top right corner) indicates HOT.
   - ❑ Sonobuoy linked to channel 8 (top right corner) indicates HOT
   - ❑ Sonobuoy linked to channel 9 (top right corner) indicates COLD
   - ❑ I am not sure what to expect.

2. **In this demo, the presence of a contact was marked by a red square on the map. Had there been no such marks, would you be able to interpret the situations based on the displays? Please rate the level of difficulty to recognize the following events in a scenario with no marked contacts.**

	Very Easy				Very Difficult
To detect that a sonobuoy is now HOT	1	2	3	4	5
To visualize the extent of a sonobuoy's coverage	1	2	3	4	5
To hypothesize possible areas of a contact location	1	2	3	4	5
To find out how long a sonobuoy has been HOT	1	2	3	4	5
To speculate movements of a held contact	1	2	3	4	5
To anticipate movement of a held contact	1	2	3	4	5

Exit Questionnaire

Your Background Experience

The following questions are necessary to maximize the usefulness of your survey responses. Because there may be varying types and levels of expertise from participants, understanding your experience will help us perform more accurate analysis.

1. Which of the following SONAR systems do you have experience with? Please check all that apply.

- ❑ Air-borne Sonobuoy Receiving System
- ❑ Sonobuoy Processing Systems (SPS)
- ❑ Canadian Towed Acoustic Sonar System (CANTASS)
- ❑ Hull Mounted Sonar (HMS)
- ❑ Other. Please specify ____________________________

2. How many years of experience do you have with SONAR technology?

- ❑ Under 1
- ❑ 1-4
- ❑ 5-9
- ❑ 10 or more

3. How many years of experience do you have with SONOBUOY systems?

- ❑ None
- ❑ Under 1
- ❑ 1-4
- ❑ 5-9
- ❑ 10 or more

7. Please rate the following systems that apply to you, on their level of difficulty to operate.

	Very Easy				Very Difficult
Air-borne Sonobuoy Receiving System	**1**	**2**	**3**	**4**	**5**
Sonobuoy Processing Systems (SPS)	**1**	**2**	**3**	**4**	**5**
Canadian Towed Acoustic Sonar System (CANTASS)	**1**	**2**	**3**	**4**	**5**
Hull Mounted Sonar (HMS)	**1**	**2**	**3**	**4**	**5**
Other	**1**	**2**	**3**	**4**	**5**