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Naval Operations Room Director Team Structure for Employing Advanced Threat Evaluation and Weapons Assignment (TEWA)

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Abstract

The advancement of automation to support threat evaluation and weapons assignment (TEWA) for anti-air and anti-surface warfare has raised the question whether the current structure for operations room directors can be optimized. Under the Impact of Automation Project (01AB), four two director teams, composed of one operations room officer (ORO) and one Sensor Weapons Controller (SWC), conducted simulated missions in Defence Research and Development Canada's (DRDC's) Combat Resource Allocation Support (CORALS) system. Two team structures were examined. In the Traditional structure, the team simulated today's team structure, with the SWC primarily responsible for both threat evaluation and weapons and the ORO approves the SWC's actions. In the Functional structure, the ORO acted as a threat evaluator and the SWC was responsible for weapons. The trial also manipulated the level of TEWA automation. In one condition, the automation only recommended actions while in the second condition, it could act upon its own decisions, unless the operators intervened. The results suggested no strong benefit for the Functional structure, but did suggest that allowing for higher levels of TEWA automation was beneficial. If the Royal Canadian Navy (RCN) employs more advanced TEWA though, it will have to address the issue of trust in the automation.

Significance to Defence and Security

The RCN is building a new fleet, and which will undoubtedly have advanced technologies and more automation. The RCN needs to understand its crewing requirements to accommodate the new technologies. This research provides insight into the roles of the directors in a naval OPS room for anti-air and anti-surface warfare and whether the RCN should make changes to director roles. Based on the results of the trial suggests that the RCN should continue using the current crew structure for the ORO and SWC, but should continue to investigate more advanced TEWA automation in the operations (OPS) room.

Résumé

Les progrès de l'automatisation pour appuyer l'évaluation de la menace et la désignation des armes (TEWA) dans la lutte antiaérienne et antisurface a soulevé la question de déterminer si la structure actuelle pour les directeurs de salles des opérations pouvait être optimisée. Dans le cadre du projet sur les effets de l'automatisation (01AB), quatre équipes de deux directeurs, composées d'un officier de la salle des opérations (OSO) et d'un contrôleur d'armes par capteur (CAC), ont effectué des missions simulées dans le système de soutien à l'affectation des ressources de combat (CORALS) de RDDC. Deux structures d'équipe ont été examinées. Dans la structure traditionnelle, l'équipe a simulé celle d'aujourd'hui, dans laquelle le CAC est responsable surtout de l'évaluation de la menace et des armes et l'OSO approuve les actions du CAC. Dans la structure fonctionnelle, l'OSO a agi comme évaluateur de menace et le CAC comme responsable des armes. L'essai a aussi permis de manipuler le niveau d'automatisation TEWA. Dans un cas, l'automatisation n'a recommandé que des actions et, dans le second cas, elle a pu agir en fonction de ses propres décisions, à moins d'une intervention des opérateurs. Les résultats n'ont montré aucun avantage important pour la structure fonctionnelle, mais ont laissé croire que le fait de permettre des niveaux plus élevés d'automatisation TEWA était bénéfique. Si la Marine royale canadienne (MRC) utilise une TEWA plus perfectionnée, elle devra aborder la question de la confiance à l'endroit de l'automatisation.

Importance pour la défense et la sécurité

La Marine royale canadienne (MRC) assemble une nouvelle flotte et disposera sans aucun doute de technologies de pointe et de plus d'automatisation. La MRC doit comprendre ses besoins en membres d'équipage afin de s'adapter aux nouvelles technologies. Cette recherche fournit un aperçu des rôles du directeur dans une salle des opérations navales pour la lutte antiaérienne et antisurface et permet de déterminer si la MRC devrait apporter des modifications aux rôles de directeur. Les résultats de l'essai laissent entendre que la MRC devrait continuer à utiliser la structure d'équipage actuelle pour l'OSO et le CAC et qu'elle devrait poursuivre l'étude d'une automatisation TEWA plus avancée dans la salle des opérations.

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1 Introduction

The Royal Canadian Navy (RCN) recently modernized the operations (OPS) room on their twelve Halifax-class frigates, also commonly referred to as Canadian Patrol Frigates (CPFs). This modernization was part of the Halifax-class Modernization (HCM) / Frigate Life Extension (FELEX) projects. FELEX was a planned mid-life refit of the CPFs to ensure their effectiveness for the remaining years of their service life. HCM was a modernization program to upgrade the CPFs' sensors, weapons, communications and combat system [1]. Some of the more notable upgrades included renewing the helicopter deck to accommodate the new CH-148 Cyclone maritime helicopter, upgrading the Harpoon Missile System and the ships' 57 mm MK3 naval gun, replacing the suite of radars (i.e., fire control radar, navigation radar, and surveillance radar), and replacing the combat management system with the CMS-330 combat management system [1].

The CMS-330 combat management system is a full combat system that allows OPS room operators to configure and adjust sensors, manage the tactical picture, engage weapons and manage many of the ship's resources. The CMS-330 is housed within new multi-function workstations (MFWs) (Figure 1). The MFWs allow for three screens, two of which are dedicated to CMS-330 functions, and a third screen for auxiliary functions [2]. The OPS room is now equipped with multiple MFWs, mostly to support anti-air warfare (AAW) and anti surface warfare (ASuW). Currently, the underwater systems are not yet directly tied to the CMS-330 system. The CMS-330 employs new automation that allows operators to manage large volumes of tactical information and employ sensors and weapons more efficiently and effectively [3]. While the new automation and technologies provide the OPS room team with new capabilities, it also changes the work processes, tasks, workload, and communication needs of the crew. New automation can also have a wider implication on crew size, its structure and the training needs of operators [3] [4].

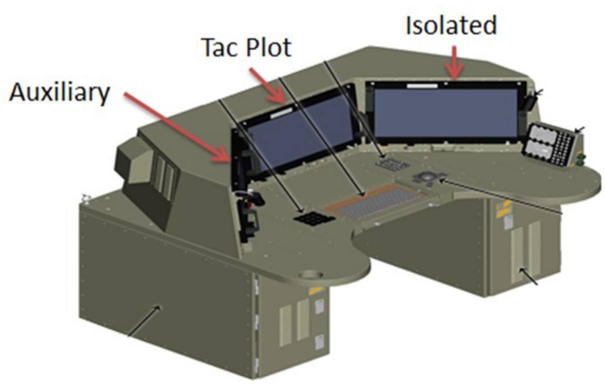


Figure 1: *An example of a multi-function workstation (MFW) for the CMS-330 [5].*

The RCN, specifically Directorate Navy Personnel and Training (D Nav P&T), has sponsored Defence Research and Development Canada (DRDC) to investigate the impact of new automation on crew performance under The Impact of Automation on Crew Performance project which is a work break down element (WBE) within the RCN's Force Structure Human Factors Program. This project has focused its efforts on the CMS-330 onboard today's post HCM Halifax-class frigates, however the implications of the work are intended to inform D Nav P&T on crewing for not only the CPF, but also for the future CPF replacement ships, the Canadian Surface Combatants (CSC).

During the initial years of the Impact of Automation on Crew Performance WBE, a task analysis was performed to identify the new automation onboard the CPF OPS room [3]. Several pieces of automation were identified, but DRDC focused on only two pieces of automation that we believed can alter crew performance [3] [4]. The first piece of automation is multi-sensor data fusion applied to maritime picture compilation [6]. This automation uses advanced algorithmic techniques to intelligently build tracks based on the kinematic sensor data of ships and aircrafts to support the picture compilation process [3] [4]. The second piece of automation is automation for threat evaluation (TE) and weapons assignment (WA), or collectively known as TEWA. This automation intelligently determines which contacts are potential threats, recommends weapons to engage the threat, and helps to manage the weapons resources [7] [8].

This document reports a laboratory-based trial on employing advanced TEWA with different team structures. A separate set of studies investigates with data fusion for picture compilation and is not reported here [9]. With the arrival of the new RCN fleet, the RCN will likely be employing more advanced automation and technology to support its crews and missions. It is anticipated that the TEWA capabilities will be more advanced. These new TEWA capabilities are expected to facilitate operator decision making and reduce workload while providing the RCN with better capabilities for mission success.

However, for new TEWA technologies to be accepted, its design must meet the functional, informational and team requirements of the RCN and its crews. As well, there is concern that the automation will have secondary effects that negatively impact work tasks. While it is expected that automation may remove some tasks completely or significantly change the way a task is performed, the hope is that the team structure can adapt and optimize its use [3]. As a result, it may be necessary (or desirable) to restructure the team, reallocate tasks amongst the operators, train operators differently and possibly even remove operators entirely to optimize the performance of the TEWA system. Thus, central to this work, is understanding the role of automation in teams and how to structure teams to optimize automation, a topic that is still not well understood.

1.1 Teamwork and Team Structure

There has been vast interest in the study of teams and teamwork over the last few decades [10]. As a result, a great deal has been learned about how teams work together and the factors that influence team performance. While there is no single definition of a team, [10] suggested that teams are social entities with members with high task interdependency and shared common goals. Team activities generally involve operation activities performed by individual team members (task work) and activities that support the collaborative effort of the overall team (team work) [11]. Many models of teamwork now exist; they all typically some type of input-process-output framework [11]. Some examples are the Integrative Framework model [11], crew resource management (CRM) model [12], the Big Five Model [13], the Teamwork Model [14], and the Anti-Air Teamwork Observation Measure (ATOM) model [15]. While these models disagree on the number of dimensions related to team work, there is some consensus on key factors that are important for teamwork [11] [13].

For example, team leadership, team orientation, and back-up behaviours are all critical components of the Big Five model, the ATOM model and the Teamwork Model. Team leadership focuses on the ability of the team leader (a) to shape the teams mental model, (b) to monitor the environment and facilitate adaptability when changes occur, and (c) to establish performance expectations and track deficiencies in team members [13] [14] [15]. Team orientation refers to the team's attitudes towards one another, the leader and the task [14]. Back-up behaviours refers to the ability for teams to back-fill roles such as when one person becomes overloaded [13] [14]. Team models also stress the importance of team members having a shared mental model [13] [14] [15] and mutual trust in each other. Effective communication and coordination are also a critical to successful teamwork [11] [12] [13] [14] [15] as it allows team members to receive significant updates and sharing of mental models in dynamic tasks [11] [12] [13] [14] [15].

Additional research on teamwork has focused on more specific items which are encapsulated by these teamwork models. For example, the concept of team cognition, which proposes that teams collectively encode, store and retrieve information has been very influential to team research [10] [13] [16]. Moreover, others have stressed the importance of the organizational shell that the team operates under. The organizational shell defines the culture of the team, the team requirements, and the training given to the team [16]. Still, others have demonstrated the usefulness of training teams to improve performance [10]. The task itself can also have ramifications on the team, such as the time pressure, uncertainty, and predictability of the situation [17].

Few studies have directly investigated the impact of introducing automation on teamwork [18]. [19] suggested that automation has three high-level functions in a team environment. It can serve individual members to facilitate a specific task; it can perform the role of a teammate (or partial teammate); or it can facilitate teamwork processes such as communication and coordination [19]. Introducing automation can sometimes have consequences to teamwork because it can impede on some of the basic processes that support teamwork. For example, automation that is complex and poorly designed is difficult to understand, difficult to predict and does not communicate its intent or understanding of the environment. Thus, it becomes difficult to trust, provides poor communication and does not provide its mental model. The lack of automation transparency then places additional cognitive demands on human team members to understand the automation and then communicate its behaviour to others [20]. Thus, automation can sometimes negatively impact the way team performance and the way members interact with each other.

Wright and Kaber [21] suggested that automation impacts to a team are, in part, task-dependent. Specifically, they found that automation that supports different aspects of information processing had different effects on teamwork. In their task, when the automation focused on information acquisition, it affected communication patterns of the team by reducing the need to communicate frequently. When automation focused on information analysis, it resulted in higher ratings of teamwork and better team coordination due to changes in the approach that teams took to better use the automation. Automation that supported decision-making had a negative effect on team coordination and greater workload when the task difficulty was low. However, there was a trend towards greater team effectiveness in this condition.

This effect of automation on teamwork raises the question whether teams should restructure themselves to accommodate for new automation. Team structure refers to the organization of people, and the division of roles, subtasks, and resources for achieving a goal [16].

Only a few studies have looked at team structure as it relates to automation. [22] compared two C2 team structures in a pilot study. In their functional structure, each team member specialized in a particular function (e.g., air warfare) and had to coordinate across multiple platforms. In contrast, in the divisional structure, each person controlled a multifunction platform that could conduct multiple domains of warfare. Their preliminary findings suggested that the ideal team structure was task dependent. For example, the functional structure was better for striking targets, but the divisional structure was better for defensive operations. [23] also separated their two teams into a functional and divisional structure to investigate their response to sudden changes in workload in a fire fighting scenario. They found that functional structure had poorer overall performance and increased communications during workload transitions, but they were faster at detecting new fires.

[24] allowed two person teams to self-determine their own structure for controlling 24 unmanned ground vehicles (UGVs) in a task to locate and mark injured people in a building. Three team structures emerged: joint, mixed and split. In the joint structure, both team members had full control all 24 UGVs. In the mixed structure, one team member was the leader and the second team member supported the leader. In the split structure, a subset of UGVs was split between the two team members. The UGVs could conduct either automated path planning or team members had to manually navigate each UGV. Teams that adopted the joint team structure had superior performance and when the UGVs had automated path planning, the joint structure was preferred. When UGVs had manual navigation, split control was preferred. This study suggests that the level of automation can impact how teams should structure.

These findings raise some questions for the RCN's future naval crewing. As the RCN embarks on the development of a new naval fleet, new technologies will be integrated that may change the way tasks are performed. New technologies (and in particular automation) can alter the work process of a team, render some tasks unnecessary, or even eliminate the need for certain team members. Automation might also change the division of labour amongst team members. Thus a team may need to restructure how they perform tasks to best accommodate the use of new technologies and automation. In the present study, we examine the impact of TEWA automation on the team structure of the directors in the OPS room of a CPF.

1.2 Threat Evaluation and Weapons Assignment

TE and WA are complementary activities for air defence. TE loosely involves detecting contacts in the battlespace, tracking and identifying the contacts, determining which entities are potential threats, understanding the nature of the threats, and ranking and prioritizing the threats [7] [8] [25]. WA involves determining and assigning hardkill and softkill weapons to counter specific threats and scheduling their engagement to maximize the countermeasure effects [7] [8] [25].

Onboard a RCN CPF, the core acts for conducting TEWA falls upon the teamwork between the operations room officer (ORO) and the Sensor Weapons Controller (SWC), who is also known as the above-water warfare director (AWWD). The ORO is the ship's Commanding Officer's (CO) primary tactical advisor and the lead officer in the OPS room. He or she is responsible for the supervision of tactical information, coordinating the OPS room crew to complete assigned tasks and to counter existing threats [3] [26]. The SWC reports to the ORO and is responsible for the effective employment of sensors and weapons for AAW and ASuW [3] [26]. Other members of the OPS room team also contribute to picture compilation, threat detection and evaluation, but the core responsibility falls on these two positions [2] [26].

While operators are relatively effective at managing simple threat situations, the TEWA task becomes difficult to execute optimally in complex multi-threat situations. From a human cognition standpoint, the human can become cognitively overwhelmed for a number of reasons. First, obviously being attacked by a missile is a highly stressful event. Stress impairs cognition in a number of ways including negative impacts on attention, memory and decision-making [27]. Second, the window of useful time to counter a missile attack can be extremely limited, sometimes allowing only a few minutes from the time of detection to the time of imminent contact. Temporal demand is itself a form of stress that impacts workload [28] [29]. Third, the actual task itself is cognitively demanding, requiring the SWC, ORO and the team to assess the threat situation, conduct several quick analyses, and make decisions under a great deal of uncertainty. For example, to conduct threat evaluation, the team (but primarily the SWC) needs to understand the proximity of the threat, its capability and its intent. The SWC and ORO may need to determine the missile type, the intended target, the closest point of approach (CPA), consider the ship's manoeuvres, and have an accurate understanding which defensive weapons are available which might be a combination of hardkill and softkill options [8] [25]. Last, missile attacks are rare events and normally only experienced in simulation and training; if a missile event were to happen in theatre, aspects of it could be quite unfamiliar requiring additional cognitive capacity to deal with additional uncertainty and time pressure of the situation [30]. Therefore, the complexity of the TEWA task, combined with the stress from the high temporal demands and extreme negative consequences of a missile attack is prone to human error.

1.3 TEWA Automation

Today's air defence problem is more complex than ever before. Both aircrafts and missiles have longer ranges, are faster and are more agile [31]. Aircrafts are now highly manoeuvrable in three dimensions and new hypersonic missiles are claimed to reach speeds surpassing Mach 5 [31]. As well, an increasing number of countries have advanced missiles in their arsenal [31] and while a simple attack may be defensible, simultaneous attacks from multiple bearings is a challenge for human naval teams [8]. Therefore, TEWA automation has been applied to reduce human error and optimize the ship's capability to defeat threats.

TEWA automation involves five main functions: target detection, target tracking, target identification, threat evaluation and weapons assessment [8] [32]. Target detection and target tracking typically involves sensor fusion from various radars to derive an optimal kinematic solution for targets in radar range [3] [6]. Target identification involves interpreting data from a host of information sources to derive an identity for tracks. The information can originate from the ship's sensors, electronic support measures (ESM), identification friend or foe (IFF) interrogation systems, data provided from other platforms, data from external tracking systems [e.g., automated identification system (AIS)], intelligence, and visual data from optical cameras to identify the target. The identification includes determining the track as an air, surface, or subsurface contact, determining its allegiance (unknown, friendly, neutral, hostile), down to specifics about the target [e.g., its name, class of vessel, maritime mobile service identity (MMSI)]. Targets identified as unknown or hostile can be further classified as a threat. Similar to a human determination of threat, algorithms will treat hostile targets as threats based on their proximity, capability and intent. Threat values are assigned based on a number of parameters to determine the level of threat, which in turn will determine the weapons assessment. Weapons assessment will assign which weapons should be launched to counter a threat which would consider both hard and softkill countermeasures. A scheduler might also be included that determines when specific weapons should be deployed to maximize the opportunity to destroy the threat. TEWA systems will also include a user interface to provide the naval operators with a way to visualize threats, interpret automated decisions, and visualize the weapons assessment [8].

For the RCN, the TEWA automation onboard the current CPFs evolved from DRDC research. In the early 2000s, DRDC began investigating single platform TEWA with one threat under the shipboard integrated sensors and weapons systems (SISWS) Technology Demonstration Program (TDP) [33]. The work on TEWA then evolved to look at single platform with multiple targets through the INCOMMANDS project. The INCOMMANDS project successfully influenced the RCN's anti-ship missile defence (ASMD) tactics in Canadian Forces Controlled Document (CFCD) 106 and fed the technical requirements for the current TEWA system in the current CPF. INCOMMANDS also saw the first development of the DRDC Combat Resource Allocation Support (CORALS) system. CORALS centres on the TEWA process and is a set of automation and decision aids embedded within combat system to support battle management during demanding engagements. In 2010, through the C3MAAD project, CORALS evolved significantly, with a number of experimental trials and at-sea trials to test and strengthen its capabilities. In its current state, CORALS can be an advanced fully automated TEWA system, capable of coalition TEWA with multiple targets [33]. While the current TEWA capability onboard the CPFs is limited, the technology from CORALS will very likely add to the CPFs capability in the near future and will likely contribute to CSC.

The employment of automation such as TEWA has undoubtedly changed naval warfare for the RCN. It also has changed the way TEWA is conducted for the crew. Like all technologies, it has the potential to reduce human error, reduce workload, and improve efficiency, productivity and safety. However, the benefits of any automation are not guaranteed. Automation that is clumsily produced and ill-vetted can do more harm than good. For example, unreliable automation can lead to excessive false alarms, mistrust in the automation and abandonment of the automation [34]. Also, workload might be reduced to the point that the human experiences underload and vigilance decrements in attention. When automation fails, underload in workload might then suddenly replaced by high workload as the human operator tries to trouble shoot the failed automation sometimes with dire consequences if a solution is not quickly found. In these situations, the operator often is out-of-the loop and has low situation awareness (SA) and is unable to quickly resolve the issue [34].

It is also not always the case that automation replaces a human entirely or the work that a human conducts. More often, tasks are only partially automated and the human still performs other aspects of a task. For example, in Canada, automation has replaced many jobs that require routine behaviours, but there's been a rise in non-routine jobs that require greater cognitive effort, non-routine manual labour and jobs that require human interaction [35]. Humans also tend to still play a vital role in monitoring automation, overseeing automated decisions and overriding automation when it fails. This has raised the question, how do organizations deal with the change their work force in order to successfully adapt, adopt and optimize the use of automation. For the RCN, this might mean selecting operators for the job with a different set of core skills or education, training operators to not only use the automation, but to understand how the automation works, and how to properly use the automation in a team environment. This might involve changing the number of operators, or even the team structure of people working together with the automation.

Indeed, during the course of this project, we encountered comments that reflected this change in work for SWCs and OROs. For example, the threat evaluation display on the TEWA automation onboard the CPF was designed to be the central display for the SWCs to gather SA and the tactical plot was to become a supporting display [3]. That is, SWCs could monitor threats as they emerge on their TEWA screen, select them, and then view them on the tactical plot as necessary. This process is a significant departure from how SWCs traditionally gather SA on threats through the tactical plot and thus there has been low adoption of this new workflow [3]. Today, the question still remains on how best configure the work of the SWC and ORO to best use advanced TEWA automation.

1.4 The Present Study

To address this issue, in this study, we examine the use of TEWA under two team structures: (a) a *Traditional* team structure, which mimics today's SWC and ORO roles and (b) a *Functional* structure, wherein one person is responsible for threat evaluation and the other person is responsible for weapons assignment. We also manipulate two levels of TEWA automation, or its Level of Automation (LOA), by comparing a *Basic* level and an *Advanced* level. The Basic condition will have automation capability similar to that of the CMS-330 where the TEWA automation provides recommendations and the operator must approve or reject the recommendations. In the *Advanced* condition, the TEWA capability automatically executes its own recommendations unless the operator overrides the recommendation within a specific window of time. A more detailed description of both factors is provided in the Methods section below.

1.5 Hypotheses

1. We hypothesized that a fully automated TEWA would better support the TEWA task and free up cognitive resources for the human operator to conduct other tasks without sacrificing the ship's defensive capability.

2. We also hypothesized that the Functional Team would be better able to handle threats and would outperform the TEWA team with respect to workload and SA. This team should have an advantage because the balance of the work is distributed more evenly over the two directors.

2 Method

2.1 Selection of Human Participants

Four teams of two naval combat operators (8 participants in total) were recruited for this study, consisting of one qualified SWC and one qualified ORO. Participants were recruited with the help of the RCN through an official RCN tasking and maritime evaluation process.[1] All participants were male with an average age of 39.5 years (standard deviation (SD) = 6.82 years). The average years of service in the Canadian Armed Forces (CAF) was 18.13 years (*SD* = 5.64) and on average, they were in their present role as a SWC or ORO for 36.25 months (*SD* = 33). The recruitment of participants was in accordance to the guidelines and approval of the DRDC Human Research Ethics Committee (HREC).

2.2 Experimental Variables

2.2.1 Crew Structure

The combat operators performed the TEWA task under two different crew structures: *Traditional* and *Functional*. In the *Traditional* condition, we instructed SWC or ORO to perform their tasks as they do today; the SWC was the director primarily responsible for threat evaluation, weapons assignment and resource allocation as well as picture compilation. The SWC reports to the ORO, who must approve actions, support the SWC as necessary, but also has the responsibility to other tasks on the ship [26].

In the *Functional* condition, we instructed our SWC and ORO to play new roles as a *threat evaluator* and *weapons coordinator.* In this study, we assigned the ORO to the threat evaluator role and the SWC to the weapons coordinator. We call this structure a *functional* team structure based on the separation of the two distinct tasks by their function. The functional team structure distributes the workload in a more balanced fashion across the two operators and allows the operator to specialize in a functional area rather than having both operators continually go back and forth between threat evaluation and weapons assignment.

2.2.2 Levels of Automation

The extent to which the TEWA was automated, or its LOA, was a second experimental factor. The LOA of any automation can have significant implications on how the human-machine system performs [36]. At low levels of automation, the human still performs much of the task and the automation assists the task. For example, a car that only adjusts for headway or assists in collision avoidance may be regarded as a low level of automation. In contrast, at high levels of automation, the human performs none of the task and allows the automation to fully execute all sensing, information processing, decisions and actions. A fully self-driving autonomous vehicle would be an example of applying a high level of automation.

Onboard today's CPF, the TEWA automation may be considered an intermediate level of automation. The TEWA automation detects and recommends threats to the SWC, who must investigate and approve or disapprove the recommended threat. The TEWA automation also develops and recommends a weapons allocation plan which also must be approved by the SWC. The SWC would confirm the plans with the

[1] While the tasking asks for specific types of personnel, the maritime evaluation specifically asks for volunteers.

ORO. In our study, the *Basic* level mimicked this level of automation in our simulation. In the *Advanced* automation condition, the operator could override the automation's recommendations, but if he or she did not, it would act and launch defences at identified threats. There are arguments for making TEWA fully automated. As mentioned, a complex, high tempo missile attack is high in workload, stressful and cognitively demanding. Allowing the automation to perform the task allows for the operators to focus on other duties that are also critical for mission success. Maybe more important, if TEWA automation is reliable, it would optimize the success of defeating threats since all of the cognitive calculations required to handle a simultaneous multi-axis attack would likely be too difficult for a human to process in a short period of time.

2.3 Trial Protocol

2.3.1 General Description of Protocol

The trial was conducted at DRDC – Atlantic Research Centre. Each team was required for three days, for 5–8 hrs per day. On Day 1 and the morning of Day 2, teams were trained on the CORALS software and the MilChat software. On the afternoon of Day 2 and Day 3 teams conducted the experimental missions in CORALS with two scenarios per day. The team structure was constant on given day, but changed the following day. The order of the team structure was counterbalanced between the four teams. Within each day, the teams conducted one mission using the Basic automation and one mission using the Advanced automation. Automation was counterbalanced across the two days for each team. In total, the trial ran four teams over a four week period.

2.3.2 Software Applications Used for TEWA Trial

2.3.2.1 CORALS

All scenarios were administered on networked computers running CORALS [25] [33] [37]. CORALS allows for the creation of a maritime mission, with realistic models of entities. The simulation allows the researchers to create a realistic naval operation with a varying number of ships and aircrafts. The user portion of the simulation is similar to a combat system on a ship and allows operators to manipulate sensors and weapons, and interact with entities on the tactical plot. CORALS provides advanced TEWA automation capability that acts as a decision-aid to identify threats, manage resources, schedule countermeasures, and launch counter attacks against threats. The software also measures critical dependent measures (e.g., completion times, accuracy) for human performance that are logged for analysis. CORALS and the use of these metrics were recently used to collect human performance data at RIMPAC 2016 [33].

The CORALS interface consists of four main windows: (a) a tactical plot for picture compilation; (b) a threat evaluation window (c) a threat engageability assessment window and (d) an effector management window (Figure 1). The tactical plot is illustrated on the top-left corner of Figure 1. The tactical plot consists of a 2D map centred around one's ownship, which is sailing within an area of operations. Sensor tracks are presented on the map representing the air, surface and subsurface contacts in the area. The battle dimension or domain of each track (i.e., air, surface, subsurface) is indicated by their respective NATO symbology and the affiliation of the track is represented by the colour of the track (i.e., hostile, friendly and neutral). Participants can click on entities to display information on each track and can edit the track [33].

The threat evaluation window consists of a list of identified threats. Threats are determined through a set of algorithms that are both reactive (e.g., assesses the time to contact) and deliberative (e.g., the intent and capability of the threat) [36] [37]. The algorithms also prioritize the threats and categorize them. Each threat is presented in what is called a “swim lane” and is shown as a red missile icon. The swim lane is labelled by the track number of the threat, the intended target, and its time to contact. It also shows potential countermeasures against the threat and when they are to be launched [3].

The threat engageability assessment window provides information on the ship’s combat inventory. It also assesses the constraints of each effector, factors the constraints into how successful they will be, and predicts the effectiveness of effectors. Finally, the effector management window shows the plans, the coordination and the schedules for the effectors [33].

Figure 2: *A screenshot of the CORALS user interface [33].*

2.3.3 Scenarios

The scenarios that were employed were based from a set of scenarios developed by the Canadian Forces Maritime Warfare Centre (CFMWC). The overaching storyline had the participant’s ownship as part of a United Nations (UN) multinational force attempting to temper escalating tensions between two nations; the adversarial nation, who has a strong military force, has already attacked the second nation which only has a small military. The adversarial nation sees the presence of the UN force as an act of war.

Eight 30 minute scenarios are presented, two practice and six experimental. Each scenario always had at least two adversarial aircrafts probing the participants’ ship (but not attacking) and four surface vessels in the vicinity and capable of launching an attack. As well there were two known submarines in the vicinity (but they were not part of these scenarios). Each scenario had three waves of attacks which could occur within each of the three ten minute segments. The attacks could be launched from fighter jets, surface vessels, UAVs, or shore batteries. The three attacks varied in intensity (arbitrarily labelled as low, medium and high). Intensity was defined by how many separate threats occurred within the ten minute period. A low intensity attack had 2–3 threats. A medium level attack had 4–6 incoming threats and a high level attack had greater than 6 threats. All of these could have threats coming in from the same or similar bearings or from multiple bearings.

2.3.4 MilChat

In addition to defending the ship, each person was asked to perform a secondary task on a separate computer. The secondary task, called MilChat, was first developed to examine communication strategies using chat in army command posts [38]. MilChat involves three subtasks. First, participants are responsible for a *chat mapping task*. They are presented with a chat interface and will be responsible for monitoring the movement of three teams (red team, blue team, and green team) who report their location through the chat. When a location is reported, the participant must move the correct team icon to the location on a map. Second, participants are simultaneously presented with an *auditory call sign task*. In this task, a call-sign is presented auditorily (e.g., Charlie) followed by number (1–8). If they hear their own call-sign, which is assigned at the beginning of the study, they must then click the associated number on the interface. Third, participants will have to respond to *chat questions*. Participants will occasionally be asked questions through the chat interface regarding the movements and location of the three teams. The participants will have to respond with a true or false response.

The MilChat task serves two purposes. First, it provides an element of realism to the TEWA task since OPS room directors are engaged in many tasks involving different cognitive resources and through separate channels of communication [26]. The second purpose is that the MilChat task serves as a real-time performance measure of workload. That is, the TEWA task is the primary task, and the MilChat serves as a secondary task. Ideally, the participants can conduct both tasks simultaneously. However, if the MilChat tasks start to degrade, it suggests that the participant's cognitive capacity has been exceeded [29]. The MilChat task taps into both the auditory and visual modalities and requires sufficient working memory capacity to complete the tasks correctly.

Prior to starting, participants wore a headset and were assigned individual call signs. In both the Traditional and Functional teams, both individuals were responsible for their own MilChat task. This mirrors more closely what is seen in the OPS room where the SWC and ORO are on separate chat nets. Accuracy and time performance in this secondary task were used as a separate measure of workload for the various conditions.

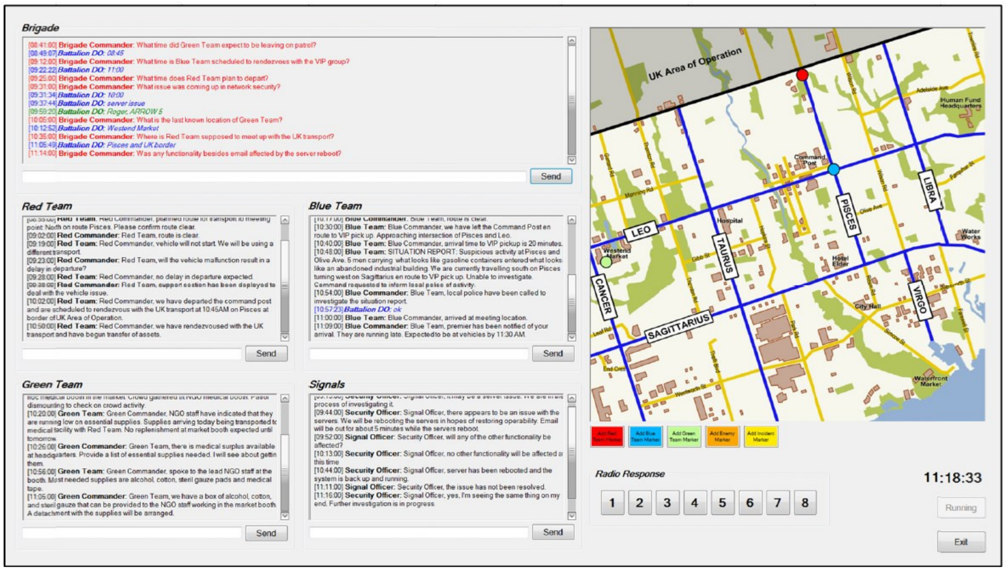


Figure 3: *The sample screenshot of the MilChat interface [38].*

2.3.5 Procedure

2.3.5.1 Training

Participants took part in 1½ days of training to familiarize themselves with (a) the CORALS simulation software, (b) the automation levels in CORALS, (c) the MilChat secondary task, and (d) the two team conditions of the study. The training was divided into these six training segments:

1. Consent Form and Demographic Questionnaire—All participants read a pre-experimental information sheet (Annex A) and signed a form to indicate informed consent (Annex B). Basic demographic information was also collected (Annex C).

2. CORALS Software Familiarity—Participants were given an overview of the CORALS software by a RCN SME who was familiar with CORALS and operations room procedures. They were seated in front of a CORALS workstation and given both PowerPoint presentations and the ability to interact with CORALS directly during the training. Participants learned the main parts of CORALS and a general familiarization of the interface layout and interactions. This was followed by specific training on the four main aspects of CORALS:

    a. Picture Compilation Familiarity

    b. Threat Evaluation

    c. Effector Assessment

    d. Effector Management

3. Automation Levels—Crews were trained on the different CORALS automation levels (Basic and Advanced) and how they were to be used in the TEWA tasks.

4. Task/Roles Familiarity—Teams were trained on their individual roles as part of a Traditional or Functional.

5. Secondary Task Familiarity—Teams were trained on how to perform the MilChat secondary task. They were given verbal instructions on how to perform the MilChat tasks and given opportunities to try them.

6. Practice Scenarios—Teams were given two practice scenarios. This allowed them to familiarize themselves with the task as a team, become familiar with the CORALS and MilChat software, and to allow the teams to practice using the two levels of automation.

2.3.5.2 TEWA Trial

During Day 2 (afternoon) and all of Day 3, the teams conducted the main trial. On each of these two days, they performed four experimental missions in the CORALS simulation; two missions were conducted under Basic Automation and two missions under Advanced Automation. Depending on the day, they played the missions as a Traditional team or as a Functional team. The duration of each mission was approximately 30 minutes to complete. Each mission had three parts:

1. Briefing: The mission was first be briefed by a RCN research confederate. This was done using a PowerPoint presentation and paper handouts.

2. Experimental Mission Scenario: Each crew played through a mission that involved performing picture compilation, threat evaluation, setting up weapon plans, and engaging multiple threats.

3. Post-Mission: After each mission, the crews were provided with questionnaires to complete to measure their workload using the National Aeronautical Space Agency—Task Load Index (NASA-TLX) [28] (Annex D) and a post-mission questionnaire (Annex E).

During the mission, the participants played the role of OPS room directors with the goal of creating the recognized maritime picture (RMP), identifying threats, and defending the ship or other important vessels using CORALS. A standard keyboard and mouse allows the player to navigate CORALS and interact with the system.

Each mission begins with a mission brief that outlines the situation of the mission. They were told that the mission places the participants onboard a RCN ship, as part of a United Nations (UN) force to maintain stability to a region where one nation has occupied another sovereign nation. The occupying nations sees the UN force as a sign of aggression and threatens escalation. While executing the simulation, the participants' ship will be attacked by multiple threats, at different levels of complexity.

When the team was ready, the researcher started the mission. Missions began with the simulation paused. The participants were allowed see their ownship in the area of interest with their sensors activated. Participants had 5 minutes to review the situation, gather SA, and discuss the key threats and issues. After 5 minutes, the simulation started. As the mission progressed, sensors started to pick up contacts and tracks on the picture compilation window (which were a mix of regular civilian traffic or potential threats).

Threats include surface ships, aircrafts, unmanned aerial vehicles (UAVs), or land-based artillery batteries. Some of the threats engaged the ship and attacked with air missiles. As a team, the participants were instructed to identify all of the threats, prioritize them, develop an engagement plan for the threats, and schedule weapons to engage the threat if necessary. During the mission, two observers evaluated the teams' performance. Both observers were from the CFMWC and were former RCN OPS room operators. Each was given a checklist for each mission (Annex E). The checklist provided a list of the critical threats and events in each mission. The observer had to determine whether the team detected the events in a timely manner and responded appropriately by marking off the item on the checklist. The simulated mission ends after 30 minutes.

After each mission, participants were given two questionnaires, the NASA-TLX [28] to measure their workload (Annex D) and a post-mission questionnaire that had participants self-rate their performance and attitudes regarding the mission (Annex E). The NASA-TLX asks participants to self-rate their workload on six workload dimensions (mental workload, physical workload, temporal workload, frustration, effort and performance). Participants then rate the importance of each dimension on their workload for the associated task. Workload scores can then be calculated for each dimension, or aggregated to produce an overall workload score [28]. The overall workload score can be weighted by the importance of each dimension or unweighted [39]. The performance questionnaire had nine statements and participants had to rate their agreement to the statements on a 5 pt. Likert scale from Strongly Disagree to Strongly Agree.

After the final mission of Day 3, after filling out the NASA-TLX and the post-mission questionnaire, the participants filled out two additional questionnaires, one pertaining to the TEWA automation and one pertaining to the team structure (Annexes G and H respectively). Then, participants attended an interview session to discuss their experiences using the TEWA automation in the different team structures. The interviews focused on questions that indicated areas of difficulty or areas where team members disagreed on their performance (Annex I). Following the completion of the interview, participants were debriefed for the TEWA portion of the trial (Annex J), remunerate and thanked for their participation.

3 Results

The results focused on the operator workload and subjective evaluations of the crew structure and the automation. Five main measures are reported: (a) Workload as measured by the NASA-TLX [28]; (b) Workload as measured by the secondary MilChat tasks; (c) SME Evaluations of the team's performance; (d) questionnaire data; and (e) interview data.

Due to a variety of constraints (i.e., funding, location of the study, access to a small specialized population group, extensive training required for using CORALS), we had to limit the size of the sample for this study. This small sample size does not provide sufficient statistical power to perform reliable inferential statistics thus we treat the data with some caution. There is some debate on how to analyze small sample data. We follow Siegal [40] and Schnell [41] suggestion to apply non-parametric analysis. In the following analysis, we focus on pairwise comparisons for the team structure and automation effect using the non-parametric Wilcoxon signed rank test. We also examine the effect of team structure and automation as a function of attack complexity when possible. Because there are three levels of attack complexity, we submit the data to a Friedman's test and provide the effect size.

The reporting of effect size is also good practice for small sample studies because effect size is not dependent on sample size and can be a good indicator of an actual effect. While the tests with small samples are typically statistically not significant due to lack of power, the effect size can be similar with small or large samples [41]. There are different methods to report effect size. For non-parametric statistics, there are few options. Thus, we chose to apply omega-squared (ω^2), which is generally a preferred estimate of effect size when sample size is small because it is a less biased estimate compared to estimates like eta-squared [42] [43]. In this report, we use partial omega-squared, ω_p^2 to explain the amount of variance associated with one particular variable, partially out the effect of other variables [43].

The quantitative data will focus on any notable trends and will be compared to the qualitative data and try to provide a comprehensive understanding of the effects.

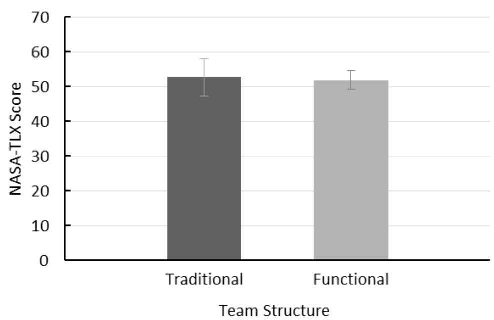
3.1 Workload—NASA-TLX

Workload is a common measure for human performance scientists. It is a used as way to quantify the mental/physical cost of performing a task. The rationale is that if one's workload exceeds a certain capacity, their ability to sustain satisfactory levels of performance and take on additional tasks is in jeopardy [29]. Experiencing long durations of high (or low) workload increases response times to events, increases errors and performance variability. High workload will also impose changes to cognitive strategies to perform tasks and commonly, fewer tasks are completed when workload is high. High workload also negatively impacts one's ability to attend and monitor different aspects of a task resulting in poor SA [44].

The NASA-TLX is a widely used and reliable evaluation of workload [45]. The tool assesses workload on six dimensions or sub-scales, mental demand, physical demand, temporal demand, effort, performance and frustration. The tool provides an overall workload score (out of 100) based on how the participants rank the workload of each of these dimensions and how each is compared to one another [28].

The overall NASA-TLX scores as a function of Team Structure and Level of Automation is presented Figure 4. As can be seen in Figure 4a, teams reported a moderate degree of workload with this task. NASA-TLX scores for the Traditional Teams were only slightly greater than the Functional Teams. The Wilcoxon Signed-Rank test was not significant for these two groups (Z = -1.26, p = .208) and the effect size was negative (ω_p^2 = -.137) suggesting that the workload was not different between the two team structures.

a)



b)

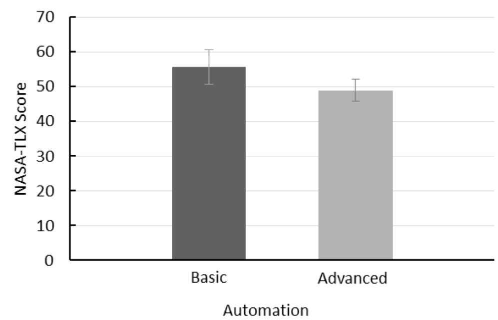


Figure 4: *Workload scores from NASA-TLX for (a) the two team structure conditions and (b) the two automation conditions.*

The mean scores for the Level of Automation factor were more divergent. The NASA-TLX scores were greater when using the Basic Automation (*M* = 55.58, *SE* = 4.97) versus the Advance Automation (*M* = 48.93, *SE* = 3.16) although the Wilcoxon Signed-Rank test was not significant for these two groups (Z = .208, p = .161). However the effect size is substantial and suggestive of a real difference (ω_p^2 = .189).

3.2 Workload—MilChat Tasks

The MilChat tasks provide three separate scores as secondary performance measures of workload. Again, the MilChat tasks are secondary tasks to the TEWA task meaning that spare cognitive capacity should be dedicated to the MilChat tasks. Therefore, any degradation in the MilChat tasks suggests that the cognitive resources of the operator have been exceeded by their attention to the TEWA task.

3.2.1 Mapping Task

The mapping task required the participants to follow the chat messages and to update a map as necessary. The chat messages were from three teams who periodically reported their location. The participants had to move the correct team icon to the proper place on the map. Whenever a chat message appeared, the participant had 15 seconds to move the correct marker to the correct location.

In general, participants performed poorly on the mapping task with most scores under 50% correct which is suggestive that the TEWA task imposed significant workload on the participants. When team structure is considered alone, there was virtually no difference in accuracy scores between the Traditional (*M* = .234, *SE* = .04) and Functional (*M* = .253, *SE* = .04) teams. The Wilcoxon Signed Rank test was not significant (Z = -.42, p = .674) and the effect size was effectively zero (ω_p^2 = -.14). Accuracy was slightly greater in the Advanced automation (*M* = .275, *SE* = .05) relative to the Basic automation

(M = .212, SE = .03) condition. However, this difference was not statistically significant, (Z = -.7, p = .484) and the effect size is again zero, ω_p^2 = .003.

The data were also examined as a function of attack complexity by submitting each condition to a Friedman's Test (Table 1). Interestingly, for both team structures, the moderate attack level resulted in the best accuracy; accuracy decreases in the lower and higher attack levels. This effect was not significant for the Traditional team structure but was significant for the Functional team suggesting that (at the very least) mapping accuracy is significantly greater in the moderate to high attack levels. The effect size for both conditions was considerable and suggestive that the attack complexity affected the accuracy of the mapping task.

In the Basic automation condition, there was a marginal effect of attack complexity with a large effect size. Again, the accuracy for the mapping task was greater in the moderate attack level relative to the other conditions. For the Advanced automation condition, there was no significant effect of attack complexity on mapping accuracy and the effect size was zero. Thus, the data suggest that under Basic automation, participants had difficulty with the mapping task and this was affected by the complexity of the attack. In the Advanced automation condition, while accuracy was still relatively low, performance was more consistent across the different levels of attack.

3.2.2 Auditory Call Sign Task

The auditory call sign task required participants to respond to auditory messages when the participant heard their own call sign. Each crew member received their own unique call sign. When they heard their call sign, they were required to listen for the subsequent number between 1 and 8. Subsequently, they had to click the correct number on the bottom-right portion MilChat screen (see Figure 2) as quickly and as accurately as possible. The response time and accuracy for this task was recorded.

Table 1: *Results of Friedman's Test* (χ^2) *for each of the conditions as a function of attack complexity (N = 8, df = 2).*

Measure	**Condition**	**Low**		**Moderate**		**High**				
Mapping Task		M	SE	M	SE	M	SE	χ^2	p	ω_p^2
Accuracy	Traditional	.20	.05	.29	.05	.25	.05	2.39	.30	.11
	Functional	.26	.05	.32	.06	.18	.05	6.00	.05	.20
	Basic	.21	.05	.29	.03	.17	.04	5.25	.07	.25
	Advanced	.25	.07	.32	.07	.27	.07	3.00	.22	.00
Auditory Call Sign Task		M	SE	M	SE	M	SE	χ^2	p	ω_p^2
Response Time	Traditional	2814.00	317.51	2327.86	165.59	2628.87	152.81	3.00	.22	.24
(ms)	Functional	2372.53	178.82	2495.70	209.80	2344.62	217.76	.75	.69	.00
	Basic	2606.04	163.44	2349.13	225.88	2463.68	327.14	1.00	.61	.01
	Advanced	2559.49	276.39	2307.27	194.47	2311.59	178.67	4.00	.14	.00
Accuracy	Traditional	0.92	0.04	0.93	0.02	0.91	0.02	.87	.65	.00
	Functional	0.92	0.03	0.91	0.02	0.93	0.03	.60	.74	.00
	Basic	0.93	0.02	0.87	0.01	0.92	0.02	1.61	.45	.01
	Advanced	0.91	0.04	0.95	0.01	0.93	0.03	.50	.78	.00
Chat Questions Task		M	SE	M	SE	M	SE	χ^2	p	ω_p^2
Accuracy	Traditional	.84	.12	.78	.09	.77	.09	1.63	.44	.00
	Functional	.94	.06	.78	.10	.63	.16	2.70	.26	.17
	Basic	.88	.08	.72	.09	.60	.09	5.82	.06	.36
	Advanced	.83	.12	.91	.07	.85	.11	.11	.95	.00

3.2.2.1 Response Time

For Team Structure, the Wilcoxon Signed Rank test for the response time data was not significantly different with respect to performance between the Traditional (M = 2479.82, SE = 190.20) and Functional (M = 2366.92, SE = 158.52) teams, (Z = -.7, p = .484). The effect size was near zero, ω_p^2 = -.063. Similarly, there was no significant difference between the Basic (M = 2479.82, SE = 190.20) and Advanced (M = 2479.82, SE = 190.20) automation groups, (Z = -.14, p = .889). Again, the effect size was (effectively) zero, ω_p^2 = -.09. Thus, neither team structure nor the automation affected the response time to the auditory call sign task.

We then examined the effect of attack complexity on each condition using a Friedman's test. The response time data for the auditory call sign task are presented in Table 1. For the Traditional team structure, the effect was not significant, but the effect size is considered large. This suggests that it is plausible that the attack complexity affected the speed of auditory responses under this structure. In the low attack complexity, the team was slowest at responding compared to other conditions. However, similar to the mapping task, in the moderate attack complexity condition, they were fastest at responding. In the Functional team structure, the teams' performance was more stable. The effect is again not significant and the effect size is zero.

The data were near identical for the two automation conditions, suggesting no difference between these conditions. Both the Basic and Advanced automation conditions resulted in no significant difference as a function of Attack Complexity and the effect sizes were both near zero.

3.2.2.2 Accuracy

Response accuracy for the auditory call sign task was good. In all but one condition, accuracy performance was better than 90%. Differences in the average accuracy for the Traditional and Functional team structures were negligible, (*M* = .914, *SE* = .06 and *M* = .92, *SE* = .04, respectively). Not surprisingly, the Wilcoxon Signed Rank test was not statistically significant, (Z = -.315, *p* = .752) and the effect size was zero, ω_p^2 = -.135. For the automation effect, the average accuracy for the Advanced condition (*M* = .924, *SE* = .05) was greater than for the Basic condition (*M* = .908, *SE* = .03). The Wilcoxon Signed Rank test was not significant, (Z = -1.28, *p* = .20), but the effect size suggested a moderate effect, ω_p^2 = .09. As shown in Table 1, accuracy was not affected by the various attack complexities in either of the two team structures, nor in either of the automation conditions.

3.2.3 Chat Questions Task

The chat questions were questions that appeared on the chat window and asked true or false statements regarding the latest information on the mapping task (e.g., The [Colour] Team at Location X). The participant had to respond *true* or *false* through the chat window. In order for the participant to accurately ascertain the answer, they had to either hold the information in working memory or read through the chat messages to get the latest up-to-date information.

Mean accuracy scores for the Traditional team and Functional Team structures (*M* = .813, *SE* = .07 and *M* = .773, *SE* = .05, respectively) were not statistically significant, (Z = -.561, *p* = .575) and effect size was zero, ω_p^2 = -.12. For the Automation conditions, accuracy for the Advanced condition (*M* = .86, *SE* = .05) was greater than for the Basic condition, (*M* = .73, *SE* = .06). This effect was not statistically significant, (Z = -1.26, *p* = .208), but once again, the effect size for this effect is moderate, ω_p^2 = .14.

When each condition is examined as a function of attack complexity, the results suggest that attack complexity does affect the conditions differently. Referring again to Table 1, in the Traditional condition, differences in the accuracy of the chat questions was not significant and the effect size was zero. However, in the Functional condition, there is a considerable reduction in accuracy as the attacks become more complex. This effect was not significant and but effect size is considerable.

A similar decrease in accuracy is seen when teams had to defend against an attack in the Basic automation condition. In this condition, we again see accuracy falls as attacks become more complex. This effect was marginally significant and the effect size is substantial. In contrast, in the Advanced automation condition, the difference in accuracy amongst the attack complexity levels is negligible. Thus, it appears that under higher levels of automation and using a Traditional team structure, the operators were better able to perform their task.

3.3 Subject Matter Expert Evaluations

During each mission run, team performance was evaluated by two subject matter expert (SME) observers who marked off whether teams detected and acted appropriately to specific mission events. These events were then tallied and averaged across the two SME observers to obtain a final score for each scenario. The Functional team structure (*M* = 89.2%, *SE* = 5.8%) was evaluated as performing slightly better than the Traditional teams (*M* = 82.7%, *SE* = 4.4%). The Basic automation condition (*M* = 86.3%, *SE* = 6.0%) was evaluated to have performed slightly better than the Advanced automation condition, (*M* = 81.5%, *SE* = 6.5%). Due to limitations with the data, these data were not analyzed statistically.[2]

3.4 Questionnaires

3.4.1 Post-Mission Questionnaires

After each mission, teams completed the post-mission questionnaire. The questionnaire asked participants to rate their agreement on a 5 pt. Likert scale on nine statements regarding their performance on the preceding mission. The statements were framed in such a way that higher ratings were more favourable. For each item, the average score was calculated for each condition. We then took the difference of the average scores for the nine items across the two team structures (i.e., Traditional team score—Automation team score) and two automation conditions (i.e., Basic automation score—Advanced automation score) to see if there was a bias for one condition over the other.

The results are presented in Table 2. For team structure, positive difference values suggest a bias for the Traditional team structure and negative values are biased towards the Functional team structure. As can be seen, there was an overall bias for the Traditional team structure for eight of the nine items. The one exception has to do with keeping up with secondary tasks which favoured the Functional condition. It should be noted though that difference scores are all less than 1, suggesting that there was not a strong bias for any of the statements.

For the automation condition, positive difference values suggest a bias for the Basic automation condition while negative values suggest a bias towards the Advanced automation condition. Overall there was a bias for the Advanced automation condition. The item pertaining to SA was neutral (i.e., no bias) and the item pertaining to communication favoured the Basic automation condition. Again, all the scores are less than 1, suggesting the bias for any one item was not strong.

[2] During the execution of the trial, one SME observer was not available for one day. Also, one sheet was not returned to the experimental team.

Table 2: *A comparison of team structure and automation responses to the post-mission questionnaire.*

Post-Mission Questionnaire Item	Team Structure		Automation	
	Bias	Difference	Bias	Difference
Sufficient time to evaluate threats appropriately.	Traditional	0.250	Advanced	-0.250
Confidence in engagement plans.	Traditional	0.188	Advanced	-0.313
Sufficient time to review and validate engagement plans.	Traditional	0.688	Advanced	-0.188
Strong understanding of our weapon and resource allocations.	Traditional	0.063	Advanced	-0.063
Division of responsibilities was appropriate.	Traditional	0.375	Advanced	-0.250
Communicating effectively.	Traditional	0.250	Basic	0.250
Able to keep up to secondary tasks.	Functional	-0.188	Advanced	-0.688
Overall awareness of the situation was high.	Traditional	0.125	Neutral	0.000
Level of support provided by automation was appropriate.	Traditional	0.313	Advanced	-0.313

3.4.2 Post-Experiment Questionnaires

Following the completion of the simulated missions, the participants received two additional questionnaires, one regarding their performance under the two team structures and the other regarding their performance under the two automation conditions. Unlike the post-mission questionnaires, these questionnaires directly asked participants their preference for either condition given specific statements. A number of the statements were similar to the post-mission questionnaire but there were some differences. One item regarding the division of responsibility was only used in the team structure questionnaire. Another item regarding the automation level that best supported the TEWA task was added for the Automation questionnaire only. Last, an item that asked about optimal workload was added for both questionnaires.

Unlike the post-mission questionnaire, in this questionnaire, a score of 3 was neutral or indicated no preference for either condition. In the Team Structure condition, scores less than 3 suggested preference for the Traditional condition whereas scores greater than 3 suggested preference for the Functional condition. In the Automation condition, scores less than 3 suggested a bias for the Basic automation condition. Scores greater than 3 suggested a bias for the Advanced automation condition.

The results of the two post-experiment questionnaires are presented in Table 3. For the Team Structure questionnaire, there was no strong bias for either structure. Unlike the post-mission questionnaire, which showed a bias for the Traditional team structure, five of the nine items favors the Traditional team and four favoured the Functional team. The scores range between 2 and 3.75, so the magnitude of the preferences was small to moderate. Of the items that favoured the Functional team structure, two of the items focused on workload and two of the items were related to performance for weapons assignment and resource allocation.

For the automation questionnaire, the results were similar to the post-mission questionnaire. The Advanced automation condition was favoured in all cases except for communicating effectively. This subjective participant data validates the workload findings in the NASA-TLX and MilChat data which found an advantage for the Advanced automation condition. Notably, participants were strongly in agreement that the Advanced automation condition freed up their ability to perform secondary tasks and they also strongly felt that the Advanced automation condition best supported TEWA tasks. Thus subjective evaluation of the Basic and the Advanced TEWA automation suggests a preference for the Advanced automation.

Table 3: *A comparison of team structure and automation responses to the post-experiment questionnaire.*

Post-Experiment Questionnaire Item	Team Structure		Automation	
	Bias	**Score**	**Bias**	**Score**
Sufficient time to evaluate threats appropriately.	Traditional	2.63	Advanced	4.38
Confidence in engagement plans.	Traditional	2.00	Advanced	3.25
Sufficient time to review and validate engagement plans.	Functional	3.13	Advanced	3.38
Strong understanding of our weapon and resource allocations.	Functional	3.50	Advanced	3.25
Division of responsibilities was appropriate.	Traditional	2.88	---	---
Communicating effectively.	Traditional	2.50	Neutral	3.00
Able to keep up to secondary tasks.	Functional	3.75	Advanced	4.75
Overall awareness of the situation was high.	Traditional	2.13	Advanced	3.13
Best allowed for optimal workload.	Functional	3.25	Advanced	4.00
Automation Level that best supported the TEWA tasks.	---	---	Advanced	4.50

3.5 Interviews

Following the completion of the post-experiment questionnaire, the teams took part in a final interview to discuss both the team structure and the automation levels for conducting TEWA. The interviews allowed them to qualify their responses and explain in more detail their attitudes and beliefs in employing a specific team structure or an automation level.

Several topics emerged from the interviews. For team structure, the majority of comments favoured the Traditional team structure. The participants were obviously more comfortable and familiar with working in this manner which may have biased their response. In particular, it was argued that the Traditional team resulted in more effective communication. This might be the result of several problems raised with working in a Functional structure.

For example, there were perceived differences in perceived SA amongst the two team structures. The Functional structure was argued to be worst for giving operators full SA. In this condition, each person has only good SA of their own half of the overall task, but not the other half. That is, one person has a good understanding of the threat situation and the other has a good understanding of the effector management and resource allocation. This split SA may have fractured communication or required more communication to gather SA or to clarify self-perceived problems in SA.

Another issue that may have affected preference for the Traditional team were the cognitive interruptions resulting from the Functional team structure. The issue arises because the two operators may be attending and focused on different threats on their screen. When the TE operator passes a threat to the WA operator, the WA operator must disengage from his or her attention from their current task and re-orient their attention to the new high priority threat assigned by the TE operator. He or she would then be required to find the threat on the screen, review and validate the engagement plan relative to the threat, and approve it or change it.

Another concern raised with the Functional team had to do with combat system reliability. At sea, the participants explained that hardware reliability is a concern. In a Traditional team system, because one operator is primarily responsible for the TEWA task, there is only one main point of failure. In a Functional team, because the task is distributed across two workstations, the electronic footprint is greater and allows for more opportunity of task failure. That is, in a Functional team, if either operator workstation fails, the entire defensive system is jeopardized.

The respondents did not express any preference for either team structure with respect to workload. Comments regarding workload were varied with some expressing preference for the Traditional team and others for the Functional team. The workload data also suggested little preference with relatively similar workload levels across teams and the interview comments appear to mirror this finding.

With respect to the LOA, participants generally agreed that the Advanced automation condition freed up their workload. This allowed them to do more analytical thinking as opposed to interacting with the system. Overall, participants also said that they could handle more threats under a higher level of automation.

The primary concern with the Advanced automation condition had to do with trusting the automation. Participants were generally skeptical of allowing the automation to handle all aspects of the task. One operator did not think that the automation was conducting threat evaluation properly. Another thought that the automation was being too liberal with resource allocation and would not have deployed as many countermeasures. Another operator was skeptical of data fusion and was concerned with its accuracy for threat evaluation.

Part of the concern with employing advanced automation for TEWA stems from the lack of transparency in how the automation makes its decision with respect to threats, developing a plan and employing weapons. One participant said that it was difficult to comprehend the automated actions so it was difficult to validate in a temporally demanding situation. Another comment expressed concern that if the automation was designed such that it was difficult for operators to validate or if the automation did not force operators to validate, then operators simply will not validate and allow the automation to take over the task.

The issue of proper validation also ties into the need for proper training when using advanced automation. Participants discussed the need to train operators on using the automation which should include training on how to interpret and validate the automation. Finally, one comment also raised doubts regarding whether RCN would ever allow for such advanced automation to take over critical decisions away from the human operator. Indeed, both the employment of a Functional team or Advanced TEWA automation would require a significant culture change in the way TEWA is done in the OPS room.

4 Discussion

The objective of the present study was to investigate whether advancement in TEWA automation warrants changes to the way current OPS room operator roles should be structured. Traditional roles, based on warfare domains have been employed for decades in the RCN, but there is no known rationale for dividing work this manner. With the introduction of TEWA automation with the HCM project, it opened the door for the RCN to consider dividing the work by TEWA function instead. In particular, if the automation removes the physical and cognitive effort that was formally required by the operators, then it stands to reason that their roles or tasks might change. In this study, four teams of naval operators composed of an ORO and a SWC, conducted a series of simulated AAW and ASuW scenarios.

The dyad teams conducted multi-threat scenarios under two team structures, a Traditional team, wherein they played their existing roles today and a Functional team, wherein their roles were separated by the two main TEWA function, threat evaluation and weapons assignment. They also conducted these scenarios under two levels of automation. In the Basic automation level, the operators had to approve automated decisions before the automation applied the action. Without human intervention, the automation did not act. In the Advanced automation condition, the operators had a limited time to override the automation. If they did not override the automation, the automation would act on its engagement plan and launch countermeasures against the designated threat.

While the data is limited due to the size of the study, the results were relatively consistent and informative. The data did not suggest any benefit for employing a Functional team structure over a Traditional team structure. A number of issues were also raised regarding the Functional team structure that suggests this work arrangement might not be effective. In contrast, the results did find benefit to employing an Advanced TEWA level of automation; however, the RCN will need to overcome trust and institutional culture issues with employing a system with a sophisticated level automated decision-making and action.

4.1 Team Structure

The participants' performance under the two team structures was captured by assessing their workload, their performance through subjective evaluations, and through their own assessment derived from both questionnaires and interviews. We had hypothesized that the Functional Team would have better outcomes because the team was structured around the two keys tasks (threat evaluation and weapons assessment) and thus the team could better distribute their workload and each individual would be able dedicate their cognitive resources to one main task.

Our data only partially supported the hypothesis. Performance between the two conditions was comparable. As well, workload measures did not indicate a strong preference for either condition. None of the direct comparisons between the Traditional and Functional condition on workload measures indicated any strong effects. It did appear that the Traditional condition had more varied auditory response times at different levels of attack complexity, but at the same time, the Functional condition appears to have had more difficulty with the mapping task at different levels of complexity. Thus it may be that the two team structures allocated resources slightly differently for the MilChat task, but the overall workload difference remained similar.

We expected that teams would do well on the auditory task, but poorly on the mapping task and chat questions task. This prediction is based on multiple resource theory [46] which argues that cognitive resources can be separated into distinct channels (e.g., a visual channel and an auditory channel). Because the TEWA tasks tap strongly into the visual system, the mapping task and the chat questions would likely suffer. This was the case for the mapping task where the accuracy values were poor and suggestive that visual resources were tied to the TEWA task such that the participants did not have time to update the map. The chat questions were less affected, likely because we did not impose a time limit for responding and participants could read back over the chat to ascertain the correction answer, so no working memory load was imposed. In contrast, the auditory task was virtually unaffected by the TEWA task, because it occurred on a separate sensory channel. Auditory call sign accuracy scores were typically over 90%. The auditory task here was meant to mimic the load of responding to auditory communication occurring over the various OPS room radio networks. These findings support the idea of offloading tasks to the auditory channel and mitigating visual workload by providing methods to store and easily information until the operator is able to deal with it.

Questionnaire data on workload were biased for the Functional team. Both post-scenario and post-experiment questionnaires suggested that the Functional team allowed participants to better manage secondary tasks. The post-experiment questionnaire also had one item directly asking about workload and again the responses favored the Functional team. Thus, while the performance data did not appear to favour one team structure over the other with respect to workload, subjectively, participants felt that the Functional team provided workload benefits.

The questionnaire data also asked participants their opinions regarding performance, teamwork, and SA. There was an overall bias for the Traditional team structure. Post-scenario questionnaires indicated that participants felt that the Traditional team allowed them to sufficiently plan and execute countermeasures, while allowing them to communicate and gather the proper SA. In slight contrast, in the post-experiment questionnaires, there was a bias for the Functional team for the weapons allocation tasks.

The interview data revealed two issues for the Functional team that was not considered prior to the study. First, participants argued that the Functional team structure limits the overall SA of the team. Each person has good SA on his or her own portion, but has less SA on the other tasks. That is, one person has good SA on threats and the other has good SA on the weapons, but neither can have good SA on both. In contrast, in the Traditional team, one person has good SA on the entire situation and can brief the other director as needed.

[12] highlight two important factors for good team SA, individual team member SA and team processes. In teams, individual SA must be shared amongst the team members. So team SA is not the sum of individual SA, but directly related to the level and quality of communication amongst the team [47]. Thus, the quality of the SA in the Functional team may have suffered for two distinct reasons. First, neither individual felt like they had good SA, so individual SA may have been lacking. Second, the participants were not trained on how to communicate and coordinate the relevant information to each other. In contrast, because the participants work similarly to a Traditional team, they were better able to communicate relevant information which allowed for better overall team SA. This suggests that with additional training and familiarity with the new roles, the Functional team might be able to overcome reduced team SA issues.

Second, participants argued that the communication resulting from the Functional team structure resulted in interruptions that were difficult to overcome. Specifically, when the weapons operator was engaged in a task (e.g., determining remaining available weapons), the threat evaluator commonly interrupted by passing along new threats. At this point, the weapons operator had to pause their current task and try to re-orient their cognitive resources to the newly defined threat. The participants argued that this re-orientation of resources was difficult and time consuming when temporal demands were critical.

The academic literature on cognitive interruptions supports the comments of the participants. Interruptions have been found to cause personal stress, increase the time necessary to complete both the initial task and the interrupting task, and increase errors in the tasks [48]. Furthermore, interruptions can result in four general cognitive effects, diversion, distraction, disturbance and disruption. Diversion occurs when attention and sensory modalities are initially redirected to the alert of the interrupting task. Distraction is the temporary redirection of attention to interpret the interruption. Disturbance is the immediate actions to address the interruption or to schedule it for later. Diversion, distraction and disturbance can propagate to a full disruption of initial task performance due to further integration requirements [48].

In the period between the onset of an interrupting event to when the actions for the interrupting event are initiated, is what is known as the interruption lag [49] [50]. During the interruption lag, individuals are aware of the interruption, but have not engaged in the interrupting task yet. This lag allows the individual to complete subtasks or a thought; it may also allow the individual to mark off their last step of the initial task or schedule when to re-initiate the initial task. This lag can be as long as 6 to 8 seconds to allow the individual to fully link cognitive representations of the initial task to external cues for later retrieval [50].

The difficulty with a TEWA task is that the consequences are dire if too much time is sacrificed to perform interruption lag behaviours. Operators must act quickly and decisively to engage incoming threats to ensure that countermeasures are launched to maximize kill opportunities. In general then, when a threat is passed to the weapons operator, the interruption requires immediate attention.

If a Functional team structure were to be realized, then a number of recommendations are provided to mitigate some of the problems that were evident in this trial. First, both operators still require access to each other's displays. This would improve individual SA and encourage shared SA by allowing each operator to communicate each other's actions and intentions more concretely. Second, and related to the first point, the TEWA user interface (UI) should be designed to suit the Functional team structure and optimize teamwork behaviours, including optimizing team SA. This might include methods for tracking and displaying actions and intentions from each member. Moreover, to mitigate interruptions from information passing, the UI could provide methods to mark the steps of their current tasks. These UI requirements would be made apparent by applying human-centred methods for designing for teams to maximize teamwork [51] and team SA [52].

Third, with the new roles, team training needs to be provided to promote new team competencies. The training should include training on proper voice procedures to communicate relevant information between the two operators. Because TEWA is being split between two operators, the communication between the two operators will be critical to ensure that they have shared mental models and general SA of the situation. The training of voice communications should also include having the threat evaluator provide the weapons operator additional information on threats, such as their threat priority and CPA. By providing additional information regarding the severity of the threat, the weapons operator may then be able to manage their interruptions and negotiate how best to handle the interruption [48].

In sum, we did not find strong evidence for moving to a Functional team structure. The performance data did not suggest any benefit to the Functional structure. The workload data was somewhat mixed, but generally also did not find any strong benefit for the Functional structure. During interviews, several issues were raised that suggested problems with this structure, including difficulties with SA and communication. However, this finding might be due to the participants comfort with the existing team structure.

4.2 Level of TEWA Automation

The comparison of the two levels of automation for TEWA is clearer. Despite the small sample of teams, in every metric of workload provided (NASA-TLX, MilChat secondary task, and questionnaires), the Advanced automation condition resulted in lower workload compared to the Basic automation condition. We expected to see the benefit of the Advanced automation particularly during high tempo attack situations and while it is difficult to draw conclusive results, the trends to point to more benefit for higher automation under high tempo complex attack situations. Notably, we did not see much benefit to the higher automation condition when participants were presented with auditory information. We note that this is likely due to the TEWA task being primarily visual, and thus it negatively affected the visual portions of the MilChat task, but not the auditory portion.

The SME evaluations pointed to slightly better performance under the Basic automation condition. However, the difference was small and we were unable to apply any further statistical analysis to the data beyond descriptive statistics. When performance-based questions were posed to participants, there was general agreement in favour of the Advanced automation condition. The only area of concern was in regards to effective team communication under the higher level of automation.

During the interviews, participants also agreed that the higher level of automation freed up their cognitive resources, allowing them to spend more time on the secondary task, do more analytical thinking, and handle more threats. However, respondents were cautious on using higher levels of automation. Participants were not always confident in the automated decisions and felt it was difficult to understand some of the choices the automation made. Clearly, operator trust in applying high levels of automation will be a concern for the RCN.

Based on the data from this trial, the RCN should strongly consider applying higher levels of automation for TEWA. We believe this will free up operator cognitive resources and allow the ship to handle more threats. However, adoption of higher levels of TEWA will be a cultural change that the RCN will need to deal with.

Training operators on how the automation works and how (and when) it works will be an important step to developing the appropriate trust in advanced TEWA systems [53] [54] (however, the effectiveness of training for trust is not guaranteed [55]). Trust can also be instilled with more transparency in the automation [56]. Thus the UI needs to communicate why decisions are being made, possibly the confidence in its own decisions, and also allow operators to examine how automated decisions are applied. Moreover, in the current simulation, the automation applied a fixed time to override the automated decision, which artificially imposed some temporal demand. Instead, the override should sufficiently allow operators the time to validate the decisions unless the engagement plan needs to be executed.

Greater acceptance may also be achieved by applying an intelligent adaptive automation approach to TEWA automation [57] [58]. Intelligent adaptive automation adjusts the level of automation to the state of the operator or situation such that it progressively increases in levels of automation when the human operator(s) less able to deal with the situation. Human teams are relatively effective when dealing with a low tempo, simple threat situations and thus in these cases, it may be more beneficial to allow for greater human control. This provides the operator with a greater sense of control and also addresses the problem of skill fade that exists when high levels of automation are used. Only when the situation shifts to a higher tempo battle should the TEWA automation become more automated and free up some of the workload for the operator.

4.3 Attack Complexity

While attack complexity is not a primary variable of interest for this study, it is a variable that moderates the effects of team structure and automation. Under increasingly complex, higher tempo attacks, we expected workload to be positively correlated and eventually, the increasing workload would impact the team structure and the use of automation [59] [60]. However, some of our data did not find workload increased systematically with attack complexity. Instead, in the MilChat task, performance was actually superior under the moderate attack level when we examined the team structure and automation effects separately in the mapping task. In the auditory call sign task, response times were fastest under the moderate attack level for the Traditional team. This effect is counter-intuitive and was unexpected.

While the design of the study did not specifically test for the effect of attack complexity, we can offer some explanation to the possible effect. First, given the small sample, this effect might simply reflect sample bias in the data. For instance, in the mapping data, there were at least two individuals whose accuracy was particularly poor in the low and high attack complexity conditions. Given the small sample, the scores from these two individuals may have biased the data to reflect weaker average performance in the low and high attack conditions relative to the moderate attack complexity condition.

Second, poorer performance at low and high attack complexity levels might reflect poorer performance when workload or stress is too low and too high. Models of workload suggest that when workload is too low or too high, task performance is generally poorer [61] [62]. These models tend to look similar to classic Yerkes-Dodson inverted-U curves that suggest that optimal performance is linked to moderate levels of arousal [63]. However, [63] is clear to point out the inadequacy of the Yerkes-Dodson law and they suggest that modern workload models are not tied to arousal. Instead, according to [62], the inverted-U is tied to the combination of stressors affecting an individual and the physiological and psychological adaptability to absorb the stress. In cases of extreme hypo and hyper stress, the individual's physiological and psychological adaptability is unable to mitigate the stress, and reductions in performance become more evident.

Third, the data might also be explained by sudden transitions in workload [64] [65] [66]. [64] [65] conducted studies demonstrating that when workload shifts from a lower workload to a higher workload, or vise versa, there is a period of impaired performance following shifts. In this study, the attacks came in three separate waves; thus, there were two significant transitions in workload. While we attempted to balance attack complexity across individuals and conditions, given the small sample, there may have been some bias resulting in poorer performance in the lower and high attack complexity conditions. It should also be noted that a more recent study have failed to find workload transition effects [66].

Last, the data might reflect different operator strategies to deal with the threats at the different levels of attack complexity. At low attack complexity levels, participants may have felt capable of dealing with threats on their own and focused their attention on the primary task, resulting in poorer performance in the MilChat task. In contrast, at moderate attack complexity levels, participants may have delegated more authority to the automation to deal with the threats and focused more of their cognitive resources on the MilChat task, resulting in better MilChat performance. At high attack complexity levels, participants may have been cognitively overloaded. After realizing that the incoming threats were complex, participants may have been compelled to focus their attention to the primary task, again neglecting the MilChat task.

At this point, these explanations are just speculative as the data do not pinpoint the exact reason for the effect. However, the improved performance in the moderate attack level could raise some important insights on how operators choose to interact with the TEWA automation. From these insights, additional training might be required on how best to optimize performance. For example, for high complexity attacks, it could be advantageous to train operators to fully delegate authority to the automation to deal with the threats and have the operators focus on command and control and communication. This effect might also suggest that operators prefer to manage simpler attacks on their own and could again point to a good opportunity for an adaptive automation situation [57] [58]. Thus, it would be informative then to run similar studies again with a larger sample to overcome some of the limitations in the data in order to address some of these explanations. We address the major limitations of this study in the following section.

5 Limitations

As in many complex studies, there were several limiting factors that restrict the interpretation of our results. The study was intended to be a small laboratory based study on the team structure used for applying TEWA automation, and as such, we limited the participants to only the SWC and ORO roles. This limitation obviously ignores the complexity of a full OPS room. Other members of the OPS room also have critical roles including front row operators who compile the picture and the electronic warfare operators, who often are first to detect threats and call zippos. Moreover, our participants did not have additional responsibilities and did not converse with other team members. The MilChat task was intended to supplement some of this workload (e.g., communications over various net, active engagements in other areas of warfare, supervising other OPS room personnel) but obviously, it was not a realistic representation.

Based on today's role for the SWC and ORO, there was obviously a bias for the Traditional team structure and for a *Basic* level of automation. Our conclusions and potentially the null effects for team structure need to be interpreted in light of these biases. It may be that the Functional team structure is the superior team structure, but additional familiarity and training would be required to see its benefits compared to the Traditional team.

Due to budget and time constraints of running a trial remotely, we only ran four teams in the trial. This sample size was too small to run parametric statistics reliably, and thus we applied various small sample size data analysis methodologies to the data. The data are reported and interpreted with caution. Still, we were surprised at the consistency in the trends of the effects that we base our conclusions on those consistent trends.

Our ability to analyze the data from our simulation ran into difficulty. While we were able to extract data from CORALS, the tables were not arranged in a manner that it would be easily processed. In the end, due to time and budget concerns, we chose to not process the log files extracted from CORALS. Thus, this work focused on the feedback from participants and we were unable to validate it with some of the data from CORALS. In the future, we recommend that data from the simulation be used to validate some of the subjective data from participants and human evaluators.

Finally, our SMEs applied subjective evaluations on the performance of the two team members. This evaluation was relatively simple (pass/fail) on a number of items or events during the scenario. This method is similar to how RCN sailors are evaluated today, which was one of the reasons we chose to apply this method. However, a more rigorous and validated form of SME evaluation is desirable. Ideally, we would employ a greater number of SMEs and the scales themselves would allow for more fidelity in the items.

6 Key Recommendations

1. Team Structure: Based on the data provided in this trial, it is recommended that the RCN continue using the current team structure, where the SWC is responsible for threat evaluation and weapons engagements for air warfare, and reports to the ORO.

    a. We found no substantial difference in performance between the Traditional and the Functional team structures, thus no change is warranted.

    b. During the interviews, the participants raised some valid concerns regarding the Functional team structure, namely a reduction in SA and communications concerns resulting in cognitive interruptions to tasks.

    c. If the RCN does decide to employ a Functional team structure, with a threat evaluator role and a weapons coordinator role, then we recommend the following:

        i. Additional team training to enhance teamwork and team SA. The training should also support communication between the two operators as to limit interruptions for the weapons coordinator.

        ii. A human-centred assessment of the user interface for the Functional team structure to ensure that user requirements for the UI are met. This should include UI support for shared SA (e.g., shared displays to encourage a shared mental model) and strategies for task tracking.

2. Level of TEWA Automation: The data support employing a high level of automation for TEWA that can act on its own decisions, but allows operators to override its actions as necessary.

    a. The data suggested that employing a higher level of automation for TEWA will reduce the workload for the operators, allowing them to focus on other tasks and apply more analytical thinking to the situation.

    b. The subjective data (based on the questionnaires and interview) suggested that employing a high level of TEWA automation will result in better performance.

    c. Employing a higher level of automation for TEWA will be met with some resistance. Trust in the TEWA automation will be a challenge for the RCN. The RCN should incorporate a training plan that helps operators appropriately trust the automation (e.g., train operators how decisions are arrived). The TEWA interface should also provide transparent communication of its decisions, allow operators to question or double-check automated decisions, and allow operators with sufficient time to validate decisions, if possible.

    d. An intelligent adaptive automation approach should be considered [57] [58]. This would allow operators to have more control of TEWA during lower workload, simpler engagements and allow the automation to take control of tasks as the situation becomes more complex (e.g., a multi-threat task group situation). This approach might alleviate trust issues and will reduce operator skill fade.

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Annex A Pre-Experimental Information Sheet

Pre-Experimental Information Sheet

Protocol Number:	2017-057	
Research Project Title:	Mission Planning Requirements for COAT and Team Configuration Using TEWA	
Principal Investigator:	Dr. Aren Hunter	(DRDC - Atlantic Research Centre)
	Dr. Geoffrey Ho	(DRDC - Toronto Research Centre)

With the RCN investing in new classes of ships, new technologies will also be available to the crew to support a wide range of tasks. The present trial investigates two separate topics related to operational use of technology. First, in order to better develop an operationally sound tool to support mission planning, DRDC is interested in understanding the planning process, and the functional, informational and user requirements necessary for developing such a tool. Second, while the current HALIFAX-Class Frigates already have some TEWA capability, there are some limitations. In the near future, TEWA will likely be more advanced than what is available today and the RCN and DRDC are interested in the role that the SWC and ORO play when using advanced TEWA automation.

Over the next 4 days, you will be participating in studies of both topics (5 – 8.5 hrs per day). On Days 1 and Day 2 (morning), you will be trained on how to interact with a TEWA simulation environment called CORALS (Collaboration Resource Allocation Support) and how to play different roles using CORALS and a piece of software called MilChat which will be used to estimate your workload.

On Day 2 (afternoon) and Day 3, you will take part in simulated missions using CORALS. On each of these days, you will play two missions. In the missions, your task as a team will be to identify and prioritize threats, develop plans to counter any threats and engage threats as necessary. You will be asked to conduct the missions under three possible team configurations. In the first team configuration, you will play the traditional role of a SWC and ORO. In the second configuration, one person will be tasked to do threat evaluation and the second person will be tasked to do weapons assignment. In the third configuration, you will be tasked to focus on the secondary task and simply approve the TEWA automation.

After completing each mission, you will be asked to fill out some questionnaires about your personal experience regarding the mission. There will also be an interview session to discuss your team performance at the end of each day. Your performance in this task will be recorded and evaluated for the trial's purposes and is not intended to test your abilities to function in your roles as part of the RCN.

On Day 4, you will take part in two course of action testbed (COAT) sessions. In the first session you will be asked to walk through the COAT interface with the guidance of the experimenter. You will be asked to answer questions about the usefulness of the information contained in the interface. You may also be asked about what information is missing and what information would be useful to have in future iterations of COAT. The second session will investigate course of action sketching requirements. You will first be asked to evaluate the sketching tools in the course of action testbed. Following that evaluation you will be provided with a scenario and asked to draw COA sketches on a paper map. These sketches will be used to identify common features (e.g., arrows to indicate movement, or circles to group assets) to prioritize digital sketching requirements for future sketching capabilities in COAT. As part of this exercise you will be asked to interpret your team member's sketches to determine how effective the sketches were at communicating their course of action. They will also be asked to interpret your sketches. We are interested in evaluating the COAT interface and sketching functionality, not your performance on the tasks.

Please feel free to ask the experimenters any questions or concerns that you may have. The experimenters will answer the questions to the best of their ability. Following completion of the experiment you will be fully debriefed regarding its specific aims and given the opportunity to ask additional questions.

Risks: There are no anticipated long-term physical, social, psychological, emotional, economic, or other risks associated with the proposed research. Some participants may experience mild eye strain or light headedness associated with playing a computer simulation for an extended period.

Benefits: The primary benefits of this study are in understanding the performance outcomes associated with automation and tool support for COA development. Results will feed into system requirements for future crewing on RCN platforms. Recommendations will help optimize crewing solutions such that the RCN can benefit from a personnel and crewing standpoint without sacrificing mission effectiveness. For individual military participants, they will have a chance to influence the development of crewing policy for future fleets.

I understand that my experimental data will be protected under the Government Security Policy (GSP) at the appropriate designation and not revealed to anyone other than the DRDC-affiliated Investigator(s) or investigators from the sponsoring CAF/DND agency without my consent except as data unidentified as to source.

I understand that my name will not be identified or attached in any manner to any publication arising from this study. Moreover, I understand that the experimental data may be reviewed by an internal or external audit committee. Any summary information resulting from such a review will not identify me personally.

I understand that, as a Government Institution, DRDC is committed to protecting my personal information. However, under the Access to Information Act, copies of research reports and research data (including the database pertaining to this project) held in Federal government files, may be disclosed. I understand that prior to releasing the requested information, the Directorate of Access to Information and Privacy (DAIP) screens the data in accordance with the Privacy Act in order to ensure that individual identities (including indirect identification due to the collection of unique identifiers such as rank, occupation, and deployment information of military personnel) are not disclosed.

I understand that I am free to refuse to participate and may withdraw my consent without prejudice or hard feelings at any time. I also understand that the Investigator(s) or their designate responsible for the research project may terminate my participation at any time, regardless of my wishes.

Should I have any questions or concerns regarding this project before, during or after participation, I understand that I am encouraged to contact the DRDC research centre below. This contact can be made by surface mail at this address provided or by phone or email to any of the individuals listed below:

Defence R&D Canada - Toronto Research Centre
1133 Sheppard Avenue West
Toronto, Ontario, M3M 3B9

Defence R&D Canada - Atlantic Research Centre
9 Grove Street
Dartmouth, Nova Scotia, B3A 3C5

Principal DRDC Investigators:
Dr. Aren Hunter, (902) 407-0457, aren.hunter@drdc-rddc.gc.ca

Dr. Geoffrey Ho, (416) 635-2023, geoffrey.ho@drdc-rddc.gc.ca

Dr. Len Goodman
Chair, DRDC Human Research Ethics Committee (HREC):
DRDC HREC Chair (416) 635-2125, HREC-CEESH-toronto@drdc-rddc.gc.ca

Annex B Informed Consent Form

Informed Consent Form for Human Participant - Military

Protocol Number: 2017-057
Research Project Title: Mission Planning Requirements for COAT and Team Configuration Using TEWA
Principal Investigator: Dr. Aren Hunter (DRDC - Atlantic Research Centre)
Dr. Geoffrey Ho (DRDC - Toronto Research Centre)

I, __________________________________ (name) hereby volunteer to be a participant in the study. I have read the information package, and have had the opportunity to ask questions of the Investigator(s). All of my questions concerning this study have been fully answered to my satisfaction. However, I may obtain additional information about the research project and have any questions about this study answered by contacting Geoffrey Ho (416-635-2023) or Dr. Aren Hunter (902-407-0457).

The duration of this experiment will be between 5 – 8.5 hrs / day for the next four days. I have been told that I will be participating in two separate studies. In one study, I will take part in the mission planning process and sketching activity in order to help DRDC understand this process and develop requirements for a software tool called COAT. In the second study, I will be playing the role of a RCN operator using a simulation tool called CORALS for conducting TEWA. My task will be to identify and prioritize threats, develop plans against threats and engage threats if necessary. My performance on this task will be recorded for experimental purposes.

Before the experiment begins, I will be given 1 ½ days of training on how to use the CORALS software. On the second and third day, I will play a series of missions within CORALS. At the end of these days, there will be a short interview session to gather my personal experiences of the different conditions of the study. I will then take part in the COAT portion of the study on the fourth day. After completing each study, I will be debriefed on the aims of each study and given the opportunity to ask questions.

Participants will be given a unique identification number. No other personal identifiers will be gathered. Only basic demographic information will be collected. I have been assured that participation in this experiment involves minimal risk, no different from spending a comparable amount of time at a computer. However, I acknowledge that my participation in this study, or indeed any research, may involve risks that are currently unforeseen by Defence Research and Development Canada (DRDC).

I have been informed that I will be reimbursed for participating according to the Treasury Board guidelines. As a CAF member, I will receive stress allowance in the amount of $40.11 and $13.37 (daily). If I decide to withdraw from the study at any time, I will still be remunerated the amount of $13.37 per day for the first 30 min completed each day and $1.27 for each additional 60 min increment.

I hereby consent to provide responses to questions that are to the best of my knowledge, truthful and complete. I understand that my experimental data will be protected under the Government Security Policy (GSP) at the appropriate designation and not revealed to anyone other than the DRDC-affiliated Investigator(s) or external investigators from the sponsoring agency without my consent except as data unidentified as to source.

I understand that my name will not be identified or attached in any manner to any publication arising from this study. Moreover, I understand that the experimental data may be reviewed by an internal or external audit committee. Summary information resulting from such a review will not identify me personally.

I understand that, as a Government Institution, DRDC is committed to protecting my personal information. However, under the Access to Information Act, copies of research reports and research data (including the database pertaining to this project) held in Federal government files, may be disclosed. I understand that prior to releasing the requested information, the Directorate of Access to Information and Privacy (DAIP) screens the data in accordance with the Privacy Act in order to ensure that individual identities (including indirect identification due to the collection of unique identifiers such as rank, occupation, and deployment information of military personnel) are not disclosed.

I understand that I am free to refuse to participate and may withdraw my consent without prejudice or hard feelings at any time. Should I withdraw my consent, my participation in this research will cease immediately, unless the Investigator(s) determine that such action would be dangerous or impossible (in which case my participation will cease as soon as it is safe to do so). I also understand that the Investigator(s) or their designate responsible for the research project may terminate my participation at any time, regardless of my wishes.

I understand that I am considered to be on duty for disciplinary, administrative and Pension Act purposes during my participation in this study and I understand that in the unlikely event that my participation in this study results in a medical condition rendering me unfit for service, I may be released from the CAF and my military benefits apply. This duty status has no effect on my right to withdraw from the study at any time I wish and I understand that no action will be taken against me for exercising this right.

I understand that by signing this consent form I have not waived any legal rights I may have as a result of any harm to me occasioned by my participation in this research project beyond the risks I have assumed. Also, I understand that I will be given a copy of this consent form so that I may contact any of the individuals mentioned below at some time in the future should that be required.

Volunteer's Name:____

Signature: _______________________________ Date: ___________________________

Notes:

FOR PARTICIPANT ENQUIRY IF REQUIRED:

Should I have any questions or concerns regarding this project before, during or after participation, I understand that I am encouraged to contact the appropriate DRDC research centre cited below. This contact can be made by surface mail at this address or by phone or email to any of the DRDC numbers and addresses of individuals listed below:

Defence R&D Canada – Toronto Research Centre
1133 Sheppard Avenue West
PO Box 2000
Toronto, Ontario, M3K 2C9

Principal DRDC Investigators:
Dr. Aren Hunter, (902) 407-0457, aren.hunter@drdc-rddc.gc.ca
Dr. Geoffrey Ho, (416) 635-2023, geoffrey.ho@drdc-rddc.gc.ca

Dr. Len Goodman

Chair, DRDC Human Research Ethics Committee (HREC):
DRDC HREC Chair (416) 635-2125, HREC-CEESH-toronto@drdc-rddc.gc.ca

Annex C Demographic Questionnaire

Demographic Questionnaire

Please fill out the form below to the best of your knowledge. If you prefer not to answer a question, please leave the question blank.

Participant ID#: ___________________________

1. Age ______ Years

2. Vision
❒ Normal (e.g., 20/20) OR Corrected to Normal (e.g., glasses / contacts)
❒ Not 20/20
❒ Unsure

3. Years of Service ______ Years

4. Role
❒ SWC ❒ ORO
❒MARS ❒NESOP

Duration in Role ______ Yrs ______ Months ______ Yrs ______ Months

Annex D NASA-TLX

NASA-TLX Mental Workload Rating Scale

Please place an "X" along each scale at the point that best indicates your experience with the display configuration.

Mental Demand: How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc)? Was the mission easy or demanding, simple or complex, exacting or forgiving?

Low High

Physical Demand: How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the mission easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Low High

Temporal Demand: How much time pressure did you feel due to the rate or pace at which the mission occurred? Was the pace slow and leisurely or rapid and frantic?

Low High

Performance: How successful do you think you were in accomplishing the goals of the mission? How satisfied were you with your performance in accomplishing these goals?

Low High

Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance?

Low High

Frustration: How discouraged, stressed, irritated, and annoyed versus gratified, relaxed, content, and complacent did you feel during your mission?

Low High

NASA-TLX Mental Workload Rankings

For each of the pairs listed below, circle the scale title that represents the more important contributor to workload in this task.

Mental Demand	or	Physical Demand
Mental Demand	or	Temporal Demand
Mental Demand	or	Performance
Mental Demand	or	Effort
Mental Demand	or	Frustration
Physical Demand	or	Temporal Demand
Physical Demand	or	Performance
Physical Demand	or	Effort
Physical Demand	or	Frustration
Temporal Demand	or	Performance
Temporal Demand	or	Frustration
Temporal Demand	or	Effort
Performance	or	Frustration
Performance	or	Effort
Frustration	or	Effort

Annex E Post-Mission Questionnaire

Post Session Likert Questions

Below are nine statements regarding the session that you just completed. On the scale below, please mark the extent that you agree or disagree with each statement.

1. During the mission, I had enough time to evaluate threats appropriately.

☐	☐	☐	☐	☐
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

2. During the mission, I had confidence that our engagement plans would defend against the threats.

☐	☐	☐	☐	☐
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

3. During the mission, I had enough time to review and validate engagement plans appropriately.

☐	☐	☐	☐	☐
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

4. During the mission, I had a strong understanding of our weapon and resource allocations.

☐	☐	☐	☐	☐
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

5. During the mission, the division of responsibilities was appropriate.

☐	☐	☐	☐	☐
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

6. During the mission, we were communicating effectively.

☐	☐	☐	☐	☐
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

7. During the mission, we were able to keep up on secondary tasks.

☐	☐	☐	☐	☐
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

8. During the mission, my overall awareness of the situation was high.

☐	☐	☐	☐	☐
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

9. During the mission, the level of support provided by automation was appropriate.

☐	☐	☐	☐	☐
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

Annex F Sample SME Evaluation Sheet

SCENARIO 1

Description and Summary

1) 4 Fighter Jets: Launch 6 Missiles (4 subsonic, 2 Supersonic)
2) 2 UAVs, 4 Fighter Jets: 2 UAVs attack + 4 Missiles from fighters (2 subsonic, 2 supersonic)
3) 3 Surface Ships, 4 Fighter Jets: Total of 11 subsonic missiles

4 Fighter Jets: Launch 6 Missiles (4 subsonic, 2 Supersonic)

Units	Attack	Actions	Yes	No
2 JH-7 Jets	4 C802 @ 50NM	Operators hook jets to evaluate threat		
		Operators approve threat level of jets		
		Operators note change in course of jets		
		Operators quickly identify missiles launched		
		Operators hook missiles		
		Operators approve threat level of missiles		
		Operators approve engagement plan		
2 JH-7 Jets	2 YJ-91 @ 25NM	Operators hook jets to evaluate threat		
		Operators approve threat level of jets		
		Operators note change in course of jets		
		Operators quickly identify missiles launched		
		Operators hook missiles		
		Operators approve threat level of missiles		
		Operators approve engagement plan		
Comments				

2 UAVs, 4 Fighter Jets: 2 UAVs attack + 4 Missiles from fighters (2 subsonic, 2 supersonic)

Units	Attack	Actions	Yes	No
2 Harpy UAVs	UAVs dive at 15NM	Operators hook UAVs to evaluate threat		
		Operators approve threat level of UAVs		
		Operators note diving UAVs		
		Operators approve engagement plan		
2 x JH-7	2 x C802A @ 50NM	Operators hook jets to evaluate threat		
		Operators approve threat level of jets		
		Operators note change in course of jets		
		Operators quickly identify missiles launched		
		Operators hook missiles		
		Operators approve threat level of missiles		
		Operators approve engagement plan		
2 JH-7 Jets	2 YJ-91 @ 50NM	Operators hook jets to evaluate threat		
		Operators approve threat level of jets		
		Operators note change in course of jets		
		Operators quickly identify missiles launched		
		Operators hook missiles		
		Operators approve threat level of missiles		
		Operators approve engagement plan		
Comments				

3 Surface Ships, 4 Fighter Jets: Total of 11 subsonic missiles

Units	Attack	Actions	Yes	No
Type 053	2 x C802A	Operators hook ship to evaluate threat		
		Operators quickly identify missiles launched		
		Operators hook missiles		
		Operators approve threat level of missiles		
		Operators approve engagement plan		
2 JH-7 Jets	4 x C802A @ 40NM	Operators hook jets to evaluate threat		
		Operators approve threat level of jets		
		Operators note change in course of jets		
		Operators quickly identify missiles launched		
		Operators hook missiles		
		Operators approve threat level of missiles		
		Operators approve engagement plan		
2 JH-7 Jets	1 x C802A @ 40NM	Operators approve threat level of jets		
		Operators note change in course of jets		
		Operators quickly identify missile launched		
		Operators hook missile		
		Operators approve threat level of missiles		
		Operators approve engagement plan		
2 Type 022	4 x C802A	Operators hook ships to evaluate threat		
		Operators quickly identify missiles launched		
		Operators hook missiles		
		Operators approve threat level of missiles		
		Operators approve engagement plan		
Comments				

Annex G Post-Experiment Automation Questionnaire

Below are nine statements regarding the performance of TEWA when using the automation. On the scale below, please indicate your preference regarding the use of the two automation conditions.

1. The automation that best provided sufficient time to evaluate threats appropriately was:

☐	☐	☐	☐	☐
Strongly Prefer Basic Automation	Slightly Prefer Basic Automation	Neutral	Slightly Prefer Advanced Automation	Strongly Prefer Advanced Automation

2. The automation that gave me confidence that our engagement plans would defend against the threats was:

☐	☐	☐	☐	☐
Strongly Prefer Basic Automation	Slightly Prefer Basic Automation	Neutral	Slightly Prefer Advanced Automation	Strongly Prefer Advanced Automation

3. The automation that best allowed me enough time to review and validate engagement plans appropriately was:

☐	☐	☐	☐	☐
Strongly Prefer Basic Automation	Slightly Prefer Basic Automation	Neutral	Slightly Prefer Advanced Automation	Strongly Prefer Advanced Automation

4. The automation that best allowed for having a strong understanding of our weapon and resource allocations was:

☐	☐	☐	☐	☐
Strongly Prefer Basic Automation	Slightly Prefer Basic Automation	Neutral	Slightly Prefer Advanced Automation	Strongly Prefer Advanced Automation

5. The automation that best allowed for effective communication was:

☐	☐	☐	☐	☐
Strongly Prefer Basic Automation	Slightly Prefer Basic Automation	Neutral	Slightly Prefer Advanced Automation	Strongly Prefer Advanced Automation

6. The automation that best allowed for performing the secondary task was:

☐	☐	☐	☐	☐
Strongly Prefer Basic Automation	Slightly Prefer Basic Automation	Neutral	Slightly Prefer Advanced Automation	Strongly Prefer Advanced Automation

7. The automation that best allowed for overall awareness of the situation was:

☐	☐	☐	☐	☐
Strongly Prefer Basic Automation	Slightly Prefer Basic Automation	Neutral	Slightly Prefer Advanced Automation	Strongly Prefer Advanced Automation

8. The automation that best allowed for optimal workload was:

☐	☐	☐	☐	☐
Strongly Prefer Basic Automation	Slightly Prefer Basic Automation	Neutral	Slightly Prefer Advanced Automation	Strongly Prefer Advanced Automation

9. The automation that best provided support in the TEWA task was:

☐	☐	☐	☐	☐
Strongly Prefer Basic Automation	Slightly Prefer Basic Automation	Neutral	Slightly Prefer Advanced Automation	Strongly Prefer Advanced Automation

Annex H Post-Experiment Team Structure Questionnaire

Below are nine statements regarding the performance of TEWA for the team configuration. On the scale below, please indicate your preference regarding the performance of the two team conditions.

1. The team that best provided sufficient time to evaluate threats appropriately was:

☐	☐	☐	☐	☐
Strongly Prefer Traditional Team	Slightly Prefer Traditional Team	Neutral	Slightly Prefer Functional Team	Strongly Prefer Functional Team

2. The team that gave me confidence that our engagement plans would defend against the threats was:

☐	☐	☐	☐	☐
Strongly Prefer Traditional Team	Slightly Prefer Traditional Team	Neutral	Slightly Prefer Functional Team	Strongly Prefer Functional Team

3. The team that best allowed me enough time to review and validate engagement plans appropriately was:

☐	☐	☐	☐	☐
Strongly Prefer Traditional Team	Slightly Prefer Traditional Team	Neutral	Slightly Prefer Functional Team	Strongly Prefer Functional Team

4. The team that best allowed for having a strong understanding of our weapon and resource allocations was:

☐	☐	☐	☐	☐
Strongly Prefer Traditional Team	Slightly Prefer Traditional Team	Neutral	Slightly Prefer Functional Team	Strongly Prefer Functional Team

5. The team that best allowed for effective communication was:

☐	☐	☐	☐	☐
Strongly Prefer Traditional Team	Slightly Prefer Traditional Team	Neutral	Slightly Prefer Functional Team	Strongly Prefer Functional Team

6. The team that best allowed for performing the secondary task was:

☐	☐	☐	☐	☐
Strongly Prefer Traditional Team	Slightly Prefer Traditional Team	Neutral	Slightly Prefer Functional Team	Strongly Prefer Functional Team

7. The team that best allowed for overall awareness of the situation was:

☐	☐	☐	☐	☐
Strongly Prefer Traditional Team	Slightly Prefer Traditional Team	Neutral	Slightly Prefer Functional Team	Strongly Prefer Functional Team

8. The team that best allowed for optimal workload was:

☐	☐	☐	☐	☐
Strongly Prefer Traditional Team	Slightly Prefer Traditional Team	Neutral	Slightly Prefer Functional Team	Strongly Prefer Functional Team

9. The team that best allowed for appropriate division of responsibility was:

☐	☐	☐	☐	☐
Strongly Prefer Traditional Team	Slightly Prefer Traditional Team	Neutral	Slightly Prefer Functional Team	Strongly Prefer Functional Team

Annex I Sample Post-Experiment Interview Questions

Q: In this study you tried different ways to configure your roles.

a. Did you have a preference for one role vs. another? Why?

b. What were the pros and cons of each team configuration?

c. Did you feel that one team configuration allowed you to better handle the threats?

Q: In this study, the TEWA automation either required your approval and made its own decision regarding threats and engagements.

a. In the high automation condition, did you trust the TEWA to make its own decisions?

b. In the high automation condition, did it reduce your workload relative to the other conditions.

c. How many threats (missiles) do you think you can properly handle under the two automation conditions?

General comments:

Annex J Post-Experiment Debriefing Form

Debriefing Form

Protocol Number: 2017-057
Research Project Title: Mission Planning Requirements for COAT and Team Configuration Using TEWA
Principal Investigator: Dr. Aren Hunter (DRDC - Atlantic Research Centre)
Dr. Geoffrey Ho (DRDC - Toronto Research Centre)

Dear participant:

Thank you for having completed this experiment.

In the near future, with the creation of a new fleet, the RCN will be employing new technologies and automation to support a ship's crew in performing their tasks. These technologies and automation will provide the RCN with improved capabilities and increase the RCN warfighting proficiency. However, if technology is not designed properly and without sufficient input from the direct users, even the most effective technology can fail. As well, when technology is employed, it commonly has secondary effects on the ship's crew, how work is performed and unforeseen outcomes.

In this protocol, you helped us define new requirements for a tool called COAT. COAT is intended to support the mission planning process and help at sea command teams thoroughly and effectively perform mission planning. Your involvement in this process helps DRDC develop a tool that is better engineered to fit your operational needs and your user needs.

In addition, you played a number of simulated multi-threat missions in CORALS. The TEWA automation embedded in CORALS is more advanced than what we have today onboard the HCM frigates. As more automation is introduced on ships, it may impact the crew size and its configuration. In this protocol, we wanted to see if the traditional SWC / ORO roles were justified when using CORALS or whether another role, based on the functionality of CORALS, results in better performance. This particular portion of the study is part of a larger effort to understand how automation might impact crewing in the future, particularly for the OPS room where much of the automation is embedded.

Through this sort of experimentation, we hope to identify the conditions under which new automation and technology is optimally effective. We can then incorporate these findings into new systems and also address secondary effects on crewing prior to introducing the technology. By acquiring this type of knowledge prior to deploying technologies, we hope to provide the RCN with better knowledge on how to best use technologies and to build technology that is better suited to meet the operational needs of the RCN.

You may obtain additional information about the research project by contacting Dr. Aren Hunter (902) 427-0457 or Dr. Geoffrey Ho (416) 635-2023.

List of Symbols/Abbreviations/Acronyms/Initialisms

AAW	anti-air warfare
AIS	automatic identification system
ASMD	anti-ship missile defence
ASuW	Anti surface warfare
ATOM	Anti-air Teamwork Observation Measure
AWWD	above water warfare director
CAF	Canadian Armed Forces
CFCD	Canadian Forces Controlled Document
CFMWC	Canadian Forces Maritime Warfare Centre
CMS	Combat Management System
CO	Commanding Officer
CORALS	Combat Resource Allocation Support
CPA	closest point of approach
CPF	Canadian Patrol Frigates
CPO2	Chief Petty Officer
CRM	crew resource management
CSC	Canadian Surface Combatant
D Nav P&T	Directorate Navy Personnel and Training
DRDC	Defence Research and Development Canada
ESM	electronic support measures
FELEX	Frigate Life Extension
HCM	Halifax-Class Modernization
HREC	Human Research Ethics Committee
IFF	identification friend or foe
LCdr	Lieutenant Commander
LOA	Levels of Automation
M	Mean
MFW	multi-function workstation
MMSI	maritime mobile service identity
NASA-TLX	National Aeronautical Space Agency - Task Load Index

OPS (Room)	operations (Room)
ORO	operations room officer
RCN	Royal Canadian Navy
RMP	recognized maritime picture
SA	situation awareness
SD	standard deviation
SISWS	shipboard integrated sensors and weapons systems
SME	subject matter expert
SWC	Sensor Weapons Controller
TDP	Technology Demonstration Program
TE	threat evaluation
TEWA	threat evaluation and weapons assessment
UAV	unmanned aerial vehicle
UGV	unmanned ground vehicle
UI	user interface
UN	United Nations
WA	weapons assessment
WBE	work break down element

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The advancement of automation to support threat evaluation and weapons assignment (TEWA) for anti-air and anti-surface warfare has raised the question whether the current structure for operations room directors can be optimized. Under the Impact of Automation Project (01AB), four two director teams, composed of one Operations Room Officer (ORO) and one Sensor Weapons Controller (SWC), conducted simulated missions in DRDC's Combat Resource Allocation Support (CORALS) system. Two team structures were examined. In the Traditional structure, the team simulated today's team structure, with the SWC primarily responsible for both threat evaluation and weapons and the ORO approves the SWC's actions. In the Functional structure, the ORO acted as a threat evaluator and the SWC was responsible for weapons. The trial also manipulated the level of TEWA automation. In one condition, the automation only recommended actions while in the second condition, it could act upon its own decisions, unless the operators intervened. The results suggested no strong benefit for the Functional structure, but did suggest that allowing for higher levels of TEWA automation was beneficial. If the RCN employs more advanced TEWA though, it will have to address the issue of trust in the automation.

Les progrès de l'automatisation pour appuyer l'évaluation de la menace et la désignation des armes (TEWA) dans la lutte antiaérienne et antisurface a soulevé la question de déterminer si la structure actuelle pour les directeurs de salles des opérations pouvait être optimisée. Dans le cadre du projet sur les effets de l'automatisation (01AB), quatre équipes de deux directeurs, composées d'un officier de la salle des opérations (OSO) et d'un contrôleur d'armes par capteur (CAC), ont effectué des missions simulées dans le système de soutien à l'affectation des ressources de combat (CORALS) de RDDC. Deux structures d'équipe ont été examinées. Dans la structure traditionnelle, l'équipe a simulé celle d'aujourd'hui, dans laquelle le CAC est responsable surtout de l'évaluation de la menace et des armes et l'OSO approuve les actions du CAC. Dans la structure fonctionnelle, l'OSO a agi comme évaluateur de menace et le CAC comme responsable des armes. L'essai a aussi permis de manipuler le niveau d'automatisation TEWA. Dans un cas, l'automatisation n'a recommandé que des actions et, dans le second cas, elle a pu agir en fonction de ses propres décisions, à moins d'une intervention des opérateurs. Les résultats n'ont montré aucun avantage important pour la structure fonctionnelle, mais ont laissé croire que le fait de permettre des niveaux plus élevés d'automatisation TEWA était bénéfique. Si la Marine royale canadienne (MRC) utilise une TEWA plus perfectionnée, elle devra aborder la question de la confiance à l'endroit de l'automatisation.