Training and Performance of Multiteam Systems in Naval Warfare Environments

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ABSTRACT

Multiteam systems (MTSs) often provide benefits over traditional teams when completing work or tasks in the context of complex and dynamic environments. However, challenges still exist in understanding and capturing the processes driving successful MTS performance. In the current effort, a cognitive task analysis (CTA) methodology was utilized to explore the driving antecedents of successful MTS coordination and integration within a carrier strike group (CSG) operating in a Naval warfare environment. The CTA identified critical incidents and emergent themes through structured interviews of 59 subject matter experts across Naval surface and air units operating in warfare environments. Researchers utilized a top down approach, leveraging existing frameworks (Ishak & Ballard, 2012; Marks, Mathieu, Zaccaro, 2001; Mathieu, Maynard, Rapp, & Gilson, 2008; Pagan, Kaste, Zemen, Walwanis, Wood, & Jorett, 2015; Wildman et al., 2012) of team knowledge, skills, and attitudes (KSAs) to be applied to the multiteam domain of the CSG. The framework was used to code CTA data to determine the KSAs necessary for successful MTS performance and modified to reflect domain specificity as required. The KSA framework was then used as guidance to provide recommendations for MTS training and performance measurement. These recommendations are currently being used to develop specific, multilevel performance measures of the KSAs needed to effectively operate in changing, complex environments. The development of these performance measures also coincides with efforts to develop training to provide feedback on coordination, information exchange, and other elements of MTS performance. Finally, efforts are also being conducted towards the development of experimental, quasi-experimental, and agent-based modeling in order to evaluate the recommendations and performance measurement criteria. Execution of these recommendations, performance measures, and training are expected to improve decision-making and information exchange of the CSG as a whole within these complex warfare environments where these processes are critical to mission success.

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BACKGROUND

Operational Challenge

Military operations often rely on teams to accomplish complex tasks or missions. These tasks are more easily carried out through the team's pooled efforts and specialization of labor amongst various team members. However, as operations within military functions become increasingly complex, the nature of how tasks are completed shifts from requiring independent teams towards teams-of-teams, or multiteam systems (MTSs). *MTSs* are best defined as systems composed of two or more teams that interface directly and interdependently to respond to environmental contingencies, and whose differing proximal goals feed into a shared, distal goal (Mathieu, Marks, & Zaccaro, 2001). For example, effective air defense of Naval carrier strike groups (CSGs) is central to the success of the fleet, and any platform (e.g. aircraft carrier, ship, aircraft) that is harmed by enemy air attacks may be significantly impaired or unable to complete its other missions. Furthermore, air defense requires the effective coordination of an extremely complex MTS that includes multiple platforms. As such, enhancing communication and coordination across the CSG MTS is critical to future mission success.

A major challenge in enhancing coordination within MTSs is in fully understanding the various factors that contribute to effective interactions between component teams in the broader MTS (Mathieu et al., 2001). Given that existing organizational and team research has only recently begun to examine the dynamic processes that occur within these complex systems (e.g., Davison, Hollenbeck, Barnes, Sleesman, & Ilgen, 2012; DeChurch & Marks, 2006; Marks, DeChurch, Mathieu, Panzer, & Alonso, 2005), there is much to learn about the various processes that facilitate MTS goal accomplishment, and the knowledge, skills, and attitudes (KSAs) that enable those processes.

Therefore, the goal of the current study was to identify the KSAs that are critical to the performance of MTSs operating in dynamic and complex Naval warfare environments. Performance in this context refers to the effectiveness of the CSG in operating as an integrated and functioning MTS, capable of coordinating component teams to achieve critical mission goals. Cognitive task analysis (CTA) methodology was utilized to leverage and refine existing frameworks (Ishak & Ballard, 2012; Marks, Mathieu, Zaccaro, 2001; Mathieu, Maynard, Rapp, & Gilson, 2008; Pagan, Kaste, Zemen, Walwanis, Wood, & Jorett, 2015; Wildman et al., 2012) of the KSAs deemed as necessary for Naval CSG-MTSs to successfully function in these environments. The decided upon framework then served as the basis for the development of training and performance recommendations in addition to a series of propositions for future research in efforts to understand and improve MTS processes.

Defining Multiteam Systems

MTSs are systems of teams operating across "traditional" team boundaries. *Boundaries* in teamwork refer to the teamwork and coordination space in which teams operate (Zaccaro, Marks, & DeChurch, 2012). MTSs often form in response to turbulent environments, which demand a sort of adaptivity in a team or set of teams to be able to rapidly respond to constantly shifting conditions (Mathieu et al., 2001). In traditional teams, team members work within their unit on defined tasks or functions. Team members rarely coordinate extensively with other entities. When they do, they do so loosely with other groups within their organization. However, MTSs are unique in that they are composed of tightly coupled groups of teams working toward highly interdependent goals, often through differing means or avenues. The collective efforts of an MTS must be well-coordinated across multiple functional teams to effectively and efficiently complete tasks or projects. Further, MTSs often cross organizational boundaries and can include teams from multiple organizations, firms, or other units (Zacarro et al., 2012).

MTSs, when compared to traditional teams, are most often implemented during highly critical missions that require coordinated, interdependent responses from multiple groups for the purpose of achieving a common goal (Zaccaro et al., 2012). These MTSs work to respond to environmental contingencies and achieve differing short-term (i.e., proximal) goals that feed into an overall (i.e., superordinate) goal. Striving to complete short-term team goals to achieve a greater multiteam goal is a major characteristic differentiating MTSs from traditional teams. When we refer to MTSs, we are referring to a larger, complex grouping of teams called "component teams" (Zacarro et al., 2012). *Component teams* have unique, hierarchically organized goals; lower-level teams are more focused on lower-level goals (e.g., correct identification of relevant information) (see Table 1 for MTS key terms). Higher-level teams (e.g., leadership teams) are focused on achieving higher-order goals (e.g., overall CSG mission accomplishment).

Table 1. Multiteam System Key Terminology

Term	Definition
Multiteam System	Systems composed of two or more teams that interface directly and interdependently to respond to environmental contingencies, and whose differing proximal goals feed into a shared, distal goal
Component Teams	Teams within an MTS which have unique, hierarchically organized goals
Boundaries	The teamwork and coordination space in which teams operate
Interdependence	A type of relationship in which teams depend or rely on other component teams to accomplish goals
Input Interdependence	The extent to which inputs, such as human, technical, informational, material, and/or financial resources, are shared by MTS teams
Process Interdependence	The level of interteam interaction required to achieve MTS-level distal missions
Outcome Interdependence	The extent to which common outcomes, such as overall mission success, are shared by MTS teams
Team Processes	Interdependent team activities that orchestrate taskwork in pursuit of shared team goals
Action Processes	Team processes that take place during action phases, or periods of time where teams are acting to directly contribute to taskwork for the sake of goal accomplishment
Transition Processes	Team processes that take place during transition or planning phases of the team's task(s)
Multilevel Theory	A theory focusing on the phenomena of nesting and emergence across differing levels of analysis (e.g. sailors nested within platform-bound teams, nested within multi-platform units, nested within the larger MTS)

MTSs are complex, dynamic, and adaptive systems (Ilgen, Hollenbeck, Johnson, & Jundt, 2005). Systems perspective conceptualizes the lifecycle of these systems in terms of importing or inputting resources into the system (e.g., team, organization, or MTS), which are processed and transformed through internal efforts into outcomes. This perspective is often referred to as an Input-Process-Output (I-P-O) model or framework (Hackman, 1987). Striving to meet shared goals means that MTS component teams have some level of *input*, *process*, and/or *outcome interdependence* with at least one other team within the larger system (Mathieu et al., 2001). *Interdependence* refers to a type of relationship in which teams depend or rely on other component teams to accomplish goals (Bennett, Lance & Woehr, 2006). Further differentiating traditional teams and MTSs is the level of complexity of the component teams, the communication and interaction linkages between component teams and team members, the development processes undertaken to create MTSs, and the scale and complexity of the problems addressed by MTSs (Zacarro et al., 2012).

In sum, MTSs are complex, dynamic groupings comprising two or more component teams with varied core missions, expertise, structure, norms, and operating procedures and these teams work interdependently towards collective ends. The MTS structure emerges to deal with highly turbulent, complex environments that require rapid responses to changing circumstances. As such, explicitly examining the ways in which the CSG-MTS operates and the KSAs needed to do so effectively is a critical need to understand and drive successful CSG performance.

Multiteam System Processes

To understand and improve MTS functioning, it is essential to first understand the various types of teamwork processes that can be enacted within these multiteam structures, especially (1) action, (2) transition, and (3) interpersonal team processes. *Team processes* are interdependent team activities that orchestrate taskwork in pursuit of shared team goals (Marks et al., 2001). As teams go through the phases of goal achievement - from planning to active taskwork - they utilize a dynamically evolving variety of processes to ensure that their outcomes are positive and that the team stays on track to goal completion. Although this typology of teamwork processes was originally conceptualized within single-team settings, it also has also been used to characterize and distinguish the within- and between-team processes in MTSs (Marks et al., 2005).

Action processes are those that take place during action phases which are periods of time where teams are acting to directly contribute to taskwork for the sake of goal accomplishment (Marks et al., 2001). These are the actions that take place during time-limited critical periods, whereby poor enactment of these action processes could lead to immediate failure to accomplish the mission. Monitoring goal progress processes are aimed at tracking the current velocity of a team's progress towards mission completion. Systems monitoring processes are those that track team resources and environmental conditions. Team monitoring and backup behavior processes are those that are performed to actively assist team members in performing their individual tasks. Finally, coordination processes are those that are focused on orchestrating a well-timed sequence of interdependent actions efficiently and without errors.

Transition processes are those processes that take place during transition or planning phases of the team's task(s). Within the context of Naval CSGs, transition processes are most likely to occur during mission planning or when significant changes in the environment require last-minute adaptation of plans. Transition processes consist of: (1) mission analysis, or the evaluation of the mission, tasks, conditions, and resources, (2) goal specification, including the identification and prioritization of team and MTS goals and sub-goals, and (3) strategy formulation, the development of alternative courses of action.

Finally, interpersonal processes are enacted within the team across all phases of a team's (or MTS') lifespan and taskwork cycle. These processes are focused on ensuring the social and emotional core of the team remains strong enough to support continued work accomplishment (Marks et al., 2001).

The scope of the current study focuses on action and transition processes as drivers of MTS performance, as these were identified as being most salient and applicable to the current research context in comparison to interpersonal processes. To date, a very limited amount of research has examined the specific processes driving successful MTS performance. Marks and colleagues (2005) demonstrated that action and transition processes at both the team- and MTS-level predicted MTS performance, but that the MTS-level action processes were more instrumental in predicting performance within highly interdependent tasks. There is also evidence to suggest that the larger an MTS is, the more its size hampers informal coordination and communication. This means that large MTSs must create clear formal coordination structures to effectively manage the boundaries between individual component teams, the MTS, and the greater environment (Shuffler et al., 2015).

Furthermore, there is a need to explore the multilevel inputs that enable the enactment of the various teamwork processes at the MTS-level. The complexity of interactions within MTSs, the complexity of their composition, and the complexity of the goal structures of the MTS require dynamic, multilevel approaches that target and study every level of the MTS: individual, component team, and the whole MTS simultaneously.

Gaps in Understanding Naval MTSs

Military operations have utilized multiteam systems for quite some time; however, research on MTS processes has only begun to gather momentum in the past decade. A recent review summarizes what is known and not known regarding critical MTS inputs, processes, and outcomes (Shuffler et al., 2015). One of the primary conclusions suggested by Shuffler and colleagues (2015) is that the complexities of MTSs limit our ability to directly apply research findings drawn from the broader team literature to the MTS level. In fact, in many cases, what is beneficial or effective at the component team level may have unintended negative consequences at the MTS level, and vice versa. For example, research has found that direct peer-to-peer coordination between team members within a team enables performance at the team level, but that it can actually have a negative impact on MTS performance to have individual members of various component teams trying to directly coordinate with one another (Davison et al., 2012). Rather than direct peer-to-peer coordination, MTSs benefit from more focused, vertical coordination occurring via clearly identified boundary spanners. In another example, research examined the extent to which individuals in an MTS psychologically identified with (i.e., felt a sense of belonging and connectedness to) their team and MTS. It was found that strong feelings of identification with the team enabled better performance at the team level, but that identification also caused more conflict between teams within the MTS, essentially hindering performance at the MTS level. In contrast, identification with the MTS as a whole was found to be critical for enabling effective MTS performance.

The existing published research on MTSs provides a promising starting point for understanding how to improve Naval-MTS processes and performance; however, the vast majority of published MTS research has been conducted using small, simulated MTSs performing relatively brief tasks (e.g., Davison et al., 2012; DeChurch & Marks, 2006; Marks et al., 2005) that may underrepresent the level of complexity inherent in Naval MTSs, which can be comprised of dozens of individuals across dozens of platforms conducting life-threatening missions that can be days or weeks long. Studying MTS dynamics in such high-stakes, real-world contexts is less common because of the obvious challenges inherent in obtaining access to these types of systems and in collecting data during these types of performance episodes. In general, studying MTS dynamics requires multiple diverse methodologies and a combination of complex systems perspective (Zaccaro et al., 2012) and theories which address the multilevel nature of MTSs (Kozlowski & Klein, 2000). Given the relative lack of research examining MTSs at the level of complexity seen in the U.S. Navy, the logical starting point is a more qualitative approach aimed at eliciting rich contextual information regarding the defining characteristics, experiences, and drivers of effectiveness for focal, Naval MTSs that can be used to develop a future research agenda as well as training and performance measurement recommendations.

Current Research Questions

Based on the review of the existing MTS literature described above and gaps identified in this stream of research, the current study focuses on several research questions to guide current efforts. First, what are the critical, multilevel inputs and processes that drive effective performance within and across component teams in a Naval CSG-MTS (i.e., which KSAs are required for effective performance)? Second, how can we effectively measure and capture those inputs, processes, and performance outcomes in complex and dynamic CSG-MTS environments? Finally, what are the implications of these processes for improving multilevel training (i.e., training both within and between component teams)? See Figure 1 below for the organizing research framework.

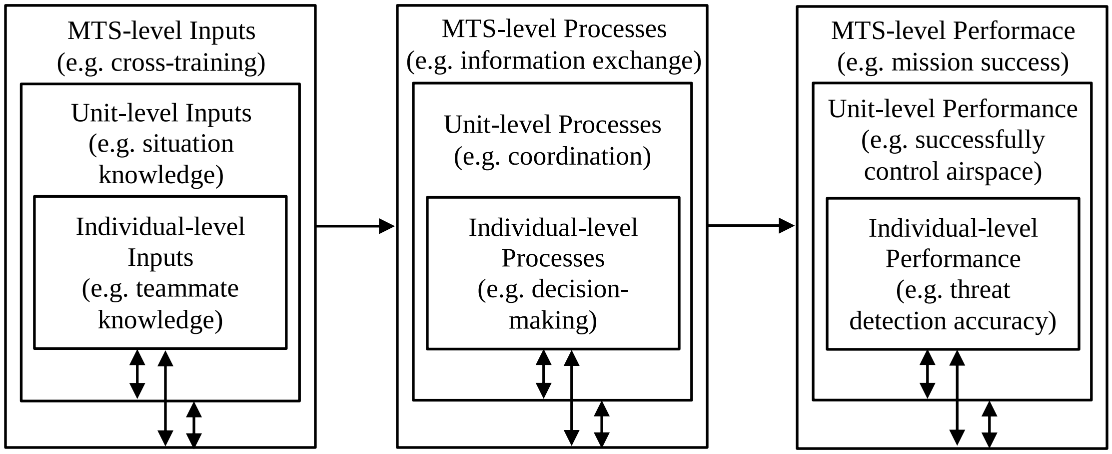

Figure 1. Organizing Research Framework

RESEARCH CONTEXT: NAVAL CSG MTSs

The current study focuses on the MTS component teams involved in the defense of a Naval CSG. A multilevel approach was taken to examine the KSAs within the CSG, where *multilevel theory* is explicitly interested in the phenomena of nesting and emergence across different levels of analysis (Kozlowski & Klein, 2000). Applying multilevel theory, the CSG can be considered a multilevel MTS, where individual sailors are nested within platform-bound teams, platforms are nested in multi-platform units (e.g., squadrons), and multi-platform units are nested in the larger MTS (i.e., the entire CSG). CSGs need to effectively coordinate and communicate within and across platforms and units in complex and dynamic environments. Interactions between individuals contribute to performance at the team level, interactions between teams contribute to performance at the squadron level, and interactions between various platforms within the CSG contribute to performance of the CSG as a whole.

Taking multilevel theory into account when aiming to improve Naval CSG performance highlights two key considerations: (1) the referent or focus for each KSA and (2) the level of analysis, or aggregation, for each KSA. Consider teammate knowledge as an example. A measure capturing this type of knowledge can focus on multiple referents relevant to MTS performance such as knowledge of teammates' capabilities and limitations within one's own team or knowledge of teammates' capabilities and limitations within other platforms or units. Furthermore, this type of knowledge can be measured at the individual level by asking respondents to report their knowledge of these various referents, but then this concept can be conceptualized at various levels of analysis by aggregating these responses to the team, squadron, or CSG levels. Specifying the multilevel referents for each KSA is critical because it helps to pinpoint exactly what may be most relevant to performance (e.g., is it more critical to performance to have a clear understanding of my own teammate's capabilities, the capabilities of another platform that I regularly interact with, or the capabilities of a platform I rarely interact with?). Specifying the level of analysis or aggregation is important because it assesses the level of sharedness of each KSA at multiple levels, and in some cases, it may be sharedness at the team or MTS level that determines ultimate performance. The CTA protocol and ensuing recommendations were thus developed to address varying KSA referents and levels to sufficiently capture the various potential predictors of CSG-MTS performance.

METHOD: COGNITIVE TASK ANALYSIS

Cognitive task analysis (CTA) refers to a variety of techniques used to identify the knowledge content, cognitive processes, and goal structures underlying performance of complex tasks (e.g., Yates & Feldon, 2011). This type of methodology goes beyond traditional task analyses to understand the cognitive underpinnings of how tasks are performed. We selected a CTA approach, as previous research on this method provides substantial insights into successful training and performance measurement of distributed teams. One meta-analysis examined the overall effectiveness of using CTA methods to develop instructional content and training, and found a large effect size

(Hedge's g = 0.87) over a wide variety of domains, indicating that CTA methods provide a robust basis for eliciting knowledge-based content (Tofel-Grehl & Feldon, 2013). According to the North Atlantic Treaty Organization's (NATO) Research and Technology Organization (RTO), the increase in automated systems within the military has resulted in jobs that are cognitive in nature, placing an emphasis on inference, diagnosis, judgment, and decision-making (Chipman, Schraagen, & Shalin, 2000). More specifically, an adaptation of the Critical Decision Method was used as previous research has suggested this is an effective CTA technique (Crandall, Klein, & Hoffman, 2006). Adaptations were made to the Critical Decision Method to identify critical KSAs considered key to the successful performance of the Naval CSG.

Prior to developing the CTA protocol, the research team conducted a domain analysis on Naval CSG, and associated platforms and positions. This included an analysis of the extant literature, including technical reports and materials provided by the Navy to better understand the roles and interactions between surface and air assets and warfare commanders within the CSG of interest. We also leveraged and refined existing frameworks of MTS KSAs to guide question development and data coding based on several recent taxonomic works from the team effectiveness literature (i.e., Ishak & Ballard, 2012; Marks, Mathieu, Zaccaro, 2001; Mathieu, Maynard, Rapp, & Gilson, 2008; Pagan, Kaste, Zemen, Walwanis, Wood, & Jorett, 2015; Wildman et al., 2012). Based on this review, a CTA interview protocol was developed with questions directed towards understanding the roles, tasks, and interdependencies of the CSG being studied within complex warfare environments.

Once the initial protocol was developed, it was piloted with Naval subject matter experts (SMEs) to expand and refine for data collection. The CTA protocol entailed administering semi-structured interviews to prime each SME to recall and describe a specific past performance episode. Each interviewee was asked to establish an initial timeline for the specific performance episode. Probing questions were then used to identify critical decision-points within the timeline.

The team conducted interviews with 59 SMEs across Naval surface and air units operating in warfare environments. Interview notes were then transcribed and analyzed using MAXQDA (i.e., qualitative data analysis software) to identify relevant themes that emerged.

A coding scheme was derived based on interview transcripts, SME input, and previous KSA frameworks. The first round of coding involved coding for content, and a second round targeted the level of analysis of the content codes. All interviews were independently coded by three people. Agreement analysis was run on coders one and two, and a 70% agreement threshold was established, such that each interview was required to reach this level of agreement to be coded by a third coder. The third coder was used to reconcile any discrepancies between the first two coders. Two forms of agreement were examined, existence and frequency. Existence refers to the level of agreement on the presence of each code and sub-code within each interview (Mean = 94.8%; Min = 79.9%; Max = 99.3%). Frequency, or correlation, refers to the overlap between two coders in frequency counts for each code (Mean = 89.6%; Min = 72.2%; Max = 95.1%) Once all codes were agreed upon, the team analyzed the frequencies of codes across the levels of analysis and platforms within the CSG-MTS.

RESULTS

Research Question 1: Critical Inputs and Processes

Two approaches were used to address the first research question. First, we examined the extent to which the preliminary KSA framework was supported by the CTA results. Preliminary findings support the KSA elements in the initial framework in that each KSA element was clearly represented in the SME interview results. This suggests that each of these factors plays a notable role in the context of CSG-MTS processes. Second, several additional KSAs were identified in the analyses and added to the preliminary KSA framework: (1) goal specification, (2) strategy formation, (3) leadership, and (4) decision-making.

Preliminary findings suggest that a number of skills that typically may not be critical in single-team environments may be more salient and influential in CSG MTSs. These findings support important factors for further research, measurement, and training development (see Table 2 below for KSA framework and definitions).

Table 2. KSA Framework

KSA	Individual	Team	Multiteam System
		Knowledge (Inputs)	
Goal Knowledge	One's own mission objectives/goals	Team mission objectives/goals	MTS mission objectives/goals
Task Knowledge	One's own tasks, systems, equipment, etc.	Team tasks, systems, equipment, etc.	MTS tasks, systems, equipment, etc.
Situation Knowledge	One's own dynamic mission environment	Team's dynamic mission environment	MTS dynamic mission environment
Teammate Knowledge	One's own capabilities and limitations (self-awareness)	Team capabilities and limitations	MTS capabilities and limitations
Process Knowledge	Communication codes, syntax, etc.	Team interaction protocols and procedures	MTS interaction protocols and procedures
		Skills (Processes)	
Mission Planning	Analysis of the mission	Analysis of the team mission	Analysis of the MTS mission
Goal Specification*	Specification of individual goals and sub-goals	Specification of team goals and sub-goals	Specification of MTS goals and sub-goals
Strategy Formulation*	Development of individual plans and strategies to achieve goals, including contingency plans	Development of team plans and strategies to achieve goals, including contingency plans	Development of MTS plans and strategies to achieve goals, including contingency plans
Information Exchange	Receiving and providing information necessary for one's own mission completion	Receiving and providing information necessary for team mission completion	Receiving and providing information necessary for MTS mission completion
Performance Monitoring	Monitoring one's own systems and progress toward goals	Monitoring the team's progress toward goals and teammates' statuses	Monitoring the MTS's progress toward goals and teammates' statuses
Coordination	Orchestrating the sequence, timing, and geometry of one's own actions	Orchestrating the sequence, timing, and geometry of team actions	Orchestrating the sequence, timing, and geometry of MTS actions
Adaptation	Adjustment of one's own strategies and plans during mission execution	Adjustment of team strategies and plans during mission execution	Adjustment of MTS strategies and plans during mission execution
Leadership*	Providing direction or assignment of authority at the individual level	Providing direction or assignment of authority at the team level	Providing direction or assignment of authority at the MTS level
Decision-Making*	Individual-level integration of information to select between multiple alternative choices or paths forward	Team-level integration of information to select between multiple alternative choices or paths forward	MTS-level integration of information to select between multiple alternative choices or paths forward
		Attitudes (Emergent States)	
Trust	N/A	Willingness to rely on others in the team	Willingness to rely on others in the MTS
Cohesion	N/A	Feelings of interpersonal attraction to and pride toward the team and commitment to the team's task	Feelings of interpersonal attraction to and pride toward the MTS and commitment to the MTS's task

**Indicates skill added to KSA framework from results of CTA*

Research Questions 2 and 3: Measurement and Training

Two types of CTA data were used to address the second and third research questions: (1) explicit, referring to cases where SMEs mentioned existing performance measures or criteria during the CTA interview, and (2) implicit, referring to cases where SME statements could be used to derive performance measures or criteria. Thematic analysis of these data and further discussion with trainers and SMEs suggested that automated, objective measurement of some of these processes during training could be beneficial and free up trainer time for other tasks. For example, objective parameters such as speed, accuracy, timing, and distance could be collected and aggregated to the team and MTS level as indicators of team and MTS processes during training. Such measures would typically need to be developed to be platform- and mission-specific; therefore, these specific parameters may not be transferable across platforms or training scenarios. However, other MTSs beyond the Naval CSG may still draw from these recommendations in developing objective multi-level (e.g. component team and MTS level) parameters specific to the unique MTS context to capture the effective performance of the MTS of interest.

Thematic analysis of the data also suggested that some degree of trainer evaluation will continue to be necessary despite advances in performance measure automation. Trainers rely on their experience to account for a multitude of contextual contingencies in their ratings for which automated, system-based measures cannot account. Human-rated measures of MTS processes also have the advantage of transferability across scenarios and platforms because items can be written to generalize across contexts. As a result, the best performance measurement approach is likely to be a combination of human-rated measures of MTS processes (completed by trainers or observers) and objective, system-based measures of MTS processes and outcomes.

Specific recommendations for performance measurement include focusing on developing multilevel measures for the KSAs identified as critical for effective MTS performance. This would entail developing knowledge measures for the competencies of teammate knowledge and situation knowledge, and skills measures for information exchange and coordination. Situation knowledge, for example, could be measured through several means, including, but not limited to: (a) self-report measures targeting the extent to which participants are aware of critical mission information before, during, and after an MTS mission or training exercise; (b) a status request (in the form of a leader request for information) sent to an operator, team, or MTS during a training exercise, responses to which are then compared to the objective reality of the scenario (i.e., ground truth) as a measure of accuracy; or (c) use of objective, system-based technology measures to capture shared perceptions across the MTS (e.g., time-stamped, shared air picture) and to make similar comparisons to ground truth as a measure of accuracy.

Drawing from the analyzed critical incidents and emergent themes, recommendations for training also include focusing on integrated MTS training earlier on in the training pipeline, with emphasis on the enactment of planning, processes, and performance at the MTS level. With a more agile and adaptive training pipeline, there lies a greater potential for cross-training component teams in the MTS to enhance teammate knowledge. While it is not expected that each team learn how to carry out specialized tasks relegated to other component teams, training could focus on increasing teammate knowledge of the capabilities and limitations of other platforms within the MTS. Through enhancing teammate knowledge, these platforms can be expected to integrate more smoothly during mission analysis, strategy formation, and mission execution phases, and ultimately lead to increased overall MTS performance.

FUTURE RESEARCH

Based on the quantitative results of the CTA (described above), as well as additional qualitative analysis of themes and critical incidents within the data, a preliminary model of key inputs to MTS processes and performance in the CSG context was developed to inform the next stage of efforts towards understanding the CSG MTS.

This model and the accompanying propositions will be used in future research on CSG training environments to evaluate the conclusions and propositions put forth by the current paper (see Figure 2).

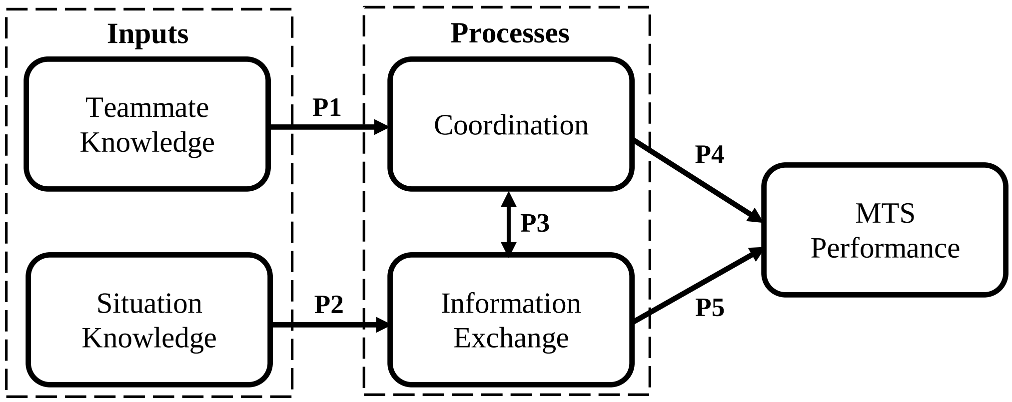

Figure 2. Causal Model of Naval CSG MTS Performance

Teammate knowledge is proposed to be a critical predictor of effective coordination (Proposition 1), as a clear understanding of capabilities and limitations across platforms is necessary to effectively time and sequence actions across platforms. Situation knowledge is expected to lead to more effective information exchange (Proposition 2), given that a clear understanding of the mission and environmental context should lead to more timely and efficient information exchanges. Coordination and information exchange are expected to be mutually causal (Proposition 3) via a reciprocal feedback loop in which information exchange enables coordination, and coordination often requires increased information exchange. Finally, these emergent and dynamic processes are expected to be important drivers of successful MTS performance (Propositions 4 and 5).

To test and expand the results and conclusions drawn from the CTA, we propose an iterative, multi-pronged future research agenda consisting of field-based quasi-experiments, laboratory-based experiments, and virtual agent-based modeling experiments. Each proposed research methodology has been selected and designed to provide complementary strengths that compensate for the limitations of the others. The proposed model should also be tested across a number of different Naval MTSs and warfare contexts in order to support its generalizability. Replicating results across these methodologies, samples, and contexts, as well as generating new propositions and hypotheses in each study that are then tested in subsequent studies, will provide more scientifically sound and operationally relevant findings than any of the methodologies used alone. This program of research is ultimately designed to inform fleet training recommendations, performance measurement, and tactical strategies that can effectively enhance MTS coordination across the CSG.

IMPLICATIONS

The current study addresses a need for context embedded research to inform recommendations based on real events by studying personnel operating in real-time warfare environments. Preliminary results suggest a set of KSAs that are essential to Naval CSG-MTS performance. Moreover, the prevalence of KSAs such as teammate knowledge and coordination suggest a significant need for added integrated training opportunities in which teams are exposed to the capabilities and limitations across platforms within the CSG.

The results of the current study can be used to not only inform the literature on MTS performance and processes, but also to improve coordination and integration of MTSs operating in real-time Naval warfare environments. The refined KSA framework and results of this study can also be used to enhance decision-making across all levels of the MTS, in a context where the future battle domain will face small decision windows where fast decisions and coordination are paramount for mission success.

These recommendations can also be carried over on a more general level to improve the processes of MTSs operating in critical and uncertain environments. For example, emergency response teams are MTSs made up of many component teams, including but not limited to, police, firefighters, emergency medical technicians, and recovery teams operating in uncertain, high-stakes environments. Each component team receives isolated emergency response training, and yet all are expected to come together seamlessly in crisis situations. These MTSs could be expected to improve MTS team performance through cross-platform training focusing on each other component teams' capabilities, limitations, and roles within a variety of emergency response situations. Further, live integrated MTS training events could be implemented into each team's training pipeline to delineate and understand the communication structures and coordination expected within and between each component team comprising the entire MTS. Objective and subjective performance measures, such as response time and quality of response, could also be developed specific to a number of different emergency scenarios to capture MTS performance in both training and real life emergency response situations.

Finally, these results can be used to drive future research in efforts to evaluate the framework and propositions put forth by the current study in a multi-method, iterative manner. Ultimately, through targeting the improvement of the KSAs identified in this research via training and performance measurement, MTS performance is expected to increase under critical mission conditions.

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