Social network analysis in submarine command and control

Neville A. Stanton and Aaron P. J. Roberts

Transportation Research Group, University of Southampton, UK

ABSTRACT

This is a world's first-of-a-kind study that compares three operational scenarios in a simulated submarine control room: Returning to Periscope Depth (RTPD), Inshore Operations (INSO) and Dived Tracking of Contact (DT). The Event Analysis of Systematic Teamwork (EAST) method was used to model the social networks. 10 teams were recruited for the study. Results indicate that, across all scenarios, the Operations Officer (OPSO) and Sonar Controller (SOC) are particularly loaded, with communication between these operators being revealed as a potential bottleneck. The type of operation being performed affected the type of information used significantly, with a higher reliance on sonar information (and the sonar operators) during a RTPD and a higher reliance on visual information (and the periscope operator) during INSO. Implications are discussed alongside suggestions for future work.

KEYWORDS

Submarine, team work, communications, networks, EAST

Introduction

A primary capability of submarines is being able to operate at great depths using sonar to generate a tactical picture. They also operate covertly at shallower depths using the periscope to undertake duties such as costal protection, intelligence collection and scientific research (Stone, Caird-Daley, & Bessell, 2009; Bateman, 2011). A submarine control room relies on effective communication between multiple technological and human agents for optimal performance and is an excellent example of a complex, socio-technical, system (Shattuck, & Miller, 2006; Walker, Stanton, Salmon & Jenkins, 2009; Stanton, 2014; Stanton & Bessel, 2014). A challenge is understanding the complexities involved in the generation and development of a tactical picture using multiple sensors, from which command team decisions and submarine manoeuvres can be made (Dominguez, Long, Miller, & Wiggins, 2006). Technological developments have the potential to improve command team performance exemplifying, that despite evolving across a century of operations and representing a high state of maturity, submarine control rooms can be improved (Dominguez, Long, Miller, & Wiggins, 2006; Stanton, 2014). Whilst the work reported on this paper focuses on submarine control rooms exclusively, the approach and findings are applicable more widely to control rooms on land, at sea and in the air (Stanton et al., 2008). Stanton et al. (2010), in particular, raise issues with commercial energy distribution control rooms, to show how shortcomings in design may be dealt with.

The development of new sensor, technology, software algorithms and architecture has the potential to optimise submarine control room performance (Wang, Chen, Blasch, Lynch, & Pham, 2011; Zarnich, 1999, Ogden, Zurk, Jones, & Peterson, 2011). Technological advancements are however, routinely implemented without rigorous assessment of their impact on submarine command teams from a sociotechnical perspective (Stanton, et al., 2009, Walker et al., 2009; Roberts, Stanton & Fay

2015). Understanding how instruments, sensors and interfaces aid the propagation of a tactical picture is difficult due to the complexity of sociotechnical systems (Loft, Morrell, & Huf, 2013; Huf, Arulampalam, Masell, Tynan, Brown, Manning, 2004; Stanton, & Bessell, 2014). In a sociotechnical system, the making of successful decisions relies on effective teamwork and communication (Stanton and Harvey, 2017; Stanton et al, 2017), such processes can be the determining factor in terms of team workload rather than the work itself (Stanton, 2011, Salas, Burke, & Samman, 2001; Carletta, Anderson, & McEwan, 2000).

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 (Roberts & Stanton, 2016) but also for surface vessels (Lützhöft, & Dekker, 2002; Negahdaripour, & Firoozfam, 2006), aviation (Rudisill, 2000; Bruce, Rice, & Hepp, 1998; Stanton, Harris, & Starr, 2016) and gas/electric/nuclear power plants (Santos, Teixeira, Ferraz, & Carvalho, 2008; Stanton, Salmon, Jenkins & Walker, 2009). The manner in which a team is configured, and how technology supports communication, can influence performance (Stanton, Rothrock, Harvey & Sorensen, 2015a,b; Espevik, Johnsen, Eid, & Thayer, 2006). This extends to all kinds of command and control activities (Stanton & Baber, 2006; Stanton et al., 2008) and even to control room work more generally (Stanton et al., 2010). The purpose of the current paper is to explore command team performance during a Return to Periscope Depth (RTPD), Inshore Operation (INSO) and the Dived Tracking (DT) of a contact.

Methods

The ComTET team built a submarine control room simulator that is based upon a currently operational Royal Navy (RN) submarine (see figure 1). A full description of the building process and the simulator capabilities is provided by Roberts et al., (2015). The simulation engine used was Dangerous Waters (DW) software, a naval warfare simulation game developed by Sonalysts Combat Simulations. The software features networked workstations. Two Sonar Operator stations (SOP), two Target Motion Analysis stations (TMA), a Sonar Controller station (SC), an Operations Officer station (OpsO), a Periscope station, a Ship Control station and an Officer of the Watch station (OOW).

Figure 1: The ComTET submarine control room simulator, with sound room on the left hand side and picture room on the right

The analysis of data used a new shortened form of Event Analysis for Systemic Teamwork (EAST: Stanton, Barber & Harris, 2008). This approach has been used to model submarine command and control (Stanton, 2014) and analyse sociotechnical systems in numerous other domains (Stewart, Stanton, Harris, Baber, Salmon, Mock, & Kay, 2008; Houghton, Baber, McMaster, Stanton, Salmon, Stewart, & Walker, 2006; Stanton & Harvey, 2016). EAST uses raw data of video and audio recordings of communications within the command team to generate the networks. The networks were processed using AGNA software (version 2.1.1 – a software program for computing the Social Network metrics). AGNA was used to compute whole network metrics (e.g. density, diameter and cohesion) and nodal metrics (e.g. sociometric status and centrality). A detailed description of metrics used is provided by Stanton (2014) and defined in Appendix 1.

Results

The average frequency of communications between operators varied depending on command team role, scenario demand and scenario type (see figure 2). OPSO and SOC had the largest volume of emissions of all operators across all scenarios, PERI had less emissions than most operators except during INSO. The volume of interactions between operators increased during the high demand scenarios but changes differ depending on scenario type.

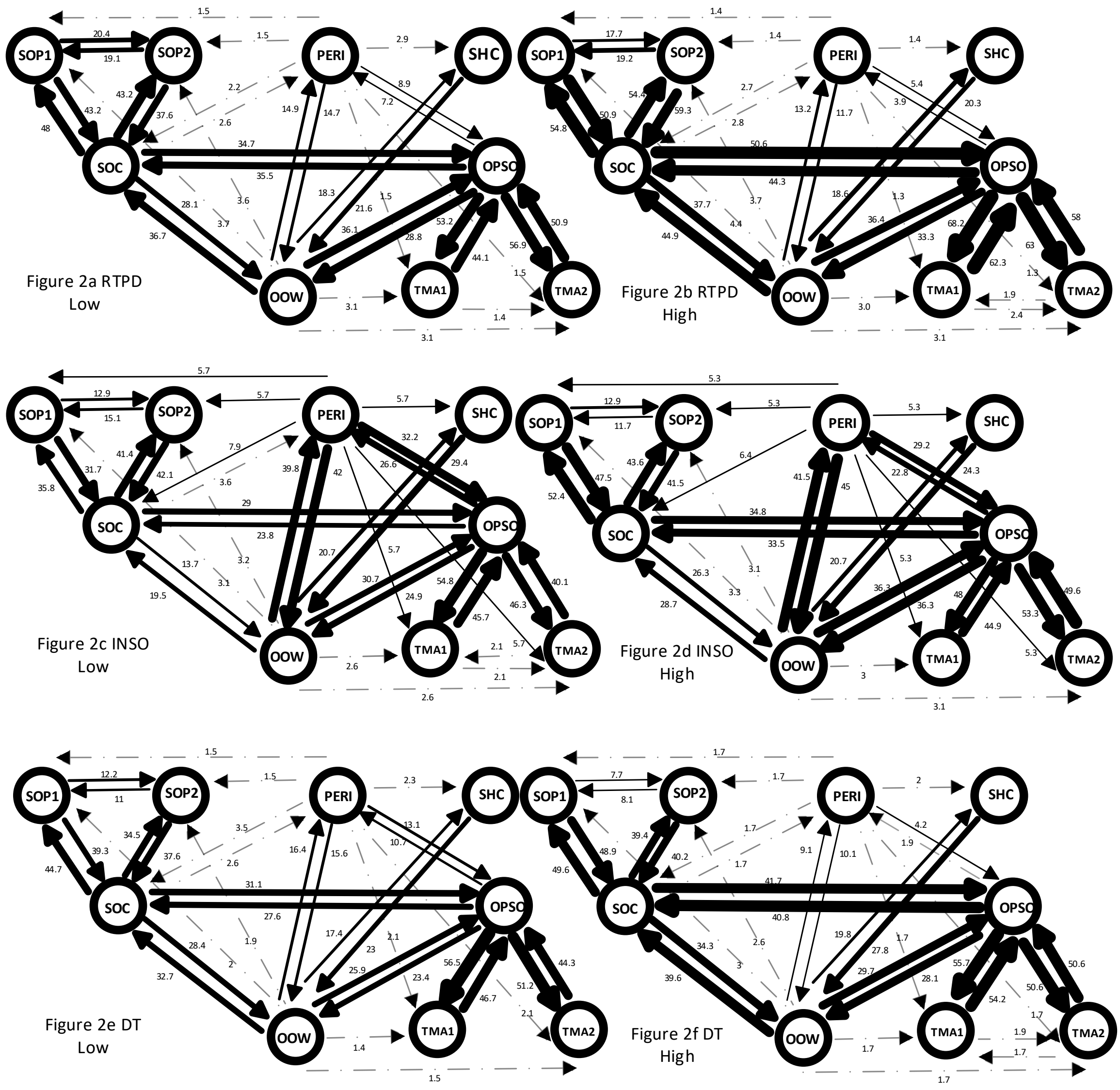

Figure 2: Social network diagrams for low and high demand RTPD scenarios

Discussion

The current work provides a detailed description of three scenarios undertaken by submarines (in both higher and lower demand conditions). The social networks presented in the current work highlight the complexities involved when completing RTPD, INSO and DT submarine operations (Loft, Morrell, & Huf, 2013; Stanton, & Bessell, 2014; Huf, Arulampalam, Masell, Tynan, Brown, Manning, 2004). In general, the work offers support for examining submarine command teams from a sociotechnical perspective (Stanton, 2014). However, a number of important differences are observable when comparing RTPD, INSO and DT. These differences show how environmental and mission-based objectives affect command team operations (Bateman, 2011; Stone, Caird-Daley, & Bessell, 2009; Duryea, Lindstrom, & Sayegh, 2008). The differences observed between different scenarios provide evidence for the requirement of flexible and dynamic control rooms within the domain. This understanding can be used to inform control room design across many different domains (Roco & Bainbridge 2003; Showalter, 2005; Rudisill, 2000; Bruce, Rice, & Hepp, 1998; Stanton, Harris, & Starr, 2016; Santos, Teixeira, Ferraz, & Carvalho, 2008; Stanton, Salmon, Jenkins & Walker, 2009).

In the RTPD, INSO and DT the operator with the highest number of emissions and sociometric status is OPSO and the second highest is typically SOC. The volume of emissions from these operators is typically 2-3 times greater than all other operators, showing that the communications demand being placed on the command team is not equally distributed. A limiting factor of team performance is how effectively communication occurs (Stanton, 2011, Salas, Burke, & Samman, 2001; Carletta, Anderson, & McEwan, 2000). The load placed on OPSO and SOC may be the result of command team structure, but this has the potential to be non-optimal in terms of command team performance (Stanton, Rothrock, Harvey & Sorensen, 2015a,b; Espevik, Johnsen, Eid, & Thayer, 2006). Similar observations have been made about key players in land-based, commercial, energy distribution control rooms (Stanton et al., 2010). In all scenarios the relationship between OPSO and SOC is particularly strong. The communications passed between OPSO and SOC are very important, as this connection links the sound room and the picture room. Without this communication it is impossible to build a tactical picture using sonar data. The accuracy of passive sonar for maintaining the tactical picture generation can be affected by oceanographic conditions and background noise (Zarnich, 1999; Ogden, Zurk, Jones, & Peterson, 2011). OPSO and SOC are responsible for checking the quality of operators work, explaining the large increase in communication between these operators in higher demand scenarios.

In all scenario types the OOW has the highest centrality score of all operators. This offers support for previous work highlighting that the OOW is responsible for the safety of the submarine and completion of mission objectives (Stanton, 2014; Dominguez, Long, Miller, & Wiggins, 2006). The OOW is the only person who communicates with SHC to alter submarine parameters and the only person alongside OPSO also, who communicates with PERI. The frequency of such communications differs depending on scenario type. OOW communicates more frequently with SHC during INSO and DT when manoeuvring the submarine is paramount to safety and mission objectives (Noren, Veirs, Emmons, & Veirs, 2009; Duryea, Lindstrom, & Sayegh, 2008). The OOW will communicate with anyone in the command team they require information from to confirm the tactical picture (Dominguez, Long, Miller, & Wiggins, 2006).

The SOPs and TMAs do not routinely communicate with anyone outside of the sound room or picture room respectively. This is reflected by the fact that across all operation types the closeness of these operators is low and farness values high. The sociometric status of the SOPs and TMAs is also relatively low. This is another example of how the structure of the command team has the potential to greatly affect the performance of the command team (Stanton, Rothrock, Harvey & Sorensen, 2015a,b; Espevik, Johnsen, Eid, & Thayer, 2006). The sociometric status of PERI is significantly higher in the INSO scenario than the RTPD and DT scenario, due to the fact that periscope cannot be used when operating in deep water. This is an example of how the manner in which a command team communicates differs across scenario, based upon the primary sensor being used.

Conclusions

The current work has explored operations in simulated submarine command teams in terms of social, information and task network analysis when undertaking RTPD, INSO and DT scenarios. The development of an understanding is a challenge due to the inherent complexity and secrecy surrounding these systems (Loft, Morrell, & Huf, 2013; Huf, Arulampalam, Masell, Tynan, Brown, & Manning, 2004; Stanton, & Bessell, 2014). In general, the social network remained stable across scenarios, potentially resulting from physical ergonomic limitations (e.g. control room layout) and command team structure (Stanton, Rothrock, Harvey & Sorensen, 2015a,b; Espevik, Johnsen, Eid, & Thayer, 2006). The greatest load is placed upon OPSO and SOC across all scenarios, with this communication route identified as a potential bottleneck in the system (Stanton, 2014). In the current control room configuration, OPSO and SOC are positioned in different rooms. Placing these operators in the same room may have the potential to reduce load on these operators. Similar changes may also allow operators who rely on each other (e.g. TMAs and SOPs) direct communication without having to first pass through OPSO or SOC. The most important information across all scenarios relates to bearing and contacts, with secondary information (e.g. speed, course and range). Future research should also examine the design of interfaces and shared tactical displays that facilitate the merging of multiple information sources (e.g. visual vs. sonar). Whilst the various social network patterns described are likely to be a reasonable facsimile of operations at sea, validating those patterns at sea would be beneficial. Nevertheless, the study does provide greater insights in some of the nuances of command and control teams (Stanton et al., 2008). This is likely to be generalizable beyond submarines to other command and control domains (Stanton et al, 2010; Stanton et al., 2015a,b; Houghton et al., 2006).

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Appendix 1

Network Metrics

Metric	**Definition**
Nodes	Number of entities in a network
Edges	Number of pairs of connected entities
Density	Number of relations observed represented as a fraction of the total relations possible
Cohesion	Number of reciprocal connections in the network divided by the maximum number of possible connections
Diameter	Number of hops required to get from one edge of the network to the other
Emission	Number of links emanating from node in the network
Reception	Number of links emanating going to each node in the network
Sociometric Status	Number of emissions and receptions relative to the number of nodes in the network
Centrality	The sum of all distances in the network divided by the sum of all distances to and from the node