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"Adapting C2 to the 21st Century"

Paper Title: Design for Submarine Command and Control in the 21st Century

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Abstract
Researcher / practitioners at Australia's Defence Science and Technology Organisation (DSTO) are endeavouring to extend the capability of future submarine combat systems. The central pillar of this work is to enable Australia's future submariners to excel in more complex environments (shallow water and high contact density) and networked operations. Command focused information display and automation will help commanders utilize the increased information. To this end, a multidiscipline analysis, design and development project has been established. The team's approach has been to initially step aside from the technology push to return to the fundamental principles of submarine command and control, that is, the tactical decision-making of the commander. A Cognitive Engineering method named Control Task Analysis has yielded a detailed set of both information and knowledge processing requirements. From these requirements, several information design prototypes have been proposed. The designs are proving useful by consolidating our understanding of undersea command and control in a pragmatic way. Moreover, the prototypes provide a requirements push for science and technology based on advancing the information processing capacity of the decision maker. The paper will summarise work to date, demonstrate prototype designs and discuss progression of the designs toward workable prototype evaluation.

1. Introduction

There is growing pressure upon many military platforms, including Australia's conventional submarine fleet, to perform increasingly complex operations in increasingly complex tactical environments and to do this with ever fewer crew. Automation and adaptive systems promise much but these are not likely to match the capabilities of human operated platforms any time soon. In particular, where the situation faced by a platform might be ambiguous, or where innovation and creativity is required, command responsibility is likely to remain vested in human decision makers for the foreseeable future. In the conventional submarine, where stealth is paramount, command ingenuity remains sacrosanct.

A small team at Australia's Defence Science and Technology Organisation (DSTO) site in Western Australia is researching future submarine combat systems with the aim of contributing to the evolving character of the systems. Current systems offer little command and control support functionality.

Command of the submarine depends upon the apparently uncanny ability of a few highly trained officers. A submarine commander has described to us that command of a submarine is like playing 3-D chess in your head. The commander or watch leader (who controls the submarine on any particular crew shift) must mentally conceive a Tactical Picture, that is an awareness of what, where and why vessels in the water around the submarine are doing what they are doing. The task for the submarine watch leader is made doubly difficult because the sensors by which he accesses the energy transmitted by nearby vessels are passive. This means that the commander has no certain measure of the range of a detected vessel. A submarine employs a range of technologies and procedures to disambiguate passive sensor information. These are beyond the scope of the present paper. Clearly, however, the task of leading the watch on a submarine is a fascinating and complex cognitive task. We take the view that to develop cognitive support concepts i.e. command decision support tools we need to employ Cognitive Engineering processes to extract the essence of command decision making from the mental and sociotechnical process of compiling a tactical picture.

To adequately support and eventually enhance the kind of flexibility that submarine command requires we have looked beyond standard operating processes to uncover less tangible aspects of human expertise. Designing displays or contriving automation according to current processes is not enough because above a certain level of complexity, design engineers cannot hope to predict all possible system states or situations faced. Of course this is no revelation. System Engineering has quite a long history of theoretical and pragmatic dealings with what might be called sociotechnical complexity. A method gaining some momentum within DSTO, Cognitive Work Analysis (CWA) has been used by the DSTO-WA team as a means of formalising the cognitive and other activities of submarine command decision making.

By applying the very detailed analysis of command cognition recommended in CWA, we are hoping to guide the hybrid application of human decision support and automation in the conventional submarine into the twenty-first century. After some 18 months of analysis and design, we are at the stage now where we are arranging implementation of prototype systems. These systems are novel concepts based not upon what technology can do but what a commander must do. Hence, new areas of research and development are being generated by melding the subtleties of information and task (tactical) requirements within the constraints and affordances of the energy transmission environs in which the submarine operates – the ocean.

In the sections to follow, we present a summary of the CWA approach, analyses conducted to date and finally outline some example information designs.

2. Cognitive Work Analysis

Cognitive Work Analysis (CWA) was developed from studies into the safe operation of complex industrial systems. It was originally targeted at nuclear power plants, but has since been applied to a variety of other domains (Rasmussen, Pejtersen & Goodstein 1994). The method holds to the premise that it is impossible, for a sufficiently complex system, to identify all the future states that the system might adopt, either by its own operation or in response to external disturbances. This implies that modelling and analyses based on predictions of possible system behaviour will be incomplete and may lead to inappropriate or even dangerous decisions. The same argument can be made against attempting the full automation of such systems because of the danger of the system entering a state that is outside the defined parameters of command. Such an undefined state may result in command responses that are inappropriate or even hazardous.

Effective decision making, command and control within complex sociotechnical systems can only be achieved by means of creative problem-solving on the part of the system's operators (or actors or agents). This is recognised within CWA, which seeks to assist such adaptability by the provision of appropriate information support. Because system complexity makes it impossible to uniquely specify correct system responses to all possible system-environment-states, some other basis must be found to guide command actions. In CWA, this guidance is obtained from identifying decision-shaping constraints that will limit, but will not usually specify, command and / or control actions. Such constraints tend to be invariant over a broad range of system-states, and can be used as a basis for the design of information and decision support systems that will encourage appropriate command decision making, The overall goal then is to maximise responsiveness of the *system* to broad issues of context while maintaining support for the *skill, rule and knowledge-based* behaviours displayed by operators. In this manner, the context-conditioned variability of human expert command responses can be best supported (Vicente 1999b; Vicente & Rasmussen 1992).

CWA Component Analyses

To identify different forms of constraint on command actions CWA provides an integrated, multi-faceted framework for modelling the work that complex systems actually do. Five different component analyses frame the ecology (i.e. the technology, the humans, the environment and their interaction) of cognitive work. These commence with the physical nature of the entire work domain and then progressively move inwards to the cognitive processes of control responses (Rasmussen 1992). The five analyses are:

a. Work Domain Analysis (WDA)
The work domain is deconstructed in terms of both abstraction and physical decomposition and the analysis allows inspection of how the overall functional purposes of the system are ultimately linked to (and afforded by) the physical components that comprise it.

b. Control Task Analysis (CTA)
This takes the form of a constraint-based input-output analysis that permits identification and examination of prototypical cognitive subroutines that experts use in

sequence to construct contextually appropriate responses to the system-states that they encounter.

c. Strategies Analysis
This phase identifies and examines how individual control tasks might be carried out. There is generally more than one method of carrying out a given cognitive task, and all such identified strategies should be supported in the design of any information support.

d. Socio-Organisational Analysis
This examines the division and coordination of work, and the social organization that controls how the various system actors communicate.

e. Worker Competencies Analysis
The final phase of the CWA investigates the capabilities, both individual and generalised, of the actors within the system.

Detailed discussion of all these activities is beyond the scope of this paper but the effort to date in the Work Domain, Control Task analyses and design activities emanating from those analyses is described briefly below.

3. Work Domain Analysis (WDA)

The work domain to be analysed was considered to comprise two separate interacting systems; the environment, and the submarine itself. These two systems were then separately analysed at the five levels of abstraction commonly used for work domain analysis, here listed in decreasing order of abstraction: Functional Purpose; Priorities and Values; Purpose-Related Functions and Processes; Physical Functions and Capabilities; and Physical Objects/Resources. The following section reviews analysis of the Submarine system.

The Collins Class Submarine System WDA

This analysis was initially based on a wide range of documentation, ranging from high-level doctrine and mission statements, down to descriptions of individual systems and equipment found on board the Collins class submarines. The initial analysis took a relatively high-level viewpoint and concentrated on identifying the functionalities of the submarine as a whole. As a result, the physical decomposition was initially restricted to identification of those broad subsystems that were identified as providing the physical functions and capabilities of the submarine.

Once the submarine had been analysed as a component system of the work domain, attention was then refocused onto its subsystems. Analysis of these commenced by identifying their functional purposes to be the physical functions and capabilities previously identified for the high level submarine system. Subsystems were then physically deconstructed down to the level of individual function units (such as an individual sonar array, for example), and WDAs were then carried out for individual subsystems using the same levels of abstraction used for the overall systems, but at this finer level of physical decomposition.

The end result is a system-of-systems approach that allows the analyst to trace the chain of affordances and functionalities that links an individual function unit to the overall functional

purposes of the submarine. The resulting abstraction-decomposition hierarchy is shown below in Figure 1.

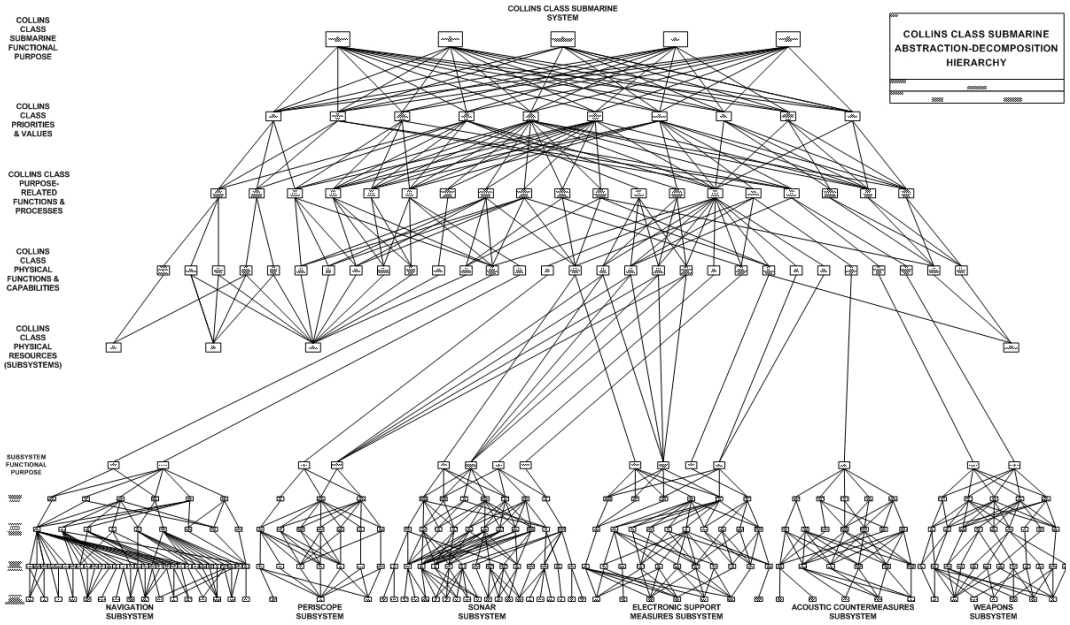

Figure 1. Collins Class Submarine Abstraction Decomposition Hierarchy

On completion of the analysis, the abstraction hierarchies were presented at interviews with a number of subject matter experts (SMEs) for checking and validation. The current status of the abstraction hierarchies derived to date is that they appear to have achieved a high level of accuracy and completeness.

One of the aims of this study was to provide a stand-alone abstraction-decomposition hierarchy that could be investigated for alternative uses, possibly by others. To this end, a formal glossary was developed to define the identified functionalities more closely than the limited labelling on the diagrams would permit. This information, together with the developed abstraction hierarchies has been imported into a web-publishable database for on-line access within the Australian Defence Force intranet.

4. Control Task Analysis

Once the WDA had been completed to the level described, the focus of the analysis was changed to the next phase of the CWA methodology; that of control task analysis. It was decided to examine first, a limited subset of the prototypical work situations or functions that might occur during a submarine mission. To this end, a number of preliminary interviews were carried out to identify work situations that pose a high level of cognitive difficulty to operators and have the potential to place the submarine at considerable risk if errors are made. One of the identified work situations; that of returning the submarine safely from deep water to periscope depth, was then selected for further analysis. Examples were also given at interview where the cognitive loading on the operators had been greatly increased by either the presence of multiple surface vessel contacts, or by the fact that equipment failure or the sound velocity/depth profile had made it impossible to maintain tactical situation awareness while deep. Accordingly, these two criteria were included in the description of the prototypical work situation to be analysed.

Three interviews were carried out, two with serving Lieutenant-Commanders and the third with a recently retired Commander. Total interview time was approximately 14 hours. All three interviews followed the same procedure. The interviewee was first asked to break the task situation into a temporal sequence of readily separable subtasks with no limitations placed on how many subtasks could be nominated. Alternative sequences of these tasks were identified, where possible, together with the reasons that might cause the operator to switch from one sequence to another. An example of such a task breakdown is shown in Figure 2 below.

Each of the identified subtasks was then examined in turn in order to investigate the cognitive decision-making processes of the interviewee, who was encouraged to recount actual experiences, rather than fall back on more generalised standard operating procedures. All information was documented onto the Rasmussen decision ladder template (Rasmussen et al 1994), and the sequence of decision ladders pertaining to the tasks identified in Figure 2 is shown below in Figure 3. Note that control task #2 is used twice.

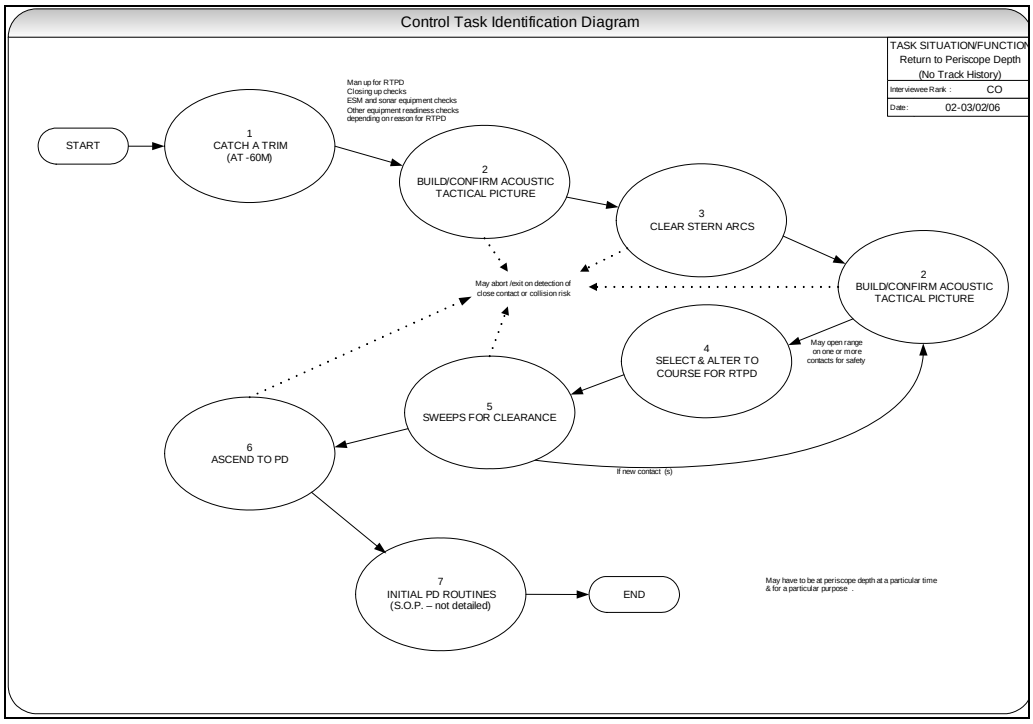

Figure 2. Control Task Identification Diagram

Figure 3 shows that each decision ladder may be considered to be a sequence of information processing activities (rectangular boxes) separated by states of knowledge (circular boxes). Every identified cognitive process was probed for details of the necessary information input, the knowledge outcomes, and the rules or constraints that governed the information processing activity that transformed the first into the second. Wherever possible, expert behaviour in the form of cognitive shortcuts and shunting paths (i.e. transition between knowledge states, and between information processing activities and knowledge states, respectively) was identified and documented.

The final outcome from this phase of the methodology was a listing (compiled across all interview data) of potential information content and knowledge processing support that might

form the basis of information support design for the watch leader position during the single work situation examined. Given the nature of the detailed information requirements of Australia's conventional submarine commanders and watch leaders, we cannot present them here. Needless to say, there is quite a substantial set. Some of these, such as the position and classification of the various vessels surrounding the submarine are very straightforward. Many other information requirements are based in complex number crunching oceanographic physics. Still others are very subtle concepts such as relative threat levels or constraints of time and space and motive.

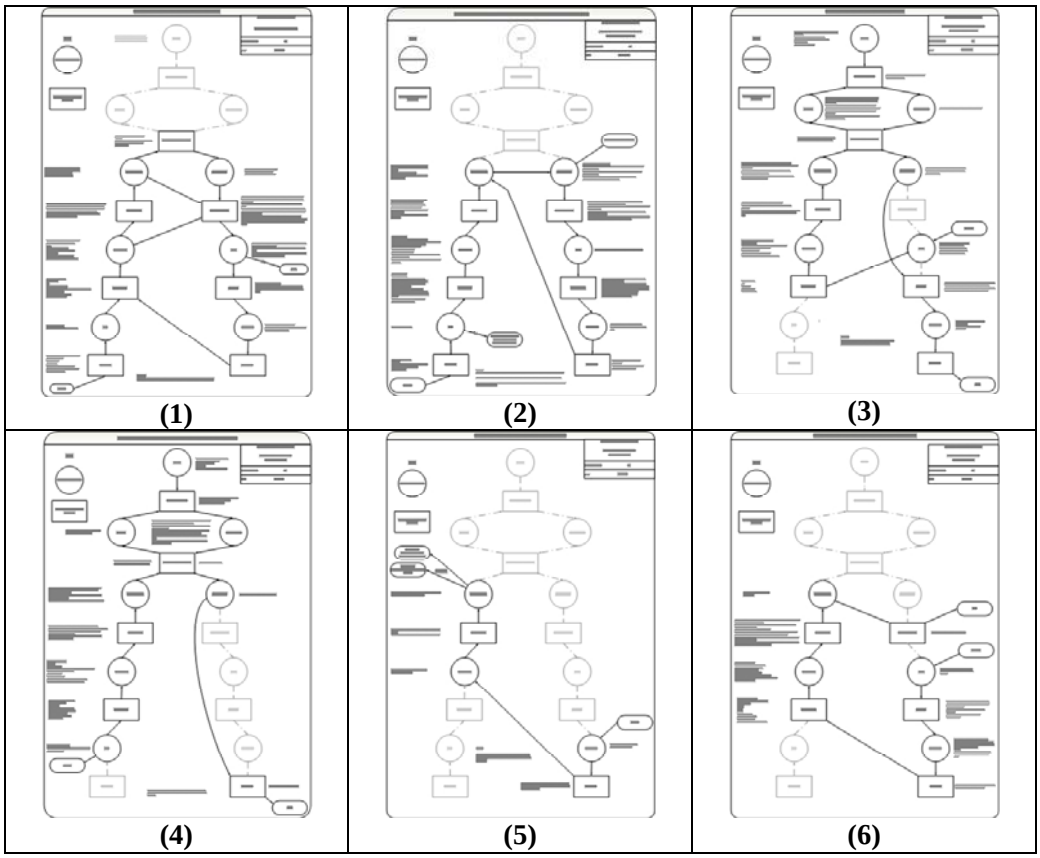

Figure 3. Decision Ladder Sequence

5. General Interface Design Guidelines

In addition to the behaviour-specific guidelines described in the previous section, a number of more general design guidelines are suggested by the cognitive work analysis methodology:

(i) The interface should preferentially encourage the use of skill-based and rule-based behaviours, as these are the hallmarks of expert and competent behaviour, respectively

(ii) The interface must also support knowledge-based behaviour to ensure an effective response to problems and situations outside the current experience of the operator

(iii) The interface should not force the behaviour of the operator to a lower level of cognitive efficiency than is absolutely necessary i.e. all behaviours should be simultaneously supported

(iv) The interface must provide an accurate representation of the work domain if it is to be used by the operators to diagnose system-states and to learn and maintain the veridical mental models necessary for effective control.

Once the recommendations of the cognitive work analysis methodology have been taken into account, interface design guidelines from other sources may usefully be taken into account. A straightforward example of this would be the consideration for use of any standard symbology already in use in the work domain. Other, more complex guidelines may also be considered.

One such guideline is the Proximity Compatibility Principle (PCP) (Wickens 1995). Broadly stated, this principle holds that the closer together items of information occur within the cognitive processes of the operator, the closer together they should appear on any interface display screen. This may be used for guidance as to how to structure information within the broader framework of the functionalities identified from the work domain analysis. The PCP also goes some way towards dealing with the problem of how to minimise the spatial and temporal integration of information that must be undertaken by the system operator.

Example Conceptual Interface Screen Design

In this unclassified setting, we are able to demonstrate some of the more basic concepts under consideration. Given the complexity of the work domain and the potential volume of information required by the watch leaders, some form of information sorting and selection is inevitable, and it is expected that compromises will be required where design guidelines come into conflict. Nevertheless, the design framework provided by the guidelines has proved to be usable, although it should be emphasised that this preliminary screen design has been derived from a very limited subset of the full range of activities that might be undertaken by a Collins class submarine. It is to be expected that further task and strategies analysis of other prototypical work tasks and situations will result in changes and additions to the information shown, and there is a large amount of analysis and design still to be undertaken. However, the results obtained thus far adequately demonstrate the use of the design guidelines to group and order the information derived from the control task analysis process, and give some confidence that the overall design framework produces workable interface designs that support the cognitive work analysis methodology. Ultimately, the usability and usefulness of the interface design can only be quantified by testing, but the conceptual design should provide the basis for initial qualitative appraisal by end-users.

To facilitate description of the display design and its components, the nested hierarchy of interface objects proposed by Woods and cited by Burns and Hajdukiewicz (2004) has been adopted. The hierarchy is listed and described, in order of decreasing scale, in Table 1.

Table 1. Woods' Hierarchy of Interface Objects

(after Burns and Hajdukiewicz, 2004)

INTERFACE OBJECTS	DESCRIPTION
Workspace	The complete display. May include multiple screens, each of which may comprise multiple views
View	Screen or window containing graphic forms related to a single process or sequence
Graphic Form	Individual graph or indicator that provides meaningful information about a process or sequence. Built up from graphic fragments
Graphic Fragment	Graphical subassembly or attribute such as a label, scale etc.
Graphic Atom	Single letters, lines, blocks etc.
Pixels	The smallest display elements. Size depends on screen resolution.

Interface Screen Design

The overall concept adopted for an interface screen design to support a watch leader in returning the submarine to periscope depth is that of a single-screen workspace containing a number of views; some of which are always visible and some of which are contextual. Contextual views may be called into the workspace as the cognitive focus of the operator changes, and he or she selects from among the functionalities identified from the work domain analysis that provide the primary basis for information grouping. Information is called by the operator using touch-screen or cursor-activated keys within the workspace and the contents of individual views may change, depending on the functionalities selected.

For the purposes of demonstration, the conceptual display design has been limited to the screen area presented by a 28-inch diagonal, square format display screen, as being representative of the type of display that might be available within the control room of a Collins class submarine. Restrictions placed on information availability because of limited screen space are probably inevitable, given the potentially large amount of information that the operator can make use of. However, any such limitations must be treated with extreme caution because they will inevitably increase workload as operators are forced to locate, remember and integrate information over greater temporal and spatial intervals.

The high degree of flexibility granted to the operator in the selection of what information to be displayed, results in the ability of the interface screen to take a wide variety of forms. The precise content of the screen will depend on the requirements of the operator and these will be governed by the particular situation in which he or she finds themselves.
The workspace developed from the control task analyses contains seven views: the Key Numerical Data view, the Chart view, the Contact Summary view, the Prediction Display View, the Vital Signs view, the Course Prediction view, and the Anti-Submarine Warfare Threat Status view. These will be briefly described in turn.

The Key Numerical Data View
This view is positioned across the top of the workspace and consists of non-selectable, digital graphic forms that present the submarine's course (degrees True), speed (knots), depth (metres), and position (degrees latitude and longitude). Also shown are Local and Zulu times.

The Chart View
This is the largest of the individual workspace views and is permanently displayed. The view is based on an electronic chart of the area immediately surrounding the submarine which can be scrolled and scaled by the operator. He/she can also select different information sets to be overlaid onto the chart view by selecting one or more of the functionality tabs that are located along the lower edge of the workspace. When necessary, these tabs also call up additional context-based views that then appear around the periphery of the workspace. As shown, the chart display contains information selected by the Navigation and Counterdetection (Active) functions.

The chart view displays seabed bathymetry contours with particular emphasis being placed on indicating the coastline and those underwater depth contours that place constraints on submarine access and movement. Additional standard chart information is also displayed, such as traffic separation schemes, wrecks, seabed type, pilotage marks and buoys etc. Ownship position and positioning error estimates are indicated, together with the present course and speed and the historical track. Navigational waypoints from the current navigation/mission plan are indicated, together with other planned track information. Additional data is shown for the next waypoint to assist the operator in monitoring progress against the current navigation plan. The current position and extent of the moving haven is also shown to provide a visual indication of the manoeuvring constraints imposed by this particular type of waterspace management.

The location and classification of all currently held contacts are shown on the chart, together with analogue indications of their current tracking solution courses and speeds. Figure 5 also shows summary information adjacent to each contact within the chart view, but this duplicates some of the information in other views and may be removed for decluttering purposes. Any contact on a zigzag course will also have available additional information on the time since the last zig, the previous zig interval and the magnitude of the previous speed and course change (consideration might be given to also providing the mean line and speed of advance). Contacts that are held but are not currently within the displayed area of the chart are indicated at their correct bearing and range on the chart view periphery.

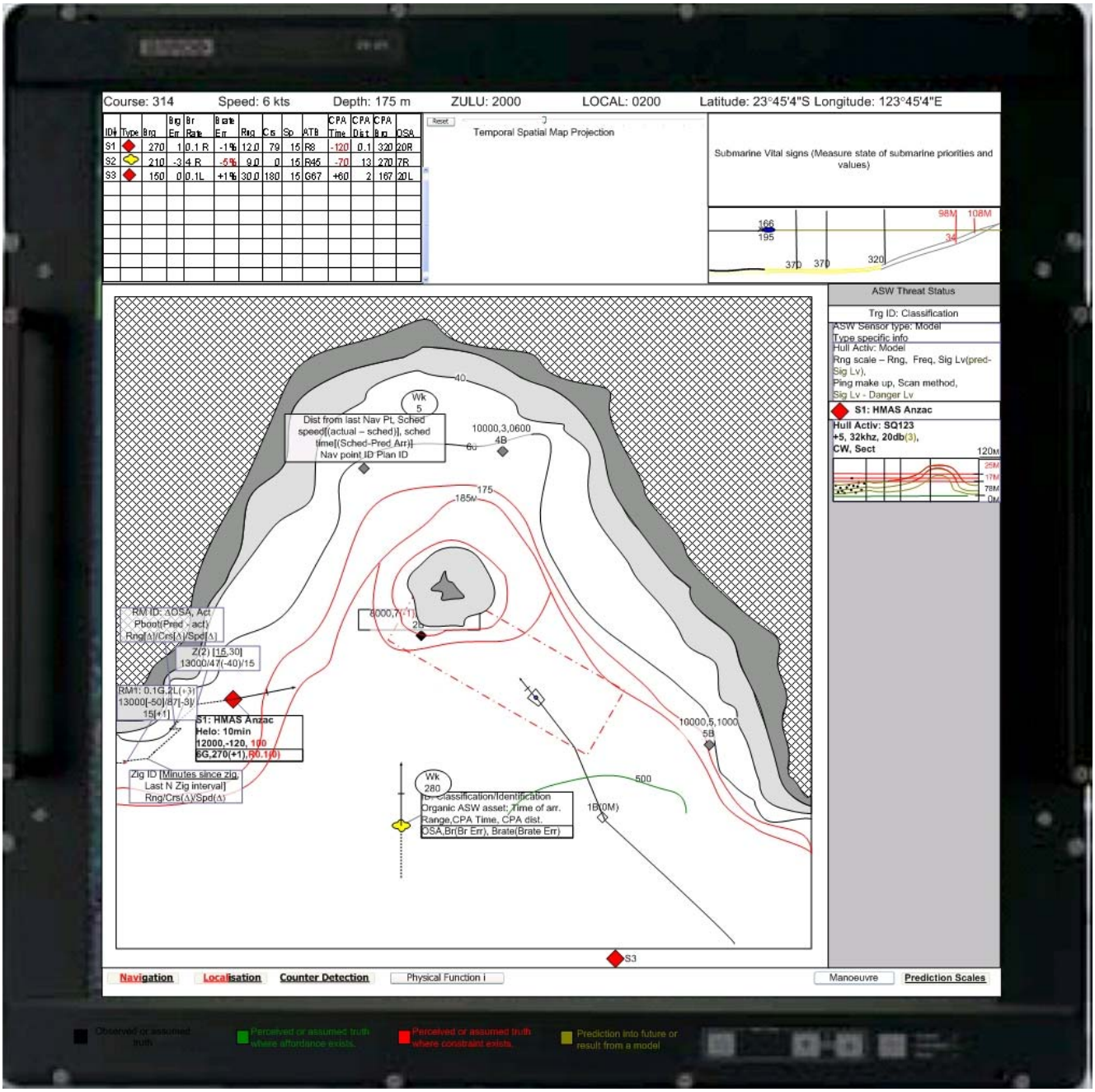

Figure 5 Interface Screen Design Concept

An important feature of the chart view is that it is associated with a touch-screen slider control to provide a prediction of the position of all contacts held, assuming that they maintain current course and speed. The scale of the look-ahead slider control can be set by the operator, and will match the other prediction scales in use. As the slider control is moved, the current prediction interval will be displayed between Zulu and Local times at the top centre of the workspace. This is directly above the slider control which is shown at the upper edge of the Prediction Display view, between the Contact Summary view and the Vital Signs and Course Prediction views. When the prediction is active, the numerical Zulu and Local time indications change colour and their value is adjusted to reflect predicted, rather than actual, time. Moving haven and other waterspace area management boundaries that vary with time will also respond to use of the slider control.

The Contact Summary View

This is located at the upper left hand corner of the workspace and comprises a scrollable list all the contacts currently held in alpha-numeric order. The actual sonar bearing and bearing rates are listed, together with error figures derived from comparison with the current solution tracker for each contact. This provides the operator with both the magnitude of any solution error and the rate at which that error is either increasing or decreasing (i.e. whether the solution is lagging or leading the actual sonar bearing). The components of the current firing solution for each contact are shown in terms of range, course, speed and angle on the bow (ATB), as are the time and distance to the closest point of approach (CPA) at current courses and speeds. The predicted contact bearing at CPA is also shown, as is the current ownship speed across the line of bearing (OSA). The operator has the ability to designate contacts as “priority”. These are then moved to the top lines of the summary table and are permanently on view because they can no longer be scrolled.

The Prediction Display View

This is located to the immediate right of the Contact Summary View and is used to display information relating to the effects of a proposed course change. It is unused in Figure 5.1 other than to include the touch screen slider control for the Chart view.

The Vital Signs View

This view is currently shown in the upper right hand corner of the workspace, and has yet to be populated. The view is reserved for direct support of Collins class functionality at the level of Priorities and Values. It is the intention to provide measures of performance indicators at this level of abstraction to ensure that the watchleader maintains an effective, high-level overview of the performance of the boat and its crew. The proposed indicators will provide high level notification to the watchleader of potential problem areas, as well as providing guidance as to where the watchleader might usefully direct his or her attention. It is likely that they will be permanently displayed.

No formal development of these indicators has yet been undertaken, but some suggestions are listed below to provide examples of the type of information that might be considered for inclusion. It should be understood that these are highly speculative at this stage of development,

and will require considerable Command input to ensure their utility. They are listed against the relevant functionality from the work domain analysis:

Sustainment

- Energy storage levels relative to planned requirements
- Breathing air quality
- Life support consumable constraints

Maintenance of Morale

- State of crew fatigue
- Direct measurement of operator error-rates
- Cumulative durations of various states of alert/readiness

Gaining and Maintaining the Initiative

- Proactive/reactive balance
- Decision cycle time measurement
- Red force manoeuvring patterns, and proximity and concentration relative to ownship

Precise Application of Force

- Overall level of contact tracking accuracy
- Potential for errors in current firing solutions

Security (Avoidance of Detection)

- Current overall probability of detection measurement
- Ownship signature measurement and control
- Overall threat level measurement

(Achievement of) Surprise

- Probability of weapon launch transients detection
- Probability of undetected weapon strike

Economy of Effort

- Selected weapon effectiveness in current tactical/environmental situation
- Ownship position with respect to expected volume of operations

Flexibility

- Range of tactical options currently open
- Available water volume for manoeuvre and historical rate of change
- Summary measurement of ownship proximity to manoeuvring constraints
- Existence and number of viable alternative plans

Selection and Maintenance of the Aim

- Adherence to mission schedule
- Adherence to navigation plan

- Ownship ability to meet critical deadlines

Cooperation

- Status of tactical communications links
- Latency of received tactical information
- Time to next scheduled communications link
- Status of ownship adherence to communications schedule(s) and any resulting constraints.

The Course Prediction View

This view is located above the top right hand corner of the Chart view, and immediately below the Vital Signs view. It comprises a projection of the current ownship course and speed over the seabed topography, viewed perpendicular to the course and over an operator selected timescale. As shown in Figure 5.1, this has been operator selected at 120 minutes. Ownship depth and height above the seabed is shown numerically, and the locations of major bottom contours are given. The time at current depth, course and speed to come within 20 metres of the seabed (at 195 metres) is given as 98 minutes, as is the time to grounding (at 108 minutes). Where known, different seabed types may be indicated along the course line and the difference between the expected water depth and that obtained from soundings (corrected for tidal effects) is indicated to provide an indication of chart depth or ownship positioning accuracy.

The ownship symbol is also linked to the touch-screen slider control and will move along the track as the operator changes the look-ahead interval. Times to the significant depth constraint boundaries will also change as the ownship symbol moves.

The Anti-Submarine Warfare (ASW) Threat Status View

The ASW Status view presents detailed information on up to four contacts that have been designated by Command as ASW threats. Each contact has the same alphanumeric identifier as in the Contact Summary view together with a type or unit classification, if known. If available, information on the sonar capabilities is presented, together with information as to its current mode of usage. The difference between the operating range scale of the threat sonar and the actual range is displayed to provide immediate indication that the submarine is detectable at the current operating mode. Also, the received sonar signal level is presented, together with any difference between the measured level and that predicted from the known sonar capabilities, the operating range, and the current environmental conditions and sound velocity/depth profile. Any significant difference will provide warning that either the ASW sonar capabilities may have been incorrectly estimated, or that the sonar propagation modelling is of poor quality and hence unreliable. As shown in Figure 5, the submarine is currently outside the current operating range of the ASW sonar, the sonar performance and environmental modelling appear to be accurate, and the received sound level is 13dB below detection threshold at the current range.

The final component of each of the individual ASW Threat Status views is a graph of modelled incident sound level (hence detection risk) along the predicted track of the submarine, if ownship and ASW threat courses and speeds are maintained. The timescale is the same as that selected for the Course Prediction view (120 minutes in the example shown) and the plot shows that the

submarine is predicted to enter the sonar detection range of contact S1 in approximately 78 minutes, and will remain detectable for a further 17 minutes. Actual intercepted sound pressure levels over the recent past are also plotted to allow ongoing monitoring of the overall accuracy of the sonar modelling.

Additional Information Overlays

At this stage in the project a series of mockups have been generated including a number of concept of overlays to add additional, operator-called information to the interface screen. This includes additional views in the periphery of the workspace and the use of the Prediction Displays. This enables, for example, the operator to investigate the consequences of a potential ownship course change in terms of improving the localisation of contacts.

User Activated Prediction View

With the Localisation functionality selected, this view is brought onto the workspace to provide additional predictive information on the contacts of interest in the form of a table that links on a line-by-line basis with the table in the Contact Summary view. As the proposed new course and speed are varied, the change in OSA for each of the contacts is continuously calculated and displayed, as are their predicted bearing rates out of the turn (PBOOT) and the ballpark range error for each of the solutions. Also calculated and shown are revised predictions of time to CPA, and CPA distance and bearing.

To the right of the table are numerical forms that give the time required to complete the proposed course and speed change, the new course and speed and their differences from the current values, and a “Lock Prediction” button that enables the operator to retain the prediction if he or she needs to switch to a different information overlay. On completion of any course change manoeuvre, the ownship course and speed indicator will coincide with the predictor line, the time to completion value will be zero, and the new course and speed will be numerically displayed. Any PBOOTs that do not agree with the new contact bearing rates will be highlighted to warn of the possibility that the contact has zigged, and the revised tracking solutions for the selected contacts will be automatically displayed in the Contact Summary view.

Status of Conceptual Interface Screen Design

Figure 5 represents an initial attempt at presenting information and knowledge processing support derived from a Control Task Analysis, structured according to the functionalities obtained from a Work Domain Analysis and informed by the design guidelines described earlier. Although incomplete, and requiring further input to ensure that all necessary information has been identified, the designs provide some confidence that the Cognitive Work Analysis methodology can result in interface designs that are both usable and useful – at least on a task by task basis.

Analysis of a greater range of control tasks should result in a deeper and more confident identification of the information required by the watch-leader of a Collins class submarine across the full range of identified functionalities. This should, in turn, begin to transform the limited results achieved thus far into a user interface that can provide support across the full range of operational and tactical situations, including those that have not been specifically analysed.

5. Summary Remarks and Projected Activities

Application of cognitive work analysis to defining and supporting decision and control within Australia's Collins class submarines has been initiated with the aim of implementing working and testable prototype systems. Although primarily targeted at information support and interface design, initial indications are that the depth and richness of the information captured by the methodology may have application across a range of broader information management aspects; some of which are already being investigated (including new technology impacts).

At this stage, sufficient confidence in the methodology has been established to continue the research, and the direction of future work is being discussed. At this stage it is likely that this will initially lead to the design of both general and context-sensitive information support for the watch leaders of the submarines. DSTO has the capability to carry out scenario-based simulation testing of the support intended for command team decision and control, and use it to quantify performance enhancements or decrements. Successful outcomes will also result in the extension of the complete CWA methodology to a range of command team functions and examination of possible human and automated information support combinations.

The high level of effort involved in carrying out a full cognitive work analysis on a domain as complex as submarine command and control demands a staged approach that can provide sufficient confidence to justify continued investment in time and resources. Such confidence can only be obtained from unequivocal demonstration that design outputs do, in fact, result in real improvements in operator performance and/or reduced workload. In turn, this can only be obtained from quantitative test data.

Accordingly, a development path is outlined below that allows for a staged increase in effort, based on the results of simulation-based testing. The path limits initial investigations to the watch leader position in the existing command team hierarchy until sufficient confidence is gained to deepen the study to include other tasks and functions, currently carried out by other members of the command team.

- Complete the current limited design study, resulting in a completed information display to support the watch leader position in returning the submarine safely from deep water to periscope depth.
- Mock-up the design to the extent that it can be used to obtain qualitative feedback from serving submarine personnel at the level of watch-leader and above.
- Ideally, test the screen in a task-specific scenario-based simulation against the currently available forms of information support.

6. References

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