Social Network Analysis of RESM in Submarine Command and Control

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ABSTRACT

In a submarine control room, the Officer of the Watch is reliant on a number of systems to inform decision making, including, Sonar, Optronics, and Radar Electronic Support Measures. The current work examines the Radar Electronic Support Measures System from a sociotechnical systems perspective using a high fidelity simulator. The Radar Electronic Support Measures System facilitates effective submarine operation; therefore, it is critical to assess whether the Radar Electronic Support Measures System is being utilised effectively. Eight participants completed two scenarios at high and low demand, and the transcripts of these formed the basis for Social Network Analysis. Results indicated that operators increased communications as a result of increased scenario demand. Furthermore, it was revealed that there was a high volume of communications between the Radar Electronic Support Measures Operator and the Operations Officer. Results are discussed, along with recommendations and areas for future work.

KEYWORDS

Submarine Control Room, Radar Electronic Support Measures, Social Network Analysis

Introduction

The Command Team Experimental Testbed (ComTET) is a program of work that aims to evaluate contemporary submarine control rooms, to reveal potential shortfalls and test novel concepts to inform future submarine control room design. Previously, the ComTET team has examined submarine control room operations from a sociotechnical systems perspective, focusing on typical operations (Roberts et al., 2017, 2018; Stanton & Roberts, 2017), novel control room configurations, reduced crewing (Roberts et al., 2019; Stanton & Roberts, 2020a, 2020b), and Optronics (Pope et al., 2019). This work has focused on the integration of information from systems such as Sonar, Target Motion Analysis (TMA), and Optronics. However, to date, the Radar Electronic Support Measures (RESM) system has not been examined. When at periscope depth, RESM can be used for the identification and classification of sources of Electromagnetic (EM) radiation to corroborate information gathered from sonar and optronics (National Transportation Safety Board, 2001). It therefore supports the three tenets of submarine operations; remain safe, undetected, and complete mission objectives (Mack, 2003).

Electronic Warfare (EW) is defined as military action that aims to prevent an opponents' use of EM energy to control the EM spectrum, while ensuring continued friendly use (Pettersson, 1993; Rao et al., 2003). Electronic Support Measures (ESM) are used for the detection, interception, location, and identification of EM energy (Moir et al., 2017; Pettersson, 1993). They are often passive, as they do not emit EM energy, and instead listen for signals from other vessels (Moir et al., 2017;

Tsui & Cheng, 2016). ESM systems measure parameters such as frequency, pulse width, and angle of arrival (Shankar & Mohan, 2013). There are a number of key requirements for an ESM receiver including analysis capabilities, bearing location capabilities, and a wide dynamic range (Tsui & Cheng, 2016; United States Naval Academy, n.d.). The location of a signal is considered one of the most critical pieces of information that can be gathered using ESM, and being able to locate the source of an EM signal can also aid in subsequent targeting of Electronic Counter Measures (Poisel, 2008).

A primary aim of the current work was to document the RESM system from a sociotechnical perspective. A submarine control room is an excellent example of a sociotechnical system where human operators and technology interact in purposeful goal directed behaviour (Stanton, 2014; Walker et al., 2008). In the current work, Event Analysis of Systemic Teamwork (EAST) was applied to evaluate the sociotechnical system. In particular, in the current work social networks are presented that analyse the organisation of the system and communications taking place between operators (Stanton, 2014). The analysis conducted can be useful in highlighting where the sociotechnical system may benefit from redesign (Stanton, 2014). Often, the RESM system is operated by a single operator onboard (National Transportation Safety Board, 2001) and on some submarines it is located in a different compartment to the rest of the control room (Lenton, 2009; National Transportation Safety Board, 2001). As the RESM system facilitates effective submarine operation, it is critical to assess whether the RESM system is being utilised effectively.

Method

Participants

A total of eight qualified submariners participated with an age range of 22 – 37 (Mean = 26.63, Standard Deviation (SD) = 5.53). All participants were male and had an average of 335.38 days of operational experience at sea in the RESM role. The study protocol received ethical approval from the University of Southampton Research Ethics Committee (Protocol No.: 10099) and the Ministry of Defence Research Ethics Committee (MODREC) (Protocol No.: 551/MODREC/14).

Design

A repeated measures design was used, in which the independent variable was scenario demand. The dependent variable was communication frequency between operators.

Equipment and Materials

A high fidelity simulator was used for the purpose of data collection. The RESM console was comprised of two screens mounted to a cabinet with a mouse and keyboard. The top screen was at approximately eye-height of a seated operator. The bottom screen was slightly below line of sight for a seated operator. Additional information about contacts such as information about a contacts radar, sonar, and information on shafts and blades was also made available to operators.

Two scenarios at different levels of demand were utilised for the purpose of the study. These scenarios were training scenarios installed on the high fidelity simulator, and therefore the experimental team did not feed into the number of contacts presented in each. The low demand scenario featured 16 contacts of which three were deemed to be dangerous. The high demand scenario featured 30 contacts of which 10 were deemed to be dangerous. After identifying a contact as dangerous, RESM operators were instructed to mark it as not posing a threat, and the RESM process was resumed. This instruction from the OOW simulated further analysis that would have taken place in the wider control room, and allowed the scenario to continue.

The operators present in the simulation included the OOW, the Operations Officer (OPSO), and the RESM operator. The role of the OOW and OPSO were assumed by Subject Matter Experts (SME). The purpose of the current work was to gain a greater understanding of RESM and the RESM operator, therefore a subset of the entire submarine command team was used. Due to the layout of the simulator, testing was completed with all operators in the same space. Onboard, however, the RESM operator would be in a separate space to the OPSO and OOW.

To record the scenario data, three Dictaphones with clip on microphones and three high definition cameras were used. The cameras were positioned to record the RESM console, all three operators, and use of the additional information, such as information about a contacts radar, sonar, and details on shafts and blades. All communications were captured using the Dictaphones.

Procedure

Participants were briefed about the aims of the work before giving informed consent and completing demographic questionnaires. If requested, participants were given a brief familiarisation of the RESM system by a SME before the scenario began. Following familiarisation with the system all recording devices were started. The OOW gave a short briefing before the scenario was started. The order of scenario completion was counterbalanced to prevent order effects. After the completion of the first scenario, operators completed paper based subjective measures (not presented in the current work), before undertaking the second scenario. Once the second scenario was completed, operators completed a second set of paper based subjective measures.

Data Analysis

The flow of information was analysed using the EAST method (Stanton et al., 2008). This method has been used previously to model submarine command and control (Stanton & Roberts, 2017, 2020a, 2020b; Roberts et al., 2017, 2018, 2019), and has also been applied in other domains such as air traffic control (Walker et al., 2010), road transportation systems (Banks et al., 2018), and emergency services (Houghton et al., 2006). EAST uses a network approach to model collaborative sociotechnical systems. Networks are based on transcriptions of the communications between operators.

To complete the EAST analysis, Dictaphone and video recordings were used to transcribe the scenarios. These transcriptions were used to generate adjacency matrices of the communications between operators. All matrices were processed using Applied Graph and Network Analysis (AGNA^{TM}) software (version 2.1.1 – a software program for computing social network metrics) which was used to compute global and nodal metrics. A description of the metrics are defined in Table 1. Averages and standard deviation were calculated using the Statistical Package for Social Sciences (SPSS) version 26. Due to time constraints associated with data processing, the current work only presents social network analysis of RESM operations at low and high demand.

Table 1: Global and Nodal Metric Definitions

Metric	Definition
Global metrics	
Nodes	Number of entities in a network (people or information in the current work).
Edges	Number of pairs of connected entities.
Density	Number of relations observed, represented as a fraction of the total possible relations.
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 side of the network to the other.
Nodal metrics	
Emissions	Number of links emanating from each node in the network.
Receptions	Number of links 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.

Results

The results of the social network analysis are presented in Table 2 and Table 3, and Figure 1 and Figure 2. The global social network metrics were similar between the two levels of scenario demand although total emissions were greater in the high demand scenario. As total emissions were equal to total receptions, these have not been included in Table 2.

Table 2: Mean and SD for global information network metrics

Metric	Low		High	
	Mean	SD	Mean	SD
Nodes	4	0	4	0
Edges	7.88	0.35	8	0
Diameter	2	0	2	0
Density	0.66	0.03	0.67	0
Cohesion	0.48	0.06	0.50	0
Total emissions	115.75	30.84	167	55.14

The nodal social network metrics revealed that emissions, receptions, and sociometric status were greater in the high demand scenario compared to the low demand scenario for all agents (see Table 3). The OPSO had the highest emissions of all operators in the scenario, however the RESM operator had the highest number of receptions, followed by the Broadcast (BC) node.

Regardless of scenario demand, the connection between the OPSO and the RESM operator was always particularly strong (see Figure 1 and Figure 2). The sociometric status of these operators was also the highest of all operators (see Table 3). The communications passed between the OPSO and the RESM operator are important as this is the main connection for the RESM operator to communicate with the rest of the control room. While in the current work, the RESM operator was located in the same room as the OOW and the OPSO, onboard they would be located in a separate space to the rest of the command team. The centrality of the OOW remained consistently high across both levels of demand and was only surpassed by the centrality of the BC node. The high

Table 3: Mean and SD for nodal social network metrics

Operator	Emissions		Receptions		Sociometric Status		Centrality	
	Low	High	Low	High	Low	High	Low	High
OOW	32.63 ± 6.19	47.63 ± 16.05	7.75 ± 5.06	11.38 ± 6.19	13.46 ± 3.33	19.67 ± 7.19	1.98 ± 0.06	2 ± 0
OPSO	49.5 ± 13.51	72.38 ± 24.27	26.13 ± 11.54	40.25 ± 12.35	25.21 ± 8.30	37.54 ± 11.98	1.69 ± 0.06	1.67 ± 0
RESM	33.63 ±11.93	47 ± 15.54	45.38 ± 12.25	65 ± 18.80	26.33 ± 7.98	37.33 ± 11.32	1.98 ± 0.06	2 ± 0
Broadcast	0 ± 0	0 ± 0	36.50 ± 6.50	50.38 ± 19.76	12.17 ± 2.17	16.79 ± 6.59	2.53 ± 0.09	2.5 ± 0

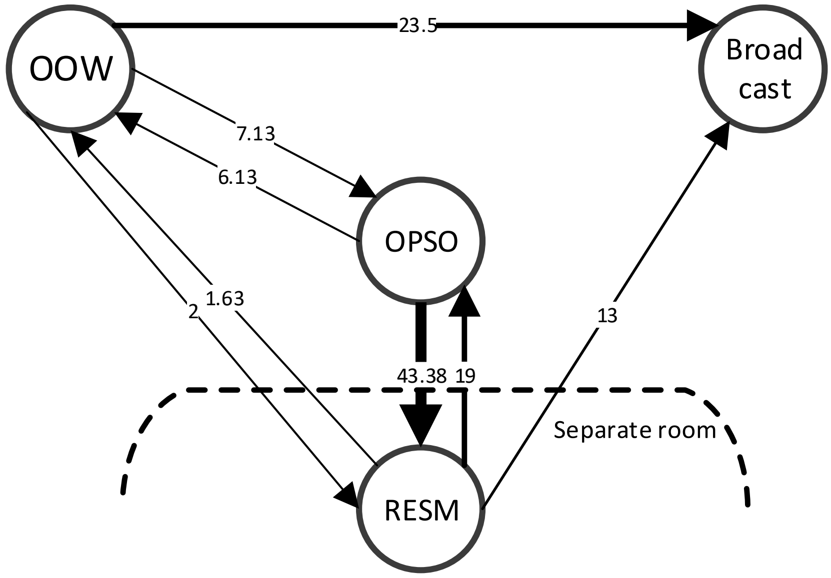

Figure 1: Social network diagram for low demand scenario

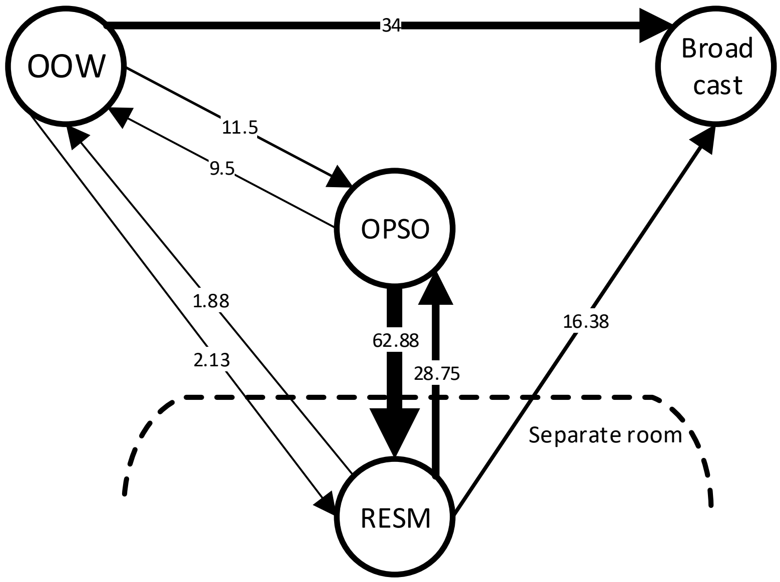

Figure 2: Social network diagram for high demand scenario

centrality but lower sociometric status of the OOW reflects their responsibility for making tactical decisions, while being removed from the precise detail of how the tactical picture is being built.

Discussion

The current work presented social network analysis of RESM operations at low and high demand. The global social network metrics were similar across both levels of demand. Examination of the transcripts revealed that the slightly lower number of edges, density, and cohesion in the low demand scenarios appeared to be due to a singular instance of a RESM operator not acknowledging the mission brief given by the OOW at the beginning of the scenario. There were a greater number of total emissions in the high demand scenarios, which was also reflected in the nodal metrics of emissions and receptions. This was to be expected due to the greater number of dangerous contacts and total contacts presented to the RESM operator in the high demand scenario. This has also been observed in previous work conducted by the ComTET team (Roberts et al., 2017, 2018; Stanton et al., 2017; Stanton & Roberts, 2020a, 2020b).

Examination of the nodal social network metrics revealed that the operator with the highest number of emissions was the OPSO, followed by the RESM operator. In the current work, the OOW was reliant on data from the RESM system in order to stay safe. However, the OOW rarely communicated with the RESM operator directly. The transcripts revealed that the OPSO acted as a go between, repeating orders from the OOW to the RESM operator, and passing pertinent information from RESM to the OOW. In the control room the OPSO is responsible for integrating information from multiple sources (e.g. sonar and visual) in order to provide the OOW with an accurate tactical picture (Roberts et al., 2017, 2018; Stanton et al., 2017). When considering the role of the OPSO in other work conducted by the ComTET team on submarine control room operations (Stanton & Roberts, 2017, 2020a, 2020b; Roberts et al., 2017, 2018, 2019) this high reliance on the OPSO has the potential to cause information bottlenecks between the RESM system and the rest of the control room. Allowing the RESM operator to hear broadcasts or instructions from the OOW would potentially relieve some of the reliance on the OPSO. Furthermore, providing a repeat of the RESM data in the control room would improve the wider command teams' awareness of information received on RESM. Alternatively, the RESM operator station could be moved into the control room with the rest of the command team. This would allow the RESM operator to overhear broadcasts from the OOW. Furthermore, the OOW would be able to walk over to the RESM station and check information, rather than requesting information via the OPSO. In the current work, however, the OPSO was not required to integrate sonar or visual data. Therefore, their sociometric status was similar to that of the RESM operator. The fact that the OPSO and RESM operator had higher receptions and emissions than the OOW demonstrates that, even in a smaller team, they are somewhat removed from the process of generating a tactical picture (Dominguez et al., 2006).

Conclusion

The submarine control room is a highly complex sociotechnical system, representing a high state of maturity, but this does not mean it cannot be improved (Stanton, 2014). The current work documented contemporary RESM system functionality from a sociotechnical systems perspective. The social network analysis revealed that operators increased communications as a result of increased scenario demand, as has been seen previously in work on submarine control room operations (Stanton & Roberts, 2017, 2020a, 2020b; Roberts et al., 2017, 2018, 2019). A large volume of communications between the RESM operator and the OPSO highlights the potential for a bottleneck of information between the RESM system and the rest of the control room. However, the current work is limited in that it focused on a sub-set of the entire command team. Future work should look to examine how RESM operations fit into wider submarine control room operations and how the reliance on the OPSO for passage of information may be relieved.

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