Team Decision Making: eliciting the structure of interdependences when returning to periscope depth

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ABSTRACT

Introduction: This paper is concerned with the elicitation and representation of team decisions when returning a submarine to periscope depth. The paper is following the trend to examine the team decisions rather than those of individuals, although the contributions of individual roles are considered. **Method**: The Decision Ladder from Rasmussen's Cognitive Work Analysis is used to elicit the team decisions in the first instance. **Results and discussion:** The elicitation of team decisions using the Decision Ladder was verified by experts as a valid representation. Further analysis was conducted using Evaluation and Execution Matrices which mapped the data gathered by the Decision Ladder approach. The SOCA-DL was used to capture the contribution of different roles. The resultant analysis was proposed as a benchmark for comparing future concepts as well as an approach to develop requirements for interface, procedure, job aid, decision support and simulator design, as well as decision making training.

KEYWORDS

Decision ladder; team decisions; submarine; representations; interdependencies; periscope depth

INTRODUCTION

Naturalistic Decision Making research has shifted focus from the individual to distributed decision making (Smith and Dowell, 2000; Stanton and Wong, 2010), whereby the decision-making process is distributed across team members (Zsambok, 1992; Stanton et al, 2010). One important aspect of this research lies in understanding the nature of distributed decision making so that effective decision support can be provided (Klein and Miller, 1999; Klein, 2008). This paper presents a case study focusing on decision making in naval teams during the return to periscope depth exercise. The aim of the paper is to model the distributed decision-making process in this context and examine the insights that may be gleaned from the models. The project began with observations of the Return to Periscope Depth (RTPD) scenario in a training simulator (e.g., travelling from 60 metres depth up to 17 metres). The analysis was further developed with two Petty Officers who had recently returned from sea. Review and validation of the analysis was undertaken with members of the training staff. Finally, the analysts presented the representations to the Maritime Warfare Centre. The attendees included a number of ex-submariners who were able to verify the analysis. Part of the complexity of the problem of returning to the surface safely is the dependency on passive sonar as a means of detecting surface vessels. Additional complexity comes from working as a team comprising personnel from the sound room, control room and ships control, as well as contributions from the rest of the ship. To analyse this system required the application of a method that would assist in identifying key features of the work and be able to clarify the constraints. Cognitive Work Analysis (CWA) was developed to analyse complex socio-technical systems such as those found in nuclear power generation (Rasmussen, 1986). This development came from the realisation that an in-depth understanding of the interrelations of social systems and technical systems was required to fully appreciate how constraints act upon the working of system functions (such as the communications and activities in and between the sound room and control room on a nuclear submarine). These systems are made up of numerous interacting parts, both human and non-human, operating in dynamic, ambiguous and often safety critical domains. The complexity embodied in these systems presents significant challenges for modelling and analysis and most methods are not well designed to capture the complexity of the interrelations and analyse the layers of interconnection within socio-technical systems (Jenkins et al, 2009; Vicente, 1999; Rasmussen, 1986). The semi-structured framework presented within CWA helps to guide the analyst through considerations of the various levels of constraints acting on systems and the effects that they can have upon the way in which work can be carried out. The CWA process has been criticised for being complex and time consuming. In order to address these concerns, and in an attempt to provide some level of guidance and expedite the documentation process, the HFI DTC (Human Factors Integration Defence Technology Centre; www.hfidtc.com) has developed

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a CWA software tool. Built to run on the Microsoft .net framework, the tool uses a familiar windows-based interface and interfaces directly with Microsoft Office applications. The tool provides templates to allow documents to be created that describe each of the five phases described in the CWA framework, providing a structure for those unfamiliar with the technique (Jenkins et al, 2009). The software tool allows data to be passed between these phases, expediting the documentation process, and facilitating updates and changes.

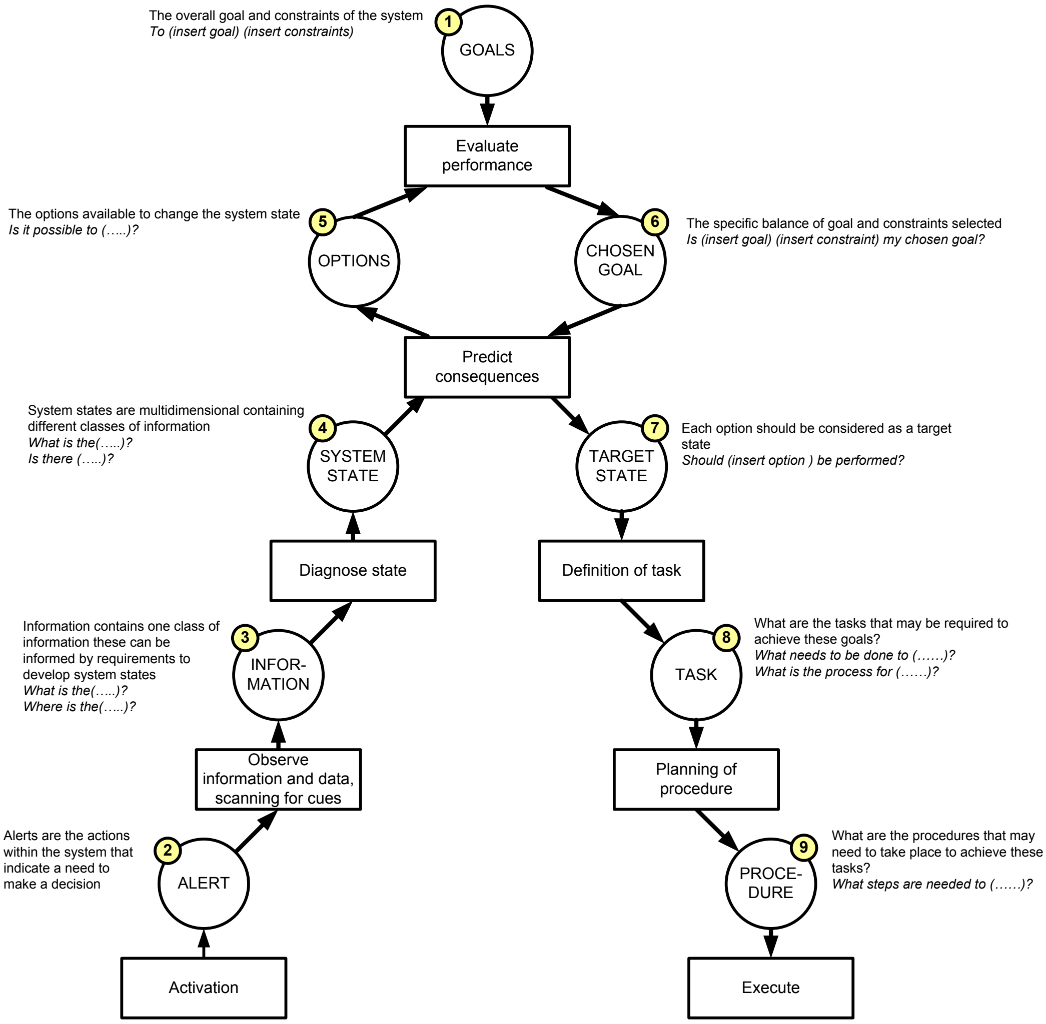

Figure 1. The decision ladder (from Rasmussen, 1986).

THE REPRESENTATION

Rasumussen's decision ladder was used as the method for eliciting and representing the deicions made by the teams (Jenkins et al, 2010). The decision ladder has two different types of node: the rectangular boxes represent information-processing activities and the circles represent states-of-knowledge that result from information-processing activities (see Figure 1). The decision ladder can be used to describe both levels of expertise and novelty of the decision processes. Novice users are expected to follow the decision ladder in a linear fashion, whereas, expert users are expected to link the two halves by short-cuts. The left side of the decision ladder represents the observation and information gathering activities to identify the system state, whereas, the right side represents the planning and execution of tasks and procedures to achieve a target system state. In between identifying the system state and target state are the options selection activities to meet the desired goal(s). In experts or proceduralised activities, observing information and diagnosing the current system state immediately signals a procedure to execute. This means that rule-based shortcuts can be shown in the centre of the ladder. On the other hand, effortful, knowledge-based goal evaluation may be required to determine the procedure to execute; this is represented in the top of the ladder. There are two types of shortcut that can be applied to the ladder; 'shunts' connect an information-processing activity to a state of knowledge (box to circle) and 'leaps' connect two states of knowledge (circle to circle); this is where one state of knowledge can be directly related to another without any further information processing. It is not possible to link straight from a box to a box as this misses out the resultant knowledge state. In an attempt to better understand decision making, the decision ladder can be used to develop prototypical models of activity. It is important to draw the distinction between typical and prototypical work situations. People tend to describe what they find to be normal, usual ways of doing things, representing an intuitive averaging across cases – typical situations. Conversely, prototypical work situations are developed from actual data from context specific cases. This then forms a set of prototypical activity elements, defined by either problem to solve or situation to solve within, which, in varying combinations can serve to characterise the activity within a work system.

This Decision Ladder analysis was undertaken with subject matter experts though interviews, as follows:

- The experts were introduced to the decision ladder model and asked to describe their overall goal in operating the system
- The experts were asked to talk the analysts through the process of making a decision about when to return to periscope depth. The experts were guided to start the description by indicating what might first draw their attention to the need to return to periscope depth (the alert).
- The experts were then asked to list the artefacts that they might use to gather information.
- The experts were asked to explain how they used this information to diagnose the current system state.
- The experts then described the options available to them.
- The experts explained how they would balance the competing constraints on their goals.
- Based upon the goal selected the experts then listed the target states available (options) and selected the target state they would take.
- This state was then broken down into a series of tasks.
- The tasks were then broken down into high level procedures.

Once recorded, the notes were read back to the expert, and at each stage of the decision ladder, the expert was asked to capture all other elements that would be available. For example, list other possible reasons why they might have to return to periscope depth.

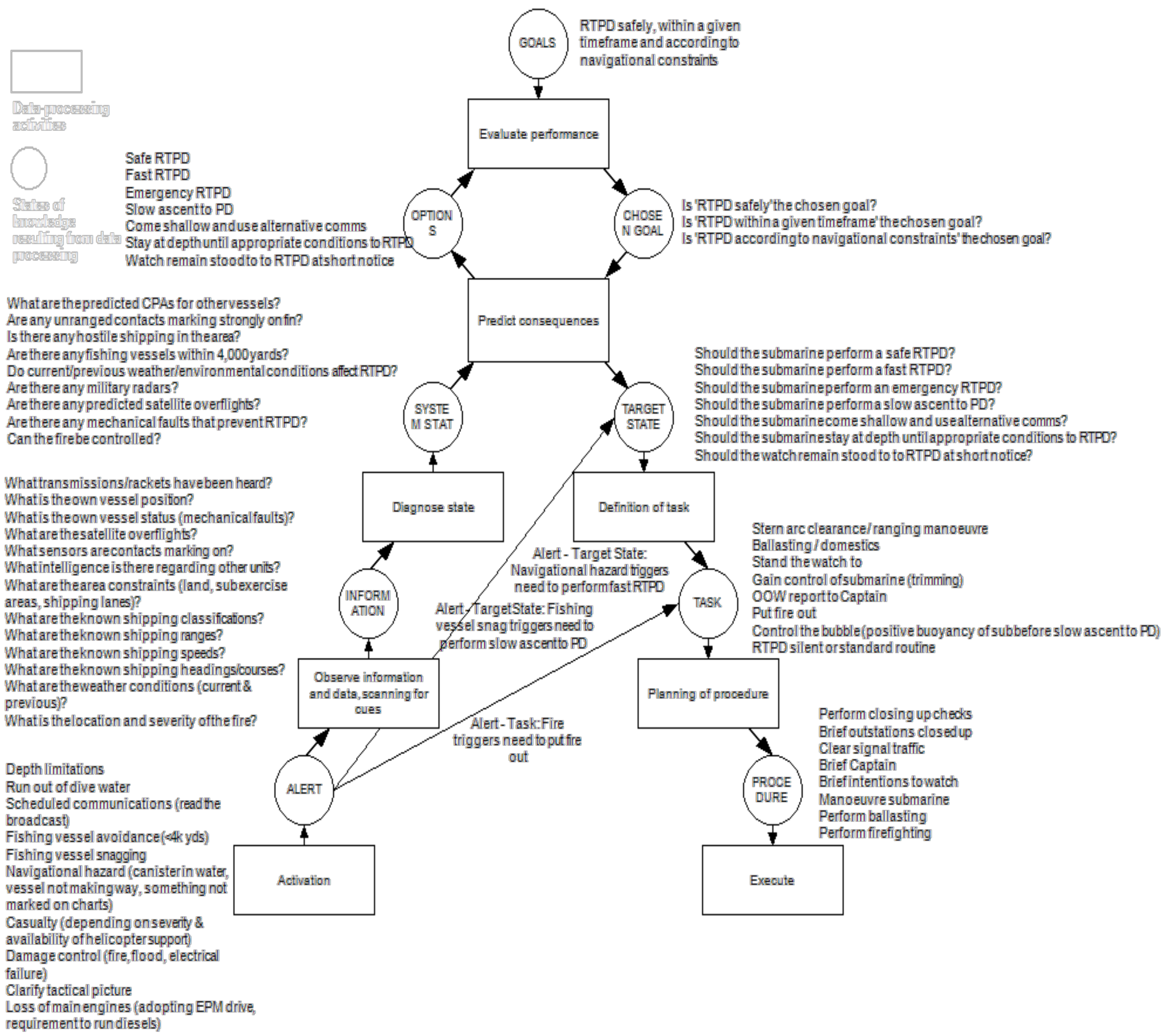

Figure 2. The decision ladder for returning to periscope depth in normal peacetime operations.

THIRTY TWO DECISIONS

The information gathered using the methods described above was used to generate the model presented in Figure 2. In order to constrain the analysis, the experts recommended that the ladder be completed for a specific scenario, with the submarine acting autonomously, conducting standard operations, under general peacetime conditions, in a home waters environment. As can be seen from Figure 2, even under these conditions a multitude of factors influenced the decisions involved in determining how to proceed for RTPD. Starting with the goals, the experts identified three constraints acting on the overall goal of returning to periscope depth; to return safely, within a given time frame and according to navigational constraints. Given that these constraints can be in conflict (the need to return safely may mean that the time frame cannot be met, for example) this then leads to three possible choices of goal.

A number of alerts, or reasons why the submarine would need to RTPD, were elicited, ranging from the need to make a scheduled communication to a casualty or fire onboard. The information that might subsequently need to be gathered included known shipping classifications, ranges, speeds and so forth, as well as the own vessel position and status in terms of any mechanical faults. The system state elements then reflect what can be ascertained from the available information. So, for example, combining information about own vessel with shipping ranges, headings, etc. enables calculation of the Closest Points of Approach (CPAs) for other vessels.

Options identified were of two types; either different ways in which a RTPD could be conducted (safe, fast, emergency or a slow ascent), or, interestingly, alternatives to returning to periscope depth, namely coming shallow to use alternative communications, staying at depth, or leaving the watch 'stood-to' ready to RTPD at short notice. These options also represented the available target states, selected on the basis of the chosen goal (RTPD safely, within a given timeframe or according to navigational constraints). Tasks listed covered the range of actions that might be necessary to achieve the possible target states, such as standing the watch to and ranging all contacts, along with the procedures for carrying out these tasks (e.g. manoeuvring the submarine). Owing to time constraints it was not possible to cover the full range of tasks and procedures, and reference to other phases of the analysis shows that there is more that could be added here. Indeed, further development and refinement of the decision ladder would be the first step in any follow-on work that aimed to take advantage of this particular output.

Finally, a number of 'leaps' were identified by the experts – shortcuts connecting two states of knowledge. One leap connecting the 'alert' and 'task' states of knowledge represented the fact that as soon as a fire is detected, it must be put out. Two leaps connected the 'alert' and 'target state' states of knowledge. Firstly, encountering a navigational hazard, for example something not marked on the charts, might trigger the need to perform a fast RTPD. Secondly, snagging a fishing vessel automatically leads to the target state of performing a slow ascent to perisciope depth, in order to minimise the risk to those onboard the snagged vessel. These leaps highlight the fact that the journey around the decision ladder does not necessarily involve travelling up one side and then down the other in a linear fashion. They also show how the decision making process can be iterative. In the case of detecting a fire, the leap to formulating the task of putting out the fire would immediately be followed by a return to the left hand side of the decision ladder in order to assess the severity of the fire and determine the correct course of subsequent action. This is also true when some of the target states relating to doing something other than RTPD are selected. If the decision is made to stay at depth, for example, then the situation will continue to be monitored until the system states are such that it becomes possible to RTPD.

Once the decision ladder had been completed, it was then possible to examine how the various elements related to each other. The left hand leg of the ladder contains information on the team's 'evaluation' of the state of the world (e.g., gathering information to understand the state of the system and identify the options available to them) whereas the right hand leg conatins information of the team's 'execution' activities (e.g., the target states and tasks they can implement when the option has been selected).

The decision ladder in Figure 2 shows the complete range of information, system states, tasks and so forth that can be involved in a RTPD, i.e. it is prototypical, as described previously. It can be useful to determine the relationships between each of these to understand which items of information contribute to which system states. This can be done for both 'legs' of the decision ladder. It should be noted that, in line with the formative nature of the CWA approach, the fact that elements are related does not mean that they 'do' influence each other, but rather that they 'could'. Firstly, the information, system states and options can be related to each other, as shown in Figure 3, with the black cells indicating a relationship.

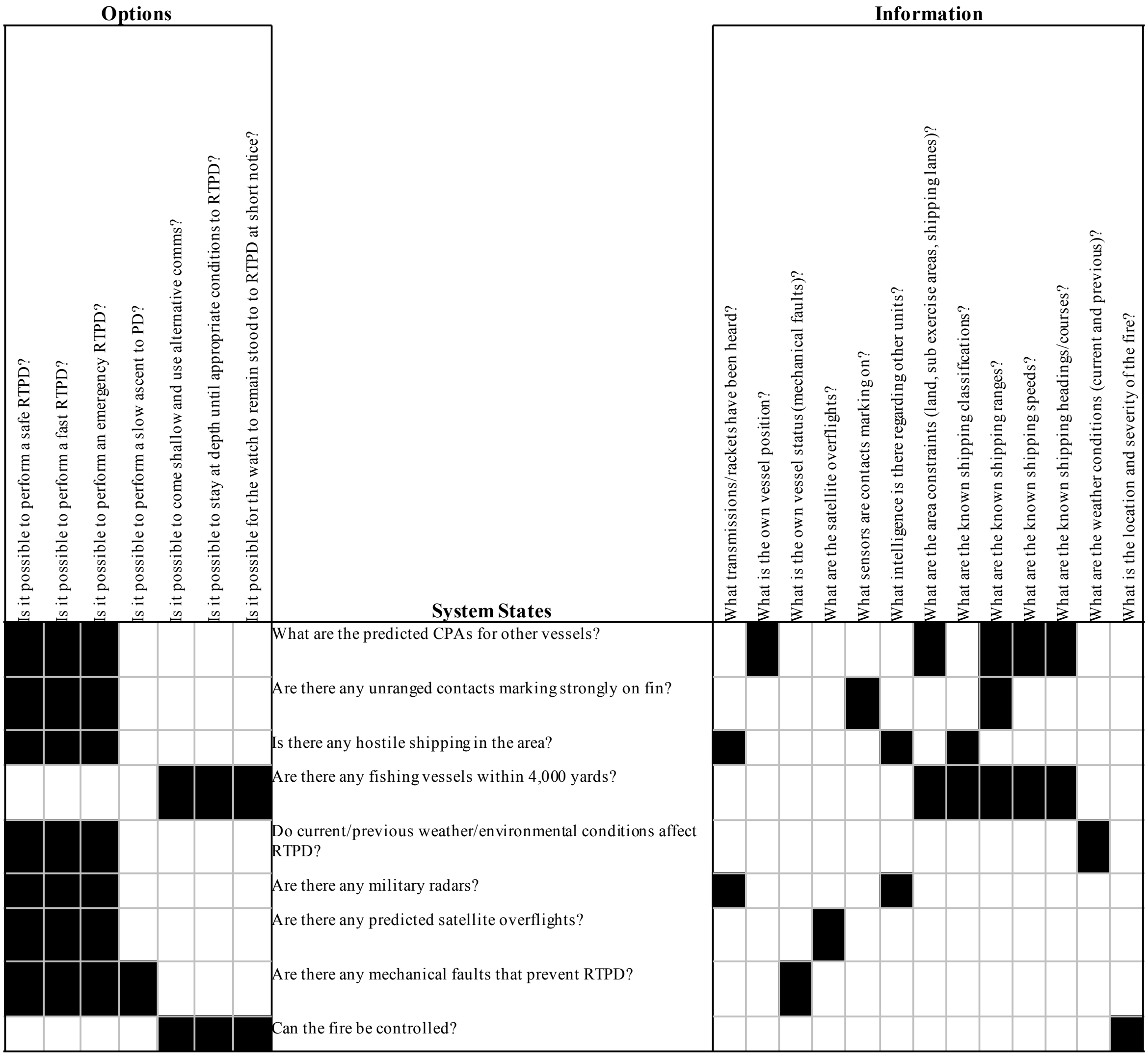

Figure 3. Matrix from the left hand leg of the decision ladder linking information to system states and options.

Relating the information and system state elements shows what information could be necessary to diagnose each system state. So, for example, determining whether there is any hostile shipping in the area requires some or all of: the transmissions or rackets that might have been heard; any intelligence regarding other units; and currently known shipping classifications. Whether there are any mechanical faults that would prevent RTPD, on the other hand, can be ascertained simply from information about the own vessel status.

The linking of the system states and options indicates how different system states might constrain the available options. It would appear that there is a basic split between states that constrain whether or not it is possible to RTPD, and states that constrain whether it is possible to choose some alternative. Where these constraints are in conflict, the chosen goal may come into play and influence the decision about the most appropriate target system state. For example, when a fishing vessel is detected within 4,000 yards, during peacetime and within home waters, a submarine is required to immediately RTPD (i.e. within a given timeframe). If, however, at the same time an unranged contact is marking strongly on fin (the contact is being detected on a particular sonar array, indicating that it may be extremely close) it could be unsafe to RTPD. In this case there is a choice to be made between returning to periscope depth and staying deep; the decision maker may choose 'RTPD safely' as the goal, leading to a decision to stay deep until the contact has been ranged. Alternatively, if 'RTPD within a given timeframe' is chosen as the goal, the submarine may RTPD whilst accepting the risk of the unranged contact.

Figure 4 relates the chosen goal, target states and tasks for the right hand leg of the decision ladder.

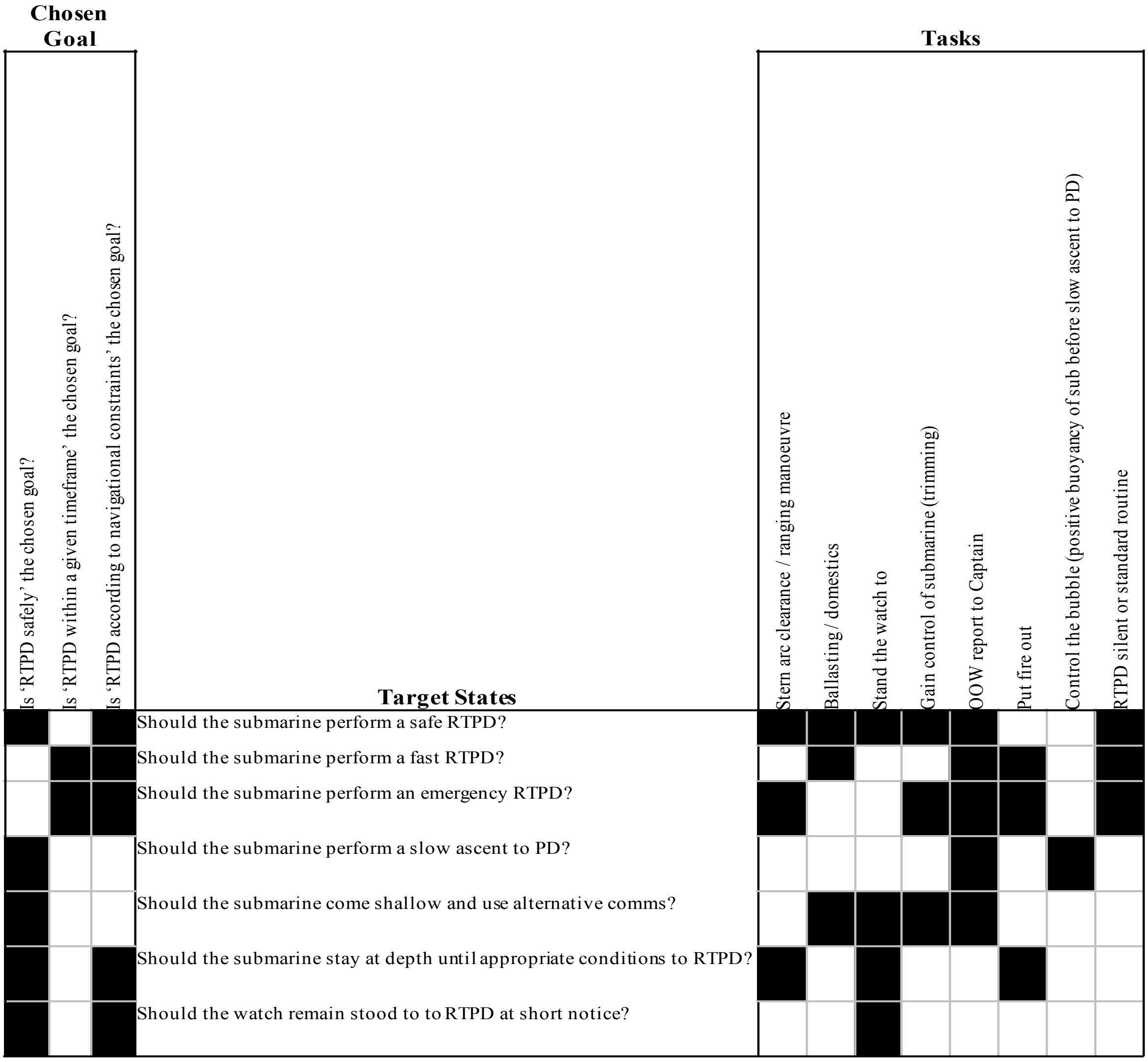

Figure 4. Matrix from the right hand leg of the decision ladder, linking chosen goal to target states and tasks.

It is apparent that, as expected, the chosen goal has an influencing factor on the way in which the submarine will attempt to return to periscope depth. For example, if safety is the overriding constraint, the RTPD will be neither fast nor emergency, meaning that the standard set of procedures will be followed. Conversely, the submarine will only ever perform a slow ascent to PD or come shallow as a result of some safety consideration (a fishing vessel snag or adverse weather conditions being the likely causes respectively).

Social Organisation and Cooperation Analysis (SOCA) addresses the constraints imposed by allocation of specific agent roles to functions in given situations. The objective is to determine how the social and technical factors in a socio-technical system can work together in a way that enhances the performance of the system as a whole. SOCA is concerned with identifying the set of possibilities for work allocation, distribution and social organisation. SOCA explicitly aims to support flexibility and adaptation in organisations developing designs that are tailored to the requirements of the various situations. In this way SOCA supports the idea of dynamic allocation of function, such that function allocation can transfer between agents as the situation changes. Flexible organisational structures are superior to rigid ones because they can adapt to local situations. Rather than defining a single or best organisational structure, SOCA is concerned with identifying the criteria that may shape or govern how work might be allocated across agents. Such criteria might include:

- Agent competencies
- Access to information or means for action
- Level of coordination
- Workload
- Safety and reliability
- Availability

The first stage of the process is to define the key agent roles in the system. The role reflects the work at any given time rather than a particular person or machine. It was observed in the control room studies that roles may change depending upon who is available, which shows that this idea has already been embraced. A list of the key roles and their related coding can be seen in Figure 5. SOCA is used to determine which roles are involved in information processing activities, and the resultant states of knowledge, at each stage of the decision making process. It can be seen in Figure 5 that the Captain or Executive Officer (XO) is solely responsible for evaluating the various options available against the overall goal, and then deciding against which constraints the goal will be achieved, leading to a desired target state. Conversely, a large number of varied roles can contribute towards alerting to the need to RTPD in the first place and then gathering the required information to diagnose the current system state. Similarly, many different roles are involved in executing the tasks and procedures resulting from the target state determined by the Captain or XO. One noticeable difference in comparing the two legs of the decision ladder is that the Planesman, Ship Control Officer and For-d Staff are only involved in responding to the target state, as might be expected given that their roles relate primarily to the control of the submarine. The Tactical Picture Supervisor, Office Of the Watch and Sound Room Controller, on the other hand, are involved at all stages of the process (with the exception of those reserved for the Captain or XO, as described previously).

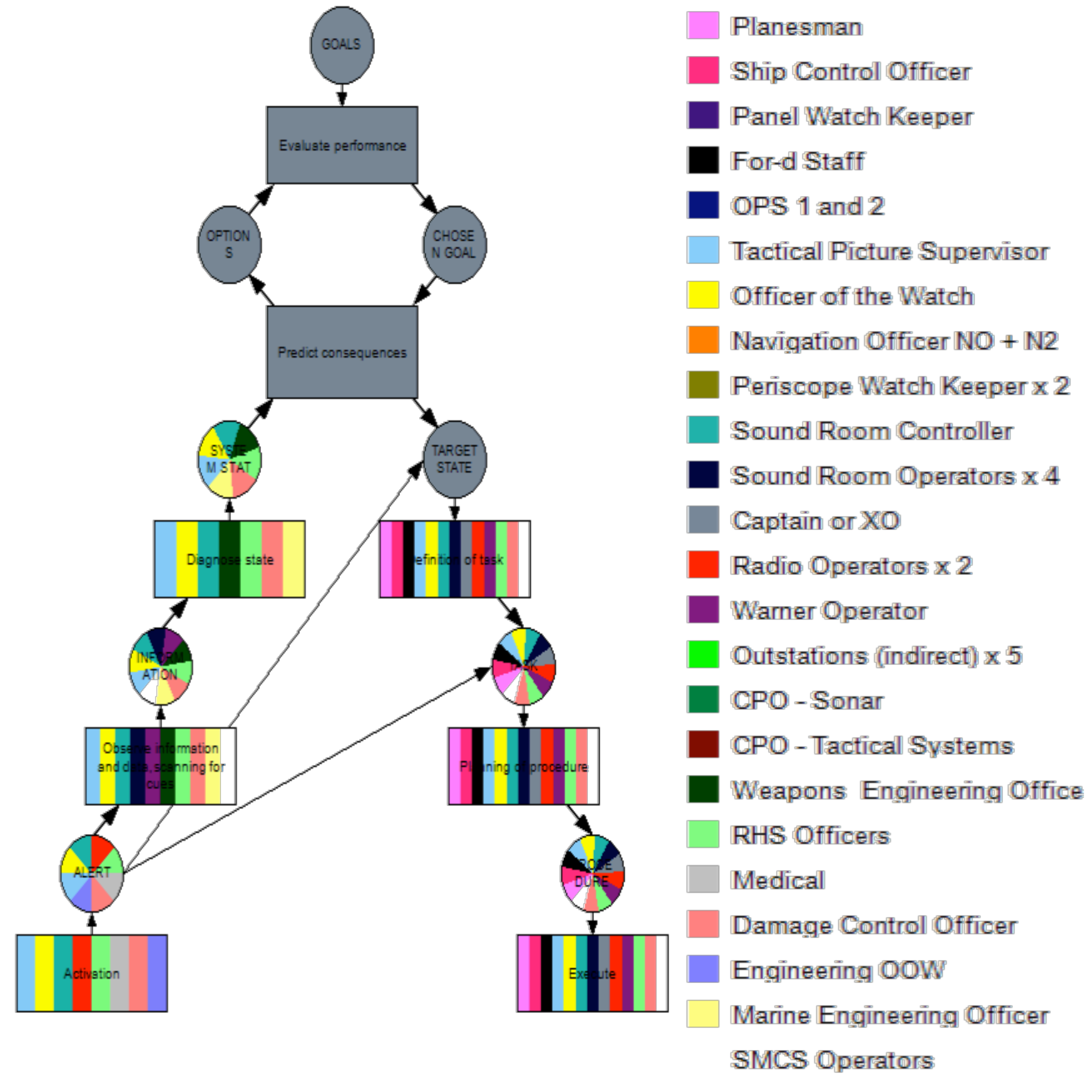

Figure 5. Social Organisation and Cooperation Analysis Decision Ladder (SOCA-DL) for returning to periscope depth in the control room.

CONCLUSIONS

RTPD is much proceduralised due to the inherent complexity and its safety critical nature. This means that many of the functions are unique to particular situations. Nevertheless, performance differences of experts were uncovered in the decision analysis, enabling the shortcut 'shunts' and 'leaps' across the ladder. Only two shortcuts were identified in this analysis (leaps across the decision ladder in emergency situations) which is due to the highly proceduralised, safety-critical, nature of the tasks. The analyses also show the activities for RTPD vary according to the situation (e.g., safe, fast emergency or slow assents).

The decsions ladder has shown utility in both the elecitation and representation of the decisions made by teams. Futher analysis is possible by using the matrices of the 'evaluation' and 'execution' legs of the ladder as well as identifying who is involved in the decisions (in the SOCA-DL phase). The mapping of information to states and options and the mapping of goals to states and tasks revelas how decisions are made in the submarine. Linking these elements in this way is useful because it provides an insight into how different pieces of information are required to determine the system states that inform option selection, and how different goals lead to various target states and their associated tasks. Once these relationships are understood they can be used for a variety of purposes such as informing interface, procedure, job aid, decision support and simulator design, as well as decision making training.

Thus the method has quite a lot of flexibility to describe quite complex team tasks. Making all of this complexity explicit is useful, as it allows the analyst to understand and question the nature of decision making and task structure. As the project was focused on next generation systems, the representations were verified with experts and will be used to support design of new system concepts. The task of returning to periscope depth currently focusses on eliciting constraints on the manoeuvre in general, and avoiding other vessels in particular. The obervational studies revealled that the team are looking for reasons not to return to the surface all the way up, only continuing with the transit in the absence of evidence to the contrary. At the moment, up to 13 roles are involved in this process, so it is quite a labour intensive activity, which requires good coordination and communication to be successful. Future concepts will investigate more efficient methods of designing the socio-technical system against this benchmark.

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