Temporal investigation of information transition in submarine command teams

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ABSTRACT

The Command Team Experimental Testbed (ComTET) is a program of work tasked with making evidence based recommendations for future submarine control room design. Previous work from the program described information flow between a submarine command team when completing a Return To Periscope Depth (RTPD) operation. A number of bottlenecks were revealed with regard to information exchange, and particular operators were required to act as information brokers. The current pilot study aims to build on such work by examining the temporal implications of operator overload and information bottlenecks. The work was conducted in a submarine control room simulator, built specifically for research purposes. A non-commercial version of Dangerous Waters was used as the simulation engine. The creation of networked workstations allowed a team of nine operators to perform tasks completed by submarine command teams during a RTPD operation. A frequency count of information attainment (i.e. task completion) and transition of information between operators was completed. The time taken for information to transit through all stages of the tactical picture development was also recorded. The volume of information reduced in a linear fashion as it was passed between multiple operators in the command team. The time taken for information to pass between operators was greater in higher demand scenarios. The reduction in information exchange may be a product of the quality checking process. However, it may also reflect limitations in information exchange due to bottlenecks in the command team. It is recommended that the current pilot study be built upon; recruiting more teams across different operation types. This would afford statistical comparisons of information transition times during different levels of demand and different operations. This could provide valuable insight into where optimisation of information transition might best be targeted in future submarine platforms.

KEYWORDS

Submarine, command team, communication, information

Introduction

The current body of work is part of The Command Team Experimental Testbed (ComTET) program. A body of work tasked with examining current submarine control room functionality and evaluation of future design and ways of working. Submarines are equipped with a range of sensors and instruments generating large volumes of data which operators must integrate to generate a tactical picture (Dominguez, Long, Miller, & Wiggins, 2006; Stanton, 2014). Submarine control rooms represent a high state of evolution, having developed across a century of operations, but this does not mean they cannot be improved (Stanton, 2014). The capacity of a submarine to Return To Periscope Depth (RTPD) from depth relies on the commanding officer (CO) having an accurate tactical picture, in a timely fashion. However, even the CO is not overtly aware of the work and interactions between members of the command team that facilitate the generation of a tactical picture (Dominguez et al., 2006).

A sociotechnical system is defined as the interaction of human operators and technology, often with growing interdependence in pursuit of purposeful, goal-directed behaviours (Walker, Stanton, Salmon, & Jenkins, 2008). A sociotechnical system promotes distributed cognition where multiple individuals and teams work together in pursuit of a common goal for which high levels of communication and coordination are required (Stanton, 2014). Advancements in technology, computing processing and sensor capacities have led to the development of highly complex sociotechnical systems; a submarine control room is an excellent example of this (Stanton, 2014; Stanton & Roberts, 2017). The continuing advancement of technology means that sociotechnical systems are primed for revolutionary changes in ways of working to increase capability (Roco & Bainbridge 2003; Showalter, 2005). This drive is not only evident for the submarine domain but also for surface vessels (Lützhöft, & Dekker, 2002), aviation (Stanton, Harris, & Starr, 2016) and gas/electric/nuclear power plants (Santos, Teixeira, Ferraz, & Carvalho, 2008). It is therefore critical to understand efficiency of information transition in current control rooms to effectively assess the impact of advancements from a sociotechnical perspective.

The functionality of expert submarines has been examined from a sociotechnical perspective in a high-fidelity simulator during a RTPD (Stanton, 2014) and in a mid-fidelity simulator during a RTPD (Stanton & Roberts, 2017). These studies revealed the frequency of information exchange between operators and the type of information typically exchanged. The studies also revealed a number of bottlenecks in the command team in regard to information transition. In particular, information exchange between the Operations Officer (OPSO) and the Sonar Controller (SOC), who were responsible for passing information from the sound room to the control room for integration in the tactical picture (Stanton, 2014, Stanton & Roberts, 2017). A weakness of such studies is that only one command team was examined, so the empirical contribution of the work was limited. However, a collection of studies examined the submarine command team performance of multiple teams, providing statistical evaluation of submarine command team performance across multiple operation types (Roberts, Stanton & Fay, 2017, Stanton & Roberts, 2017). Again, these studies revealed that a number of bottlenecks in the command team existed with regard to information flow, in particular between OPSO and SOC. The current study aims to build upon such work examining temporal aspects of information transition within the command team. The current piece of work is an exploratory pilot study that assessed the feasibility of the study; therefore, no statistical analyses were conducted. Despite this, a number of predictions were made.

Hypothesis 1: The volume of information correctly exchanged will reduce as is passed between multiple operators in the command team.
Hypothesis 2: The greatest loss of information will occur between OPSO and SOC.
Hypothesis 3: The average time taken to pass information will be larger in high demand conditions.

Method

Participants

Three teams of eight individuals were recruited (24 participants in total). A total of 22 males and two females participated with an age range of 18-55 from a variety of backgrounds including undergraduate students and graduate recruits from defence companies and organisations. One team were submariners from the British Royal Navy (RN). This cohort was selected to be representative of the command structure that would be encountered in a submarine command team; 1 x Lieutenant Commander, 1 x Commander, 2 x Chief Petty Officers, 1 x Petty Officer, 2 x Leading Rating and 2 x Able Rating.

Design

The study employed a 1 x 2 within subjects design. The independent variable was scenario demand and had two levels (high and low demand). Scenario demand was manipulated by adjusting the number of contacts detectable in the scenario and their behaviour (see Table 1). The dependent variables included a collection of frequency counts and timing calculation concerning the frequency of task completion and passing of information derived between members of the command team.

Table 1: Description of scenarios designed

Name	Demand	No. Contacts	Mission
Return to Periscope Depth (RTPD)	Low	4 - Fishing	RTPD from deep to send intelligence home, large temporal window of opportunity. All contacts held must be ranged to find optimum course for RTPD. Scenario complete once periscope has marked all contacts.
	High	9 - Fishing 3 - Catamaran 1 - Biological	RTPD as quickly as possible due to submarine damage. Attempt to range all contacts to find optimum RTPD course.

The submarine control room simulator

The ComTET team designed and built a submarine control room simulator that is based upon a currently operational RN Astute class submarine. Roberts, Stanton & Fay (2015), provide a full description of the building process and the simulator capabilities. In brief, the simulator is composed of nine workstations each with two stacked monitors (one touch screen), a keyboard, an input device (e.g. mouse) and a communications headset (see Figure 1).

Figure 1: The ComTET submarine control room simulator (a) Left – Sound room, (b) Right – Control room

The workstations run Dangerous Waters (DW) software, a naval warfare simulation game developed by Sonalysts Combat Simulations. The software features networked player-controllable stations from on board a submarine, allowing the completion of the majority of submariner command team tasks, simultaneously to fulfil global (team) mission objectives. The number of operators, (including their skills and experience) present in the control room was decided by Subject Matter Experts (SMEs) to be representative of an operational submarine. They include two Sonar Operator stations (SOP), two Target Motion Analysis stations (TMA), a Sonar Controller station (SOC), an Operations Officer station (OPSO), a Periscope station (PERI), a Ship Control station (SHC) and an Officer of the Watch station (OOW). A set of unclassified scenarios were also designed and programed in DW. A tutorial package was developed (with SMEs from the RN) to train novice participants to be representative of a submarine command team. For a description of the training package see (Roberts & Stanton 2017, Stanton & Roberts, 2017).

General procedure

The novice participant testing consisted of a training day and subsequent testing days. On the training day, informed consent was obtained from participants and team roles were randomly assigned. Participants then spent the day watching seven video tutorials. Each tutorial lasted approximately 45 minutes. The morning contained general submarine command team training (e.g. awareness of sensors, objectives and communication structure), whilst the afternoon included workstation-specific tutorials (e.g. operation of interfaces for individual task completion) and practice sessions. Experimenters with extensive DW experience were present to answer questions and provide training support.

On the second (testing) day, participants first completed a practice scenario as a command team. Performance was monitored by experimenters to ascertain that all tasks were being executed correctly; further training was provided if performance was not adequate. Participants then completed the two RTPD testing scenarios (see Table 1). Each team of eight participants completed both scenarios, occupying the same positions in the command team.

Analysis of data

To complete the analysis, raw data from video and microphone recordings were used. This included videos of the operators themselves and their screens. For each scenario a frequency count was conducted assessing whenever a task was completed that resulted in the eliciting of information to be integrated into the tactical picture. A frequency count of the information being passed through various members of the command team was also made. The time taken for each sub-task and transit of information was also recorded. A summary of the metrics collected is presented in Table 2.

Table 2: Frequency and timing measures of information elicitation and transition

Measure	Description
Classification found	The SOP has used sonar narrow band to identify the vessel type of a contact
Classification sent to SOC	Classification has been passed to SOC for quality check
Classifications sent to OPSO	Classification has been passed from the sound room to the picture room
Classifications given to TMA	Classification has been passed to operator working on solution for contact
Speeds found	The SOP used DEMON to derive a speed estimate of contact
Speeds sent to SOC	Speed estimate has been passed to SOC for quality check
Speeds Sent to OPSO	Speed estimate has been passed from the sound room to the picture room
Speeds given to TMA	Speed estimate has been passed to operator working on solution for contact
Speed used by TMA	Correct speed estimate integrated into the contact solution
Solutions Started	Number of contact solutions (privately) started by TMA operators
Solution quality checked	Number of solutions quality checked by OPSO
Solution shared publicly	Number of solutions publicly integrated into OOW tactical picture
Refined solutions started	Number of contact solution refinements (privately) started by TMA operators
Refined solutions checked	Number of solution refinements quality checked by OPSO
Refined solutions shared	Number of solution refinements publicly integrated into tactical picture
Time to designate	Time taken for a contact to be designated from initial appearance

Time for cuts	Time taken for contact designation bearing cuts being checked by operator
Time to classify	Time taken for classification of contacts to be completed
Time to speed	Time taken for speed estimate to be derived by operator
Time to pass speed	Time taken for speed estimate to be passed from SOPs
Time to solution	Average time taken for initial solution to be shared

Results

The flow of information between members of the command team across the control room had an impact upon the frequency of task completion and the time taken for information to be passed through the control room. A description of task ownership and the flow of information between operators is presented in Figure 2. The tasks of designation, classifying and deriving speed estimates for contacts begins with the SOPs. This information is required by the TMAs for development of contact solutions and integration of solutions into the tactical picture for OOW. This information is routinely passed through SOC and OPSO, who act as information brokers between the sound and picture room.

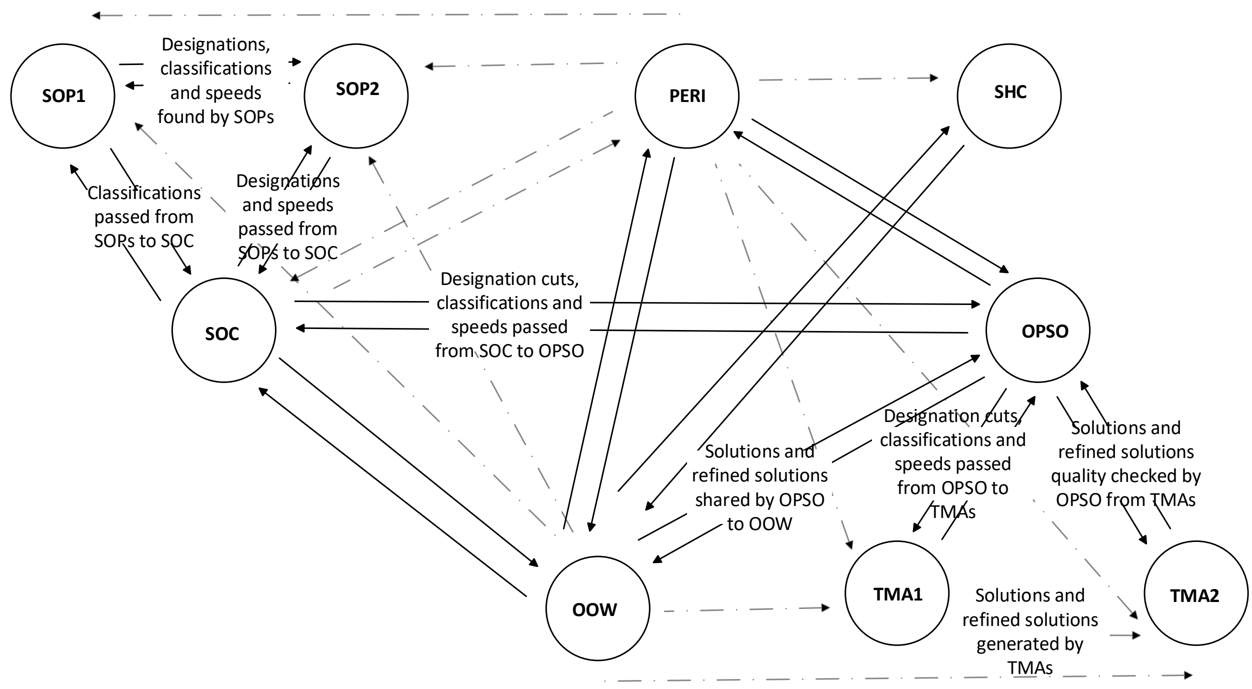

Figure 2: Representation of task ownership and transition of information between operators in the command team

The frequency of task completion is generally higher in the high demand scenarios (see Table 3). This is to be expected, as there is a much greater volume of contacts in the high demand scenarios. Interestingly, the volume of information passed (e.g. classifications and speed estimates) appears to reduce in a linear fashion as it passed between operators in the command team (see table 3). The greatest reduction in classifications occurs when information was passed from the SOC to OPSO (RTPDL = 12, RTPDH = 12). One of SOCs primary duties is to quality check work and filter information sent to OPSO. A large reduction in speed estimates was also observed (RTPDL = 17, RTPDH = 1), predominantly in the low demand scenarios.

Table 3: Frequency counts of task completion

	Team 1		Team 2		Team 3	
	RTPDL	RTPDH	RTPDL	RTPDH	RTPDL	RTPDH
Classifications found	4	9	8	17	4	7
Classifications sent to SOC	7	7	4	11	5	5
Classifications sent to OPSO	0	6	0	0	4	6
Classifications given to TMA	1	0	0	0	2	4
Speeds found	4	10	15	21	10	10
Speeds sent to SOC	4	6	17	20	8	6
Speeds sent to OPSO	0	6	8	19	4	6
Speeds given to TMA	1	0	1	6	5	6
Speed used by TMA	2	0	8	14	8	7
Solutions started	4	8	11	16	5	9
Solutions quality checked	3	8	8	15	3	9
Solutions shared publicly	4	8	11	15	5	7
Refined solutions started	11	15	11	23	7	6
Refined solutions quality checked	1	2	2	7	4	2
Refined solutions shared publicly	7	14	7	13	6	2

The time taken for overall information transition is typically greater in the high demand scenarios. Again, this is to be expected, as there are more contacts to process in the high demand scenarios. However, it potentially reveals that information transition becomes less efficient as demand increases. The information is being 'held' by operators for longer periods of time, rather than being passed effectively to the operators requiring such information. In general, the command teams took much longer generating speed estimates than generating classifications (see Table 4). There was great variation in the overall time taken to generate tactical solutions between teams, suggesting that different teams were employing different strategies in terms of information exchange.

Table 4: Average time taken for task completion and information transition

	Team 1		Team 2		Team 3	
	RTPDL	**RTPDH**	**RTPDL**	**RTPDH**	**RTPDL**	**RTPDH**
average time to designate	00:02:59	00:02:48	00:00:49	00:02:35	00:02:00	00:02:23
average time to check cuts	00:02:11	00:04:43	00:01:05	00:02:25	00:06:06	00:09:53
time to classify	00:00:17	00:00:41	00:02:36	00:02:48	00:01:19	00:03:48
time to speed	00:00:49	00:02:34	00:04:41	00:03:39	00:06:59	00:08:15
time to pass speed	00:03:11	00:01:22	00:01:38	00:00:48	00:03:36	00:03:16
time to solution	00:01:40	00:01:07	00:21:49	00:06:26	00:07:15	00:04:28

Discussion

The current work was a pilot study examining the impact of bottlenecks in the sociotechnical system upon the speed of information transition through the control room. The results indicate that the method used has the potential to reveal impacts of bottlenecks in the system in terms of where information may be lost and where critical delays occur. The current work offered tentative support for all three hypotheses proposed. The volume of key information (e.g. classifications and speeds) reduced as it was passed between multiple operators. Moreover, the majority of information loss occurred in the transition between SOC and OPSO. It is important to note that this information loss may reflect the natural quality checking and filtering processes required to be completed by these operators. However, the manner in which information loss occurred, particularly in higher demand scenarios suggests this is an area worthy of further investigation. The results offer support for previous work which revealed a number of bottlenecks in the command team, in particular between the OPSO and the SOC (Stanton, 2014, Stanton, Roberts & Fay, 2017; Roberts & Stanton 2017). The current work builds on such findings, which were descriptive in terms of information flow between operators, information type and task completed. The current work provides a more objective assessment of the impact that bottlenecks of information transition may have in terms of time taken to complete operations.

Submarines are equipped with a range of sensors and instruments which require the transition of large volumes of information between many operators (Dominguez et al., 2006; Stanton, 2014). The requirements of submarine platforms of the future will be shaped by technological advancements, operational need and economic constraints. This might include additional instruments, improved sensor capacity, automation and changes to staffing requirements. Submarine command teams of the future will therefore be required to manage greater volumes of data. It is important that objective assessment of information transition times can be completed. Perhaps more importantly it is also critical to assess where in the sociotechnical system information might be lost, as the consequences of lost information regarding contacts may be catastrophic.

Anecdotal feedback received from the non-naval teams that participated in the current study supported the fact that passing information was sometimes difficult, particularly during the high demand scenarios. An example of this is that the two sonar operators frequently held contact information (e.g. speeds and classifications) for long periods of time due to not being able to communicate with SOC. This was due to SOC being involved in higher command discussions with OPSO and OOW or completing additional tasks such as priority contact monitoring. This frequently led to information being outdated and a backlog of information being communicated in large chunks. Consequently, this resulted in frustration from the operators generating this information (e.g. SOPs) and the operators requiring this information for their own task completion (e.g. the TMAs). Anecdotal feedback from the non-navy SOCs revealed similar issues, with these operators frequently left frustrated that they were unable to pass information to OPSO in a timely fashion. This was due to the OPSOs being engage with additional tasks such as facilitating OOWs interpretation of the tactical picture and/or managing the workload of the TMAs. It should be noted that such feedback does not represent the views of the RN. However, the current research provides insights that are at least representative of the issues that may be encountered by operational submarine command teams.

The continuing advancement of technology means that sociotechnical systems are primed for revolutionary changes in ways of working to increase capability (Roco & Bainbridge 2003; Showalter, 2005). The ComTET program has successfully demonstrated that it is possible to build a low cost mid-fidelity simulator and conduct a series of studies using novice participants, to provide evidence for how submarine control room operations of the future might be improved, by understanding the current system. Such work has applicability across many domains, as the drive for optimisation is evident across many domains including surface vessels (Lützhöft, & Dekker, 2002), aviation (Stanton, Harris, & Starr, 2016) and gas/electric/nuclear power plants (Santos, Teixeira, Ferraz, & Carvalho, 2008). Whilst the current work may be specific to submarine control rooms, the findings are generalizable in terms of what the primary causes of information loss or slow information transition might be.

The current work was a pilot study and so did not afford statistical comparisons that are crucial for providing robust evaluations. Therefore, future work should aim to recruit a greater number of teams to afford empirical investigation of information transition timings and information loss. It would also be beneficial to examine different operation types to examine if temporal aspects of information are affected by the particular operation being completed. This knowledge can help to inform the design of future sociotechnical systems to maximise the efficiency of information transition, although this needs to be balanced with maintaining a quality check of information passed.

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