TEAM INTERACTION STRATEGIES FOR HUMAN–AUTONOMY TEAMING IN NEXT GENERATION COMBAT VEHICLES

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The current study focuses on improving team effectiveness in Next Generation Combat Vehicles (NGCVs) that combine humans, intelligent agents, and unmanned assets working together toward common goals, "teaming", through the development of interaction strategies for this future contextual domain. Twenty interaction strategies were derived from three objectives to account for system changes anticipated from the introduction of NGCVs. In particular, consideration is given for improving awareness of team members, maintaining flexible coordination, and working within the constraints of the new environment. Future work should focus on validating the strategies and the implementation of strategies into NGCV design.

INTRODUCTION

Next Generation Combat Vehicle (NGCV) concepts include the introduction of unmanned variants and increased use of artificial agents, which will change how combat vehicle crews operate (Department of Defense, 2017; Feickert 2019). Artificial agents may enable new system capabilities that were previously impossible for human operators, such as coordinating a larger number of vehicles to be operated by fewer personnel (Holder, 2017) or flexible task allocation between humans and agents. For example, driving a combat vehicle in existing systems is typically coordinated between a driver and other crew members. In future systems, the driving task may be allocated between human and non-human agents as needed, and agents will need to give and receive inputs that are appropriate for their roles. Designers, researchers, and users need to understand how these changes will impact teamwork to effectively guide future training, doctrine, and design efforts as well as employment.

Current combat vehicle systems include tactics, techniques, procedures (TTPs) and tools that facilitate team coordination (US Army, 2019). As NGCVs are introduced, new or revised TTPs and tools may be necessary to manage these systemic changes. Whereas a common approach may be to structure team interactions around new technological capabilities, explicit team interaction strategies may guide design to improve team effectiveness. The purpose of this study is to propose interaction strategies relevant for unmanned variants of NGCVs which could possibly be expanded to other applications in human–autonomy teaming.

Human–Autonomy Teaming

Traditionally, a team has been defined as two or more humans working together interdependently toward shared goals (Salas et al., 1992). In previous decades, however, advancements in software agents and robotic technology brought into question whether nonhuman agents could be considered teammates (Groom & Nass, 2007; Klein et al., 2004). At the time, team player behaviors (e.g., performance monitoring, backup) were thought to be beyond what artificial agents were capable of—relegating these agents to be considered tools to human teams. Future agents such as those in NGCV concepts may be expected to perform more complex cognitive work and play more interdependent roles in teams. Human–autonomy teaming concepts attempt to integrate agent interactions with knowledge of team interdependence (Johnson et al., 2014). For instance, role clarity (i.e., who is doing what) becomes relevant for each agent when artificial agents and humans perform different interdependent functions over time. This work describes the application of Human-autonomy teaming (HAT) in NGCV concepts. Other applications include surgical robots, autonomous drone control, and robot-assisted search and rescue. In this paper, the terms "agent" and "teammate" will be used to refer to both humans and non-human intelligent agents.

Team Interaction Strategies

Although there are numerous instances of ways in which research has informed the structure of team interactions (Chen et al., 2018, Johnson et al., 2014), the concept of a team interaction strategy remains relatively undefined. In this work, we define a *team interaction strategy* as the specification of some properties of team interactions (e.g., how, when, with whom) to achieve one or more objectives. A benefit of focusing on team interaction strategies is that they focus on specific qualities of team interdependence rather than a specific tool or capability, allowing them to generalize better across similar teaming contexts. For example, Patterson et al., (2004) identified 21 role hand-off strategies across various safety-critical domains to compare to processes in observational healthcare data. They were able to provide suggestions for improvement in the handoff process within the healthcare context, including training and interface design. This approach is particularly useful for systems that have not been fully defined and developed, such as NGCVs.

Team interaction strategies proposed in this study include assumptions about the anticipated interaction requirements for team effectiveness in NGCV crews. The future environment may impact teams at smaller (e.g., one operator and one vehicle) and larger (e.g., multiple crews) scales. Thus, team interaction strategies should address coordination needs at low levels of organization as well as from a macro level. The strategies are also grounded in team states and outcomes, including appropriate trust, situation awareness, manageable workload, and resilience. An ineffective strategy may increase awareness of status information in ways that reduce trust or increase workload. Additionally, a strategy may only be viable when a team is already working well together, or a strategy may lose viability in the context of competing priorities. Therefore, consideration for the tradeoffs and dynamic context of these strategies should also be given.

Finally, as strategies provide structure to team interactions, some insight into possible team interactions is needed for strategies to be developed. Possible interactions may be derived from analysis of essential interactions involved within the defined scope of application. In the current study, we focus on team interaction strategies for NGCVs with unmanned ground vehicles to improve team effectiveness.

METHODS

The procedures used to develop team interaction strategies included subject matter expert interviews, literature review, application scoping, and utilizing a taxonomy of team interactions. Initial references and interviews were synthesized to determine the scoping, which guided further review. The application scope helped to identify the state of current systems as well as anticipated system changes with the introduction of NGCVs. Then, literature review helped to identify human systems requirements for NGCVs and potential solutions through interaction strategies. Finally, a taxonomy of team interactions developed for this application of NGCVs was used to generate strategies.

Subject Matter Expert Interviews

Semi-structured interviews were conducted with two subject matter experts regarding essential interactions in combat vehicle crews and their work context. Both were active duty Army majors with over 10 years of time in service. Each SME had experience in tactical leadership positions. SME #1 was an armor officer and with experience as a Bradley scout platoon leader and the other was an infantry officer with experience as an infantry platoon leader and infantry school instructor. Additional insight into armored vehicle operations was provided by the second author of the current work, who was a tank platoon leader with four and a half years in service.

Literature Review

A literature review was conducted to develop the application scope and identify analogues to team interaction strategies in this context. The review included Army manuals and documentation relevant to combat vehicle operations, supplementary unpublished documentation from Army Research Lab, and academic literature on command and control teams, interaction strategies, and human–autonomy teaming.

Application Scoping

NGCVs are expected to fill similar roles and tasks performed by modern armored fighting vehicles such as the M1A2 Abrams tank and M2 Bradley. These roles include providing mobile, protected firepower on the battlefield in order to conduct offensive, defensive, and stability operations (US Army, 2019). NGCVs can be expected to coordinate in heterogeneous formations alongside infantry, aviation, field artillery, and other armored fighting vehicles. They are also anticipated to incorporate advanced displays and intelligent vehicle automation (Department of Defense, 2017). One specific case—the Robotic Combat Vehicle (RCV)—is envisioned to have a range of capabilities to maneuver in various environments and perform using advanced sensors, as well as in degraded sensing environments. Many of these capabilities may be automated, including driving, decision-support, and target detection or recognition assistance. An example application of this system is the vehicle section shown in Figure 1. This configuration includes seven crew members, two RCVs, and one Manned Combat Vehicle (MCV). The crew members operate within the MCV.

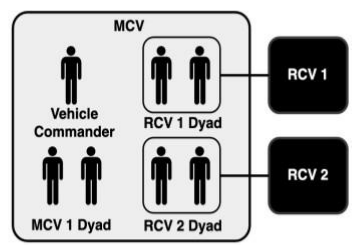

Figure 1. Structure of the vehicle section for our application scope. There are seven members in each section who are physically located in a MCV. Two dyads operate each RCV, one operates the MCV, and the vehicle commander facilitates vehicle-level coordination (Johnson et al., 2020).

RESULTS

We present the findings in the following sections: (a) an overview of existing components of combat vehicle systems that structure crew interactions; (b) anticipated system changes and objectives based on next generation concepts; (c) application of an interaction taxonomy to identify possible new interactions; and (d) human systems requirements based and novel interaction strategies to meet these requirements.

Existing Structures for Team Interactions

Current combat vehicle systems include TTPs and tools to structure coordination in vehicle crews. Although no single document describes TTPs and tools in terms of their underlying interaction strategies, we describe example elements of combat vehicle systems that structure crew interactions meaningfully.

Communication tools. Communication tools include crew voice intercoms, multi-frequency radios, and digital map systems with embedded chat abilities (Huang et al., *in press*). Radio allows communication to occur synchronously over networks, as well as the option to distribute information to one or more recipients but can have issues with signals and clarity.

Digital display systems provide the opportunity to present various information types (e.g., graphical, temporal, and/or text), but can also present more risk in terms of visual distraction, update delays, and information mismatches across teammates.

Information pushing and pulling. Information pushing refers to providing information to a teammate without being asked and pulling refers to requesting information from a teammate (Wilson et al., 2007; Gorman et al., 2006). Pushing information is useful for improving the efficiency and timeliness of communication and may be critical when the recipient of the information may not be aware or available to request information. Pulling information helps specify the requested information when needed. In contrast, pulling is more relevant when the agent providing information is not aware of who needs it or when it is needed. The military hierarchy and reporting rules can also impact the timing and balance of pushing and pulling.

Closed-loop communication. Closed-loop communication refers to a communication process in which the sender transmits a message, the receiver accepts the message and acknowledges to the sender that they have received it, and the sender verifies that the receiver accepted and properly understood the message. (US Army, 2009). Closed-loop communication serves multiple functions including increasing confidence in the transmission of a message, providing structure for repair when information was not appropriately understood, and accounting for situational factors (e.g., distance, technology malfunction) which may affect transmission.

Phraseology. Phraseology describes standard ways in which a message is conveyed. These include the use of standardized terminology, call signs, standardized reporting templates, and short messages (Wilson et al., 2007). Phraseology improves the predictability, and in some cases completeness, of communications.

Commander's intent. Commander's intent describes the purpose or desired end state of an operation. Commander's intent is generally conveyed as a clear and concise expression in order to provide focus and allow subordinates to act in the absence of further orders (Holder, 2017; Shattuck & Woods, 2000).

Limited customizability. Whereas doctrinal and regulatory matters tend to be universal across much of the military, a certain level of customizability is allowed in the implementation of standard operating procedures and specific TTPs on the unit-level. Customization accounts for individual and team-level differences and allows for controlled deviation to address complex and varied situations. However, customization is generally limited to aspects of work which do not interface between units, thus preserving standardization and predictability.

In sum, these existing structures provide context for crew interactions in the current systems and inform the interaction strategies in the context of anticipated system changes.

Anticipated System Changes

The NGCV section concept introduces notable shifts from existing systems. Increasing interactions with artificial agents suggest vehicle operation may adopt different forms of control (e.g., supervisory control). Humans have extensive experience interacting with humans but not necessarily with the various intelligent agents of NGCVs. Each agent (i.e., humans and artificial agents) need to have accurate expectations for effective team interactions. Therefore, one of our objectives for crew interaction strategies is *increasing awareness of teammate behaviors, roles, and responsibilities.* In addition, vehicle operation tasks may be conducted by artificial agents, freeing vehicle operators to perform other tasks. As operators become more available, the nature of tasking may change from more pre-defined responsibilities to task switching and on-demand tasking. In order to allocate tasks appropriately, agents assigning tasks should be able to observe the current task allocation of the team.

Invoking on-demand tasking alludes to an objective of *managing crew flexibility for changing conditions*. Although mission planning may be extensive, flexibility is needed to adapt plans in surprising situations and can allow wider optimization of resources at the potentially higher risk of confusion. These adaptations may include revisions to task allocation, courses of action, and reorganization of military assets. Such adaptations must be coordinated across agents in a vehicle crew, including artificial agents. For on-demand tasking to benefit flexibility, coordinators must consider each agent's capacity to perform tasks when replanning under surprise. For instance, although artificial agents may offer more efficient sensing, they may fail to interpret anomalies or complex situations accurately. Thus, a human may be required to compensate for this gap or even override the system when necessary. For these reasons, vehicle crew members are anticipated to have many ways of coordinating the same tasks which must be explored over time.

Finally, the constraints of the new working environment are anticipated to affect vehicle crew interactions. For example, the shift from manned control to remote operations has several implications. First, human operators will be physically distant from activity and direct sensation, relying more heavily on inputs from intermediary sources (e.g., agents, displays) whose location and perspective will be different from that of the operators. Feedback previously accessible passively (e.g., motion cues) and actively (e.g., using a hatch) via physical presence will need to be provided through other means. Second, improved sensing may afford an increased capacity to observe teammates and receive situation information but may also introduce needs for information filtering to ensure that each agent obtains information relevant for them in a timely manner. A third constraint is the need to control additional vehicles per section, which may affect the span of control for each agent. Overall, these changes lead our final objective: *understanding and working within the constraints of the new environment.*

Interaction Taxonomy

A taxonomy was developed for the unmanned NGCV variant in this study which characterizes NGCV team interactions under three different categories, each with multiple dimensions: task, team composition, and communication (Johnson et al., 2020). Task dimensions describe tasks,

Table 1. Interaction requirements and strategies based on our three scoped objectives: *I) increasing awareness of team members behaviors, roles, and responsibilities, II) managing flexibility for changing situations, and III) understanding and working within the constraints of the new environment.*

Objective	*Requirement*	*Strategy*
I	Each agent that depends on other teammate's input will need transparency regarding the underlying reasons or supporting information for behaviors of other teammates (Chen et al., 2018).	[1] Agents utilizing another teammate's input are provided supporting information as needed to understand and use the information.
I	Teammates will need access to relevant contextual information that is not easily observable for them.	[2] Each agent pushes relevant contextual information when that information is not easily observable by relevant recipients.
I	Teammates need to understand which teammates need information updates and which do not.	[3] Each agent is informed of other teammate's needs for relevant contextual information.
I	Teammates need to understand which teammates are likely to have information that they might require.	[4] Each agent obtains information about who will likely have required information before it is needed.
I	Humans must be able to distinguish actions and input as provided by humans vs. agents.	[5] The inputs of human and artificial agents are represented in a manner that is easy to distinguish from one another.
I, II	For crews with fluid roles, current task allocation status will need to be available to all crew members.	[6] The team's ongoing and upcoming tasks and overall workload demands are made observable when coordinating task allocation.
I, II	Exchanges in responsibility during role handoffs needs to be efficient and understood by each agent (Patterson et al., 2004).	[7] Each stage of a role handoff follows a clear and consistent phraseology with closed loop take-over communicated to all relevant agents.
I, III	The human in the loop of RCV control will need to translate RCV inputs and perspective to their teammates with different perspectives.	[8] Translating artificial agent inputs between humans follows a clear and consistent phraseology and common reference systems.
I, II. III	The performance limits for humans and artificial agents need to be clearly understood and observable for each agent.	[9] Agents receive feedback when their requests of other teammates are likely to exceed that teammate's performance limits.
I, II, III	Teams will need to calibrate trust over time as agents gain knowledge, skills, or change in condition (de Visser et al, 2019).	[10] Agents are provided supporting information and mechanisms to calibrate their expectations of other teammates' actual knowledge, skills, or states of those teammates.
I, II, III	Acceptable conditions for task reallocation need be established in advance (workload limits, proficiency sets, etc.).	[11] Agents are provided information about the conditions for task reallocation (e.g., during mission planning, predictive analytics, in real time).
I, II, III	Operators will need to coordinate with RCVs in multiple ways to respond effectively to unexpected events (Gorman et al., 2010).	[12] Humans proactively explore multiple ways of coordinating with artificial agents. [13] The levels of autonomous support are negotiated between the RCV and operators over time.
I, II, III	Crews with remote vehicles will have to coordinate within the control boundaries of all vehicles.	[14] Remote control boundaries of robotic combat vehicles are observable to agents coordinating with those vehicles. [15] Agents involved in planning maneuvers obtain information regarding remote control boundaries and terrain considerations.
II	The human needs to be able to override the system when required and have the information required to get up to speed.	[16] Humans are provided contextually relevant information regarding an automated system's task when they may override the system as well as when an override is initiated.
II, III	Responsibility for control and tasking of agents must be available at multiple levels of the human chain of command.	[17] RCV Operators may be designated to make decisions regarding tasks of RCV automated agents as situations demand. [18] Supervision of an automated agent functionality is clearly assigned and acknowledged within the team.
III	Remote or distributed systems will need to provide supplementary cues to operators in order to compensate for lost or reduced feedback.	[19] Information normally obtained passively via physical presence (e.g., motion cues) is also provided in remote operation. [20] Information regarding gains or losses in functionality are provided to teams as assets are updated, dynamically allocated to the team, or reallocated elsewhere.

subtasks, and essential interactions that form the context or purpose for team interactions. Examples of tasks include driving, gunnery, and navigation. Team composition characterizes agents, their roles, and their relationships within the team. These include different types of agents involved in an interaction, and interdependencies between team members. Communication dimensions include aspects of communication such as medium and the communication flow. This interaction taxonomy was used as the basis for possible interactions in the NGCV section and their components.

Team Interaction Strategies

Based on the anticipated system changes and human system requirements, we proposed 20 team interaction strategies for achieving these requirements and meeting the following three objectives (see Table 1).

Objective I: Increasing awareness of teammate behaviors, roles, and responsibilities. The first step in developing strategies that improve awareness was to scope the relevant teammate behaviors, roles, and responsibilities relevant for different agents and increase the team's understanding of each other's strengths and performance limitations. We identified information about current task allocation, workload, and underlying causes of behaviors. Then, we determined which agents need what status information (e.g., operators, artificial agents, commanders). Finally, we identified possible structures for exchanging the information, such as when information should be pushed or pulled or how information may get from an artificial agent to a specific team member. Overall, 13 strategies address this objective.

Objective II: Managing crew flexibility for changing conditions. We identified conditions that demand performance variability including environmental changes, changes in team states (e.g., workload), and unexpected events. Then, we considered interactions that could proactively benefit flexibility by either increasing the range of possible coordination solutions, increasing awareness of when adaptation may be required, or facilitating the transitions between teammates. Finally, we considered interactions that may occur in response to changing conditions, including on-demand tasking, replanning, or adapting communication to reduce demand. Nine strategies were generated for improving flexibility.

Objective III: Understanding and working within the constraints of the new environment. Finally, addressing the constraints of the new environment on teaming first involved identifying changes in feedback and control. These include a need to coordinate more entities (e.g., vehicles, humans, and artificial agents), the shift from manual to supervisory control across multiple tasks, and potential limitations to control (e.g., remote control boundaries). Then, we brainstormed potential compensations for these changes, including increasing operators' initiative when making vehicle-level decisions and reproducing the feedback previously obtained through physical presence (e.g., motion cues). In total, 8 strategies address this objective.

DISCUSSION AND CONCLUSION

The purpose of this study was to provide general guidelines for interactions that support team effectiveness in foreseeable NGCVs environments. Team effectiveness goes beyond outcomes to consider the inputs, processes, and states of the team. It is proposed that facilitating effective teaming starts with understanding the environment and its impact on team interactions and effectiveness. This work approached that understanding by examining anticipated changes in interaction strategies, which may be overlooked in design. The proposed team interaction strategies focus on the interaction-level while considering inputs (i.e., the capabilities of NGCVs) and relevant states (e.g., team workload, team situation awareness). To that end, we identified three major objectives in improving awareness of other team members, improving system flexibility, and adapting to constraints imposed by the future environment.

Designers may employ these strategies in multiple ways (e.g., training, displays, TTPs). The current study considered a single application of NGCVs at the section-level of operation, which must fit into a larger scope of operations as well as other existing systems. Because the actual technological capabilities and demands of the work context may change over time, the proposed strategies require further development and validation as the concept of NGCVs evolves.

In conclusion, team interaction strategies are presented to improve team effectiveness in future NGCVs. Overall, the design of interfaces for human–autonomy team systems should be designed with consideration for how the interfaces structure team interactions. Interaction strategies may aid this design process. Future work may consider strategy validation through controlled experimentation as well as testing the implementation of strategies in NGCVs interfaces.

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