Team Situation Awareness in Next Generation Combat Vehicle

by

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ABSTRACT

In human-autonomy teams (HATs), the human needs to interact with one or more autonomous agents, and this new type of interaction is different than the existing human-to-human interaction. Next Generation Combat Vehicles (NGCVs), which are envisioned for the U.S. military are associated with the concept of HAT. As NGCVs are in the early stage of development, it is necessary to develop different training methods and measures for team effectiveness. The way team members communicate and task complexity are factors affecting team efficiency. This study analyzes the impact of two interaction strategies and task complexity on team situation awareness among 22 different teams. Teams were randomly assigned different interaction conditions and went through two missions to finish their assigned tasks. Results indicate that the team with the procedural interaction strategy had better team situation awareness according to the Coordinated Awareness of the Situation by Teams (CAST) scores on the artillery calls. However, the difference between the strategies was not found on CAST scores of perturbations, map accuracy, or Situation Awareness Global Assessment Technique (SAGAT) scores. Additionally, the impact of task complexity on the team situation awareness was not found. Implications and suggestions for future work are discussed.

ACKNOWLEDGEMENTS

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INTRODUCTION

Next Generation Combat Vehicles (NGCVs) have an increasing application in the U.S. military. NGCVs include unmanned vehicle variants and artificial agents that affect combat vehicles' operation (Department of Defense, 2017; Feickert 2019). Artificial agents may take over from human operators and reduce human operators' workload. These technological advancements may allow unmanned vehicles with autonomous capabilities to coordinate with humans on the battlefield. For example, with this new system, human operators can share trivial tasks (e.g., driving) with agents and get inputs from them, or one operator can control multi-agents at once (Holder, 2017). This change has an impact on team interaction structures. However, it is unclear what types of team interactions are required for team effectiveness and change in the evaluation of team effectiveness is also needed. The purpose of this study is to examine the impact of team interaction strategies and task complexity on team situation awareness, in the context of human autonomy teaming with NGCVs.

CHAPTER 2

BACKGROUND

Human-Autonomy Teaming

The definition of a team is a heterogeneous group of individuals interdependently working to achieve their goals (Salas et al., 1992). Traditionally, the study of a team is based on human-human team interaction in human-only teams. However, with the development of autonomy, this technology is starting to be considered a teammate, and it introduces the concept of human-autonomy teaming (HAT; McNeese et al., 2018). HAT is perceived as one of the important ways to realize the powerful capabilities of automation (Shively et al., 2017). The difference between automation and autonomy is that autonomy can perform essential taskwork and teamwork like a human teammate, whereas automation needs humans to supervise (McNeese et al., 2018). Autonomy is defined as a system that possesses intelligence-based capabilities that show decision-based responses in an unexpected situation and some extent of self-government and self-directed behavior (Endsley, 2015). HAT will become more common, but the integration of these technologies is not simple, and the outcome of the integration is not easy to predict. Thus, understanding how teams will operate with different types of autonomy and automation is important.

However, as the HAT concept is in the early stage of development, team interactions are still difficult to capture within the existing set of routine assessment techniques. That is, team-level interactions need distinct assessment techniques from the individual-level interactions, because individual human-autonomy interactions do not always extend to team-level interactions. (O’Neill et al., 2020). A team with a non-human teammate may have different team interactions, and it will impact situational awareness. Team situation awareness created by team communication and coordinating processes is linked to overall team effectiveness and outcome. In the context of NGCV, the team is composed of 3 crews and 2 Remote Combat Vehicles (RCVs). Therefore, the existence of autonomous team members changes the interactions between human members, compared to current operational crewing. This HAT creates a different team situation awareness compared to a team consisting of only humans, because autonomy can create high cognitive demands on a human teammate with system complexity and lack of human-like behavior (Demir, McNeese & Cooke, 2016).

This project aimed to optimize teamwork effectiveness within human-autonomy teams by understanding the communications between humans and intelligent agents at their key tasks. Although testing which training methods were more efficient for HAT, this project also experimented with various metrics for measuring team-level efficiency. Data collected from Zoom, Qualtrics, Minecraft etc., was used to capture various team-level states including team workload, trust, situation awareness, resilience and effectiveness (Huan et al., 2020). Among the team states, this study focuses on team situation awareness. To be specific, this study started with the question; What team interactions help the team to improve team situation awareness in a human-autonomy team, further which interaction strategies have better efficacy on team performance? It is hypothesized that teams with autonomy have a lack of overall team situation awareness because of the limited ability to understand autonomy (Demir et al., 2017). Thus, the mechanisms to improve team situation awareness are needed based on the understanding the interaction between human and autonomy teammate. Specifically, this study focus on the situation awareness of three human teammates in the context of a larger human-autonomy team.

Communication in Team

Teams need to share information about other team members and situations to accomplish the common goals and act jointly (MacMillan, Entin, & Serfaty, 2004). Team cognition is based on communication to build and maintain a shared mental model of the situation. Team cognition is observed from communication and coordination patterns (Cooke et al., 2013). Effective team cognition has a communication “overhead” that aligns with the exchange of information between team members. In HAT, human team members are in a highly dynamic environment with a highly automated system causing high cognitive demands (Demir et al., 2017). As a highly dynamic environment goes through change, adaptive team cognition needs continuous coordination through communication. In a human-autonomy team, the autonomy should understand its task and communicate with other team members. By extension, effective human teammates enable them to share the right information or to request information needed at hand via communication (McNeese et al., 2018). However, Demir et al. (2017) revealed that human-autonomy teams had lower team situation awareness and performance than human-human teams because of insufficient information shared.. Thus, communication is a crucial element of team effectiveness.

A work team is defined as a team that members are interdependent and connected to each other in various ways (Humphrey & Aime, 2014; Kozlowski & Ilgen, 2006), and it is increasingly investigated from a network perspective (Park et al., 2020). Stanton et al. (2018) suggested that team communication networks are associated with team performance and workload in all-human and human-autonomy teams in a command-and-control task. Most of network studies are devoted to how the centralization was associated with team-level outcomes. Park et al. (2020) defined network centralization as "a measure of the extent to which ties are organized around particular focal nodes". Stuart (2017) revealed that team adaptation is an essential factor of team success, examining how team networks adapt to disruption. For example, when the team faces a novel and disruptive situation, the team with less centralized communication performs better and has flexible problem-solving strategies and information processes. According to Shaw (1964), the flow of information among group members determines the efficiency of the group. Shaw established the network characteristics with persons as positions in the network and communication channels between positions. The communication networks are characterized as two types of networks: centralized and decentralized. The time taken to finish tasks given to teams in one type of structure versus the other is not different, but the number of errors is greater in a decentralized network than in a centralized one (Leavitt, 1951). How the spatial arrangement is constructed among the team members does not affect the group performance; however, the relationship between the team members is important (Christie et al., 1952). The communication patterns used by the group determine the group behavior. For example, the team member in a central position generally sends more messages and demands less time to solve the problem than the team member in a peripheral position. The direction of network difference is determined by the extent of the complexity of the task. When simple problems such as symbol identification tasks are provided, people in centralized networks finish their tasks faster and make fewer errors than in decentralized networks (Leavitt, 1951). In this study, communication patterns will be used as one index of team situation awareness and the effects of interaction strategy trained and mission complexity on team situation awareness will be examined.

Team Interaction Strategy

Interaction strategy is an important factor for team effectiveness. The effective team works as an integrated unit (MacMillan, Entin, & Serfaty, 2004; Gorman, Cooke & Amazeen, 2010). Fussell et al. (1998) showed that discussion of team goals and strategies advanced coordination and performance because it helped members to develop a shared mental model of their tasks and goals.

There are many definitions of team interaction strategy. However, in this study, it is defined as “a team specification of some properties of team interactions (e.g., how, when, with whom) to achieve one or more objectives” (Lematta et al., 2020). Team interaction strategies help members focus on team interdependence, not on a specific tool or capability. Focusing on the team allows improved adaptation across similar team contexts.

Lematta et al. (2020) suggest three objectives for team interaction strategies. The first is improving awareness of teammate behaviors, roles, and responsibilities. Team members possess information about current task allocation, workload, and a reason for their behaviors. Members can exchange information when other agents on the team need it. With this objective, possible information exchanging structures are identified, including when information should be pushed or pulled, or how specific team members receive it from an artificial agent. The second objective for team interaction strategies is managing crew flexibility for changing conditions. Some conditions create performance variabilities, such as changes in team states, environmental changes, and unexpected events. Improving awareness of when adaptation is needed or encouraging the transitions to other roles or responsibilities between team members can increase flexibility. For example, during role handoffs, the responsibility exchange needs to be efficient and understood by each agent (Patterson et al., 2004). Therefore, the strategy is to follow clear and consistent instruction at each stage of a role handoff. The third and last objective for team interaction strategy is understanding and working within the constraints of the new, changed environment. The interaction strategy should aim to identify necessary changes in feedback and control, which help define constraints of a new environment. Then team members generate potential compensations for the changes.

Gorman et al. (2010) compare three training approaches with the goal of training adaptive teams. Adaptive teams can coordinate their actions both under routine and novel conditions in which the teams have not been trained. They perform well under novel task conditions because they change their interactions to align with the change of environment. A challenge of training is how to balance between the training of routine task conditions and training of novel task conditions. Gorman et al. used training approaches including cross-training, procedural training, and perturbation training. In cross-training, team members are trained on other team members' responsibilities and roles. This condition has the benefit of shared knowledge, which helps teams to perform well under stress. In procedural training, team members in complex systems are positively reinforced to follow a procedure each time they encounter the trained conditions. Perturbation training is a form of process training that interrupts standard coordination procedures several times during training, forcing teams to coordinate in novel conditions to achieve their goals. The results showed that procedural training created the least adaptive teams, whereas perturbation training significantly outperformed other training conditions (Gorman et al., 2010). Based on the result of Gorman et al. (2010), the training method was developed based on perturbation training, that is, every team has a chance to handle a unexpected situation.

The current study tests two interaction strategies: (1) an exploratory interaction strategy condition and (2) a procedural interaction strategy condition based on Lematta et al. (2020). Each condition has a different amount of information, and team members are encouraged to communicate with each other about how to complete the mission with the provided information. In the exploratory interaction strategy condition, the team is given brief information about the mission. This includes phase boundary, which indicates the active working area of each phase in which the team can safely navigate. In the procedural interaction strategy condition, the team is given detailed information, including lists of each operator's tasks as well as an active working area. Thus, the team in the exploratory condition needs to communicate how to complete each phase and task allocation more than in the procedural condition, in which task allocation is already provided. This communication should help team members to develop a shared mental model like cross-training in Gorman et al.(2010), and thus the team in the exploratory condition is anticipated to improve coordination and team situation awareness.

Complexity of Tasks

Teams operating in high-risk situations with low error tolerance are more likely to face novel situations full of uncertainty and complexity. To deal with this situation, teams may change their communication structures (Salas, Rosen, & King, 2007). However, in this situation, the time to size up the situation is limited. Therefore, the role of situation awareness is especially important. Situation awareness in this context is considered a continuous process that works as a prerequisite for adjustment to complex situations (Gorman et al., 2006). Task complexity is a difficult concept to define, but most definitions have the following attributes (Brown & Miller, 2000): (1) the amount of information to complete the task (Kelly, Futoran, & McGrath, 1990); (2) the number of subtasks that require specific knowledge and skills (Wood, 1986); (3) task uncertainty when there is a lack of information regarding the task and potential solutions (Volkeme, 1988); and (4) the number of goals and pathways to them (Kelly et al., 1990; Segal, 1982).

In general, situation awareness is expected to increase with the decreasing complexity. The communication patterns combined with the task complexity affect the team situation awareness. The team in decentralized communication patterns perform better on high complex tasks than the team in centralized communication pattern. Thus, The decentralized communication pattern, along with the complex task, improves situation awareness relative to the centralized condition.

Situation Awareness

Situation awareness (SA) is “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future” (Endsley, 1988). It consists of three levels. The first level is perception, which means the operators need to be aware of the important pieces of information relevant to the situation currently happening around them. Comprehension, level 2, processes the perceived information and interprets and evaluates it with knowledge in long-term memory. By integrating the information, operators can confirm if the information affects their goals or not. Level 3, projection, helps the operator decide what will happen in the near future through comprehension of different situations and mental models, which help simulate potential near-term outcomes. In a dynamic environment, SA can be summarized as a person’s knowledge of task-related events (Nguyen et al., 2019). Relevant to the current project, unmanned systems are usually teleoperated or semi-autonomous, and they depend on human operators’ interaction and control. Unmanned vehicles (UVs) are usually located remotely where human operators cannot reach, so human operators are limited in their ability to understand the vehicle’s surrounding environment (Nguyen et al., 2019). Also, circumstances in which one person operates multiple UVs, or multiple personnel operate a single UV are cognitively demanding to human operators. Yet, in the mission with UVs, the operator’s situation awareness about the environment and UVs’ state is essential to proceed with the mission even though it is hard to obtain.

Many of these work environments that rely on situation awareness also rely on team performance; for example, 70% of air accidents/incidents worldwide are caused by flight crew action resulting from the loss of SA (Helmreich & Foushee, 1993). When the flight crew's mental model differs from reality, they lose awareness of the situation, and it sometimes leads to accidents/incidents (Nguyen et al., 2019). With the development of the situation awareness theory with systems thinking, theoretical models of SA subdivide into individual, team, and system levels. Individual situation awareness focuses on how individuals obtain SA cognitively while they carry out their tasks. It helps to understand the process of how individuals develop awareness (Endsley, 2015).

SA in the team perspective can be defined as "the degree to which every team member possesses the situation awareness required for his or her responsibilities" (Endsley & Jones, 1997). In this view, SA includes shared SA requirements, which means, in a decentralized command and control (DC2) environment, each team member has an independent task requirement as well as system coordination demand to contend with – creating overlapping requirements among team members. In this approach, team SA is measured by querying the individuals and summing the outcomes of an individual's response, in other words, shared SA is performance-based SA.

Although evaluating individual SA in team members is important to measure team SA, it is not enough. Gorman et al. (2006) said SA is a continuous perception where the ongoing activity is essential to what needs to be perceived while adapting to external constraints. Thus, action and perception are closely related, especially in a highly dynamic situation with no time to reflect on the situation; that is, SA is coordination-based adaptation process. They assumed that the team DC2 environment is naturally dynamic, so team coordination changes over time. Thus, when the team has good team SA, the team can handle unexpected events through team coordination better than the team with relatively bad team SA. They suggested a process-based team SA assessment named 'Coordinated awareness of situations by Teams (CAST).' CAST does not require a memory retrieval process like other knowledge-based measurements. Instead, it is process-oriented, where team SA can be captured while the team members coordinate for problem-solving.

Before using CAST, five concepts should be identified first: roadblocks, primary perceptions, secondary perceptions, coordinated perceptions, and coordinated actions. Roadblocks are unexpected events that force a team to arrive at an adaptive and timely team-level solution. Primary perceptions are when one or more team members in the DC2 environment perceive the roadblock and respond to it. For secondary perceptions, the team member who perceives the roadblock first interacts with others who have diverse aspects of the environment to experience the roadblock in new ways. For coordinated perceptions, the team provides a reciprocal effort to discuss what they perceived to put together the situation, which is more than the aggregation of individual awareness. Based on coordinated perceptions, coordinated actions come out. Often team members' actions are limited by others' actions and the situation itself, so team-level coordinated action is needed. The CAST focuses on the patterns of coordinated interaction and based on it, can assess team cognition.

CHAPTER 3

PROJECT OVERVIEW

This study is inspired by three research questions. First, does the communication strategy affect team effectiveness from the perspective of team situation awareness? Second, does the complexity of tasks affect team effectiveness from the perspective of team situation awareness? Lastly, could interaction-based metrics regarding team situation awareness be a valid predictor of team effectiveness?

The study has three hypotheses:

H1: Exploratory interaction strategy results in high team situation awareness, compared to the procedural interaction strategy.

H2: More complex tasks are associated with lower team situation awareness.

H3: The exploratory interaction strategy condition mitigates the impact of task complexity on situation awareness compared to the procedural interaction strategy condition.

This study aims to compare effective team interaction strategies for the training in the NGCV setting. In other words, two different interaction strategies may cause different team situation awareness, and be heavily reliant on the communication networks formed as a result of the strategy. In decentralized networks the team shares the information more evenly than in centralized networks, improving team effectiveness. In the exploratory interaction strategy condition, the team is provided ambiguous task information, which makes the team discuss its tasks and share the environmental information. In this condition, the team usually forms decentralized communication networks, and needs to discuss who will do what and what kind of information is needed to share. These discussions help team members understand one another’s responsibilities. Thus, the decentralized communication pattern shown in the exploratory condition helps to improve team situation awareness.

In comparison, the team is provided the detailed task information in the procedural interaction strategy condition, which allows the team member in the central position to lead the mission. Having a single person lead the mission might decrease the team situation awareness. This is because the other teammates generally do not pay attention to group communication and have a low understanding of the tasks of others around them.

The performance of the team on the tasks is the result of an interaction between the communication structure and task complexity (Shaw, 1964). The centralized team performs better in simple tasks, but when the task is complex or when the information is ambiguous, a decentralized team performs better. In a task of lower complexity, the team might minimize the communication. If the operators know what they need to do and finish their tasks by themselves with minimum engagement from the coordinator, the centralized networks are developed while centered around the coordinator. However, in a highly complex situation such as an unexpected event or one that required fast decision making, a team needs to discuss their task and utilize the environmental information; sometimes the team needs external support. The complex situation maximizes the communication and develops the decentralized networks. Thus, the more complex the tasks are, the better team situation awareness will be, and particularly so with decentralized communications.

When it comes to the combination of either the procedural condition and high complex tasks or the exploratory condition and low complex tasks, the latter might show higher team situation awareness than the former. This is because the behavior of the group and group process has more impact on the communication patterns than the complexity does (Shaw, 1964).

CHAPTER 4

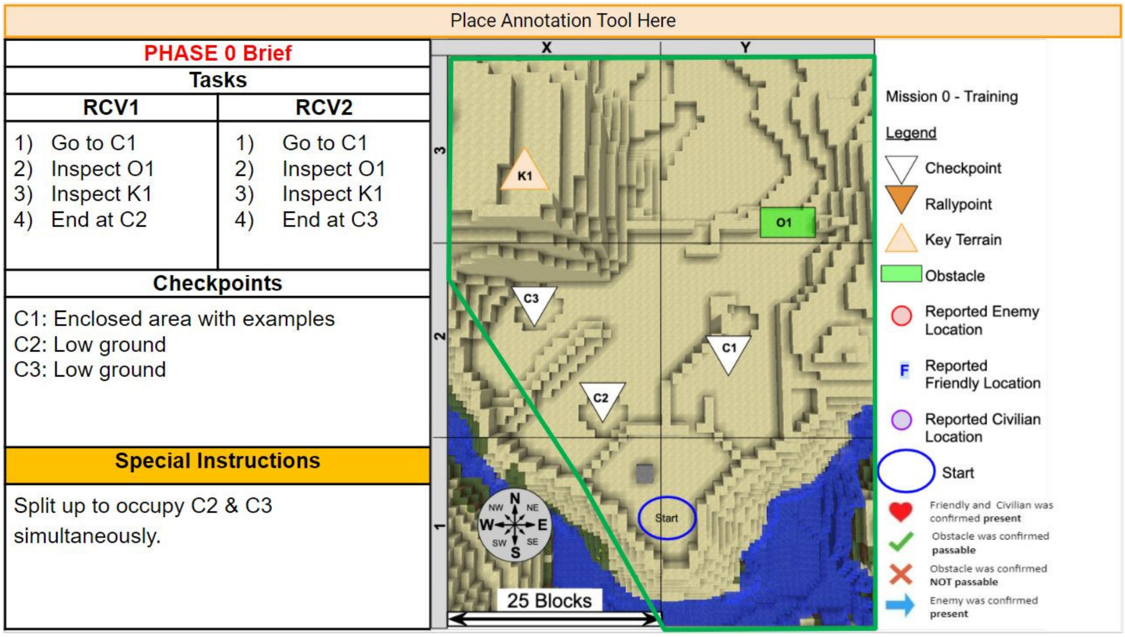
METHOD

Participants

Sixty-nine participants (44 males, 19 females, 2 ‘Do not wish to disclose’ and 4 no answer, M_{age}= 21.4, SD_{age}=3.2) were recruited from Arizona State University and the surrounding area. Participants were required to have computer gaming experience, feel comfortable playing video games using a keyboard and mouse, have a computer that can run Zoom and game streaming programs, and work in a quiet and uninterrupted environment. Additionally, they were expected to be at least 18 years old, fluent in English, and have normal or corrected-to-normal hearing and vision. A team was randomly assigned to one of the two conditions. Twenty-three teams completed the experiment, with eleven teams in each condition, and one team was removed from the dataset because it could not finish the experiment due to technical difficulty. Teams were composed of two operators and one coordinator and each participant was randomly assigned to each role. Each participant was compensated $15 per hour.

Material and Design

This study had two communication strategy conditions: procedural interaction strategy condition and exploratory interaction strategy condition (Figure 1 and 2). In each mission, the team of three participants conducted two missions composed of three phases each. During the mission, participants needed to finish their tasks to end the mission successfully, and the complexity varied with phases. In both conditions, before starting the mission, the team had 3 minutes during a task brief session to check the boundary of the active working area for each phase, examine checkpoints and special instructions, and to discuss how to take on the tasks. In the exploratory interaction strategy condition, the team received rough instructions of tasks to encourage exploration of variable solutions. However, in the procedural interaction strategy condition, the team received detailed instructions of tasks by roles.



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PHASE 0 Brief

Tasks

RCV1	RCV2
1) Go to C1 2) Inspect O1 3) Inspect K1 4) End at C2	1) Go to C1 2) Inspect O1 3) Inspect K1 4) End at C3

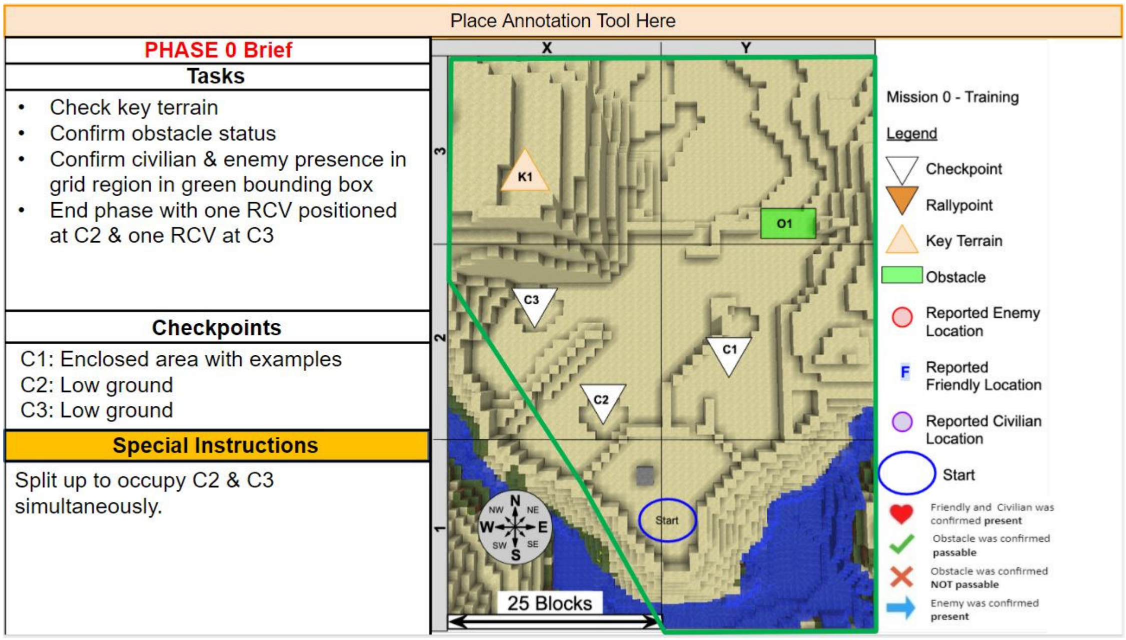
Checkpoints

C1: Enclosed area with examples
C2: Low ground
C3: Low ground

Special Instructions

Split up to occupy C2 & C3 simultaneously.

Figure 1. *Example of the Instructions for the Procedural Conditions*



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PHASE 0 Brief

Tasks

- Check key terrain
- Confirm obstacle status
- Confirm civilian & enemy presence in grid region in green bounding box
- End phase with one RCV positioned at C2 & one RCV at C3

Checkpoints

C1: Enclosed area with examples
C2: Low ground
C3: Low ground

Special Instructions

Split up to occupy C2 & C3 simultaneously.

Figure 2. *Example of the Instructions for the Exploratory Conditions*

Roles

The team consisted of 2 roles: 1 Coordinator (Blue 6) and 2 Operators (Blue 1 and 2; Figure 2). The coordinator (Blue 6) was responsible for keeping track of the team's progress and ensuring that the team was successful by calling support and providing oversight. Coordinators were using a full map of the environment but could not see the battlefield directly. The coordinator's goals were staying aware of operators' tasks, making sure any special instructions for the mission are accounted for, calling external support (Blue7) including maintenance support and artillery, and reporting events to the commander. Operators (Blue 1 and 2) were reconnaissance patrol teams who inspected the battlefield for hidden obstacles, enemies, and other infantry that could impact operations. The operators should eliminate as much of the enemy as possible. Operators were assigned to complete battlefield missions with unmanned combat vehicles called Robotic Combat Vehicles (RCVs), which helped them to search for targets, and focused primarily on moving the RCV safely around the battlefield, searching for targets and inspecting the environment, and communicating and coordinating with the team.

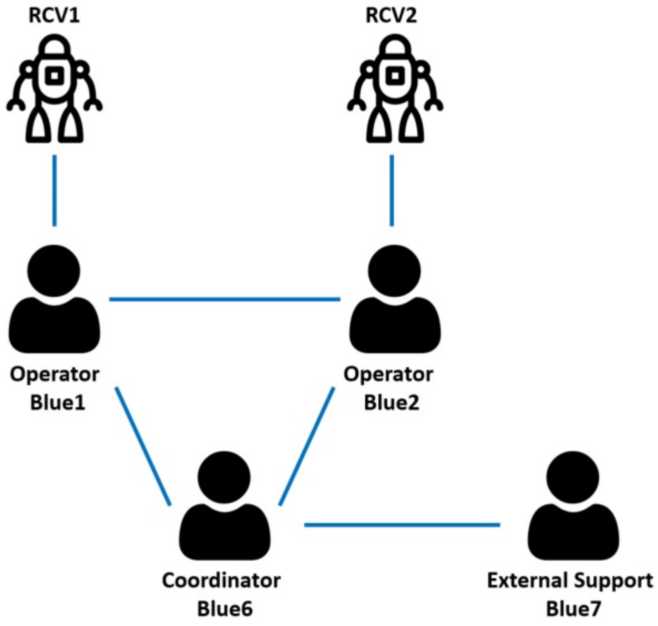

Figure 3. *Team Composition*

Complexity

In the study, there were three phases for each mission, and there were two missions in total. The purpose of the mission was thoroughly inspecting the battlefield and making sure the battlefield is clear from the enemy. The phases were divided by the position of the battlefield between the start and end points of the mission. In the mission, the complexity was varied with phases and it was classified after the experimental design was done. There were three levels of complexity: low, medium, and high. Complexity was determined by four criteria: (1) time limit of the phase; (2) number of tasks in the phase; (3) number of hidden targets and perturbations; (4) number of special instructions.

On these criteria, each phase was scored, and the complexity was determined based on the scores.

The time provided to the team to complete the phase varied from 10 to 16 minutes and converted into one point per minute. The number of tasks of each phase also converted into one point per task, and the number of tasks in each phase was divided by the location (each phase had a different number of tasks). The hidden target was the enemy or civilian who does not appear in the provided map, but that the coordinator needed to mark based on the operators' report. One hidden target also counted as one point. Perturbation is "an extrinsic application of force that briefly disrupts a dynamic process, forcing the reacquisition of a new stable trajectory, and is typically used to probe the stability of that process" (Gorman, Amazeen & Cooke, 2010). It was an unexpected event, for example, the first perturbation of the mission was that one of the RCVs got blind when they evacuated the civilian. To overcome this event, the other RCV should lead the blind RCV to the extraction site. The perturbation counted as two points per event. The special instruction is needed to be handled prior to other regular tasks and included prerequisites for the task, or detailed information about how to handle the specific tasks (see special instructions section in the interface shown in Figures 1 and 2). It is one point per each special instruction. Based on the above criteria, the complexity was calculated by phase (Table 1) and divided into three levels, 2 phases per level (Table 2). Phase 1 and 3 in Mission 1 were the least complex phases. Phase 2 in Mission 1 and Phase 1 in Mission 2 had a medium level of complexity, and Phase 2 and 3 in Mission 2 were the most complex phases.

Table 1. *Complexity Scores of Each Phase*

Criteria	Phase		
Mission 1	**Phase 1**	**Phase 2**	**Phase 3**
Time limit	10 min	12 min	12 min
# of tasks	8 tasks	10 tasks	7 tasks
# of hidden targets and perturbations	2 hidden targets	2 hidden targets	1 hidden target, 1 perturbation
# of special instructions	1	1	1
Total scores for Mission 1	21	25	23
Mission 2	**Phase 1**	**Phase 2**	**Phase 3**
Time limit	12 min	16 min	12 min
# of tasks	11 tasks	10 tasks	12 tasks
# of hidden targets and perturbations	None	3 hidden targets, 1 perturbation	1 hidden target, 1 perturbation
# of special instructions	2	1	3
Total scores for Mission 2	25	32	30

Table 2. *Level of Complexity*

Mission	*Phase1*	*Phase2*	*Phase3*

1	Low Complexity (21)	Medium Complexity (25)	Low Complexity (23)
2	Medium Complexity (25)	High Complexity (32)	High Complexity (30)

Note. Numbers in parentheses indicate the complexity score of each phase.

Team Situation Awareness

Team situation awareness was measured in two ways: performance-based TSA and process-based TSA. Performance-based TSA measures how each team member is aware of their independent task requirements and system coordination, such as their overlapping requirements (Endsley & Jones, 1997). Performance-based TSA was a direct result of team communication on how to complete the team's tasks. In this study, performance-based TSA was captured in two ways: SAGAT (Endsley, 1988; 2017) and coordinator's map accuracy. SAGAT was implemented in the second phase of each mission at random after requesting the artillery call. SAGAT was used to measure the performance-based team situation awareness by summing the individual situation awareness. The mission was paused for the team and each team member was asked to answer the SAGAT questionnaire via Qualtrics and discussion between the team to get an answer was not allowed. The individual situation awareness questionnaire included modified questions asking team status and other team members' task progress. The SAGAT questionnaire (see Appendix A) consisted of 8 questions on Mission 1 and 9 questions on Mission 2, reflecting three levels of situation awareness. Unlike traditional SAGAT measures, there was a fixed set of questions, though those differed by the mission. The questionnaires were developed based on Redden, Elliott, Turner, and Blackwell (2005) and adapted to the mission with the help of a human factors expert. When the participants correctly answered an SA question, they got one point with the maximum points being 20. Individuals' SAGAT scores were calculated and the average score across the team members was the team score. The average team score was compared across the conditions.

For the second method of scoring performance-based TSA, the accuracy of the coordinator's map was scored. During the mission phase, coordinators had a map of the battlefield, and they were required to mark targets on the map when operators reported it. The marks were made by the report of operators and feedback of external support, so it reflected the level one and two of situation awareness. The marks were wiped out at the end of each phase. The accuracy of the coordinator's map was scored for each phase, by comparing the location of targets marked on the map to the battlefield to score the accuracy. If the marks were in the same grid as the actual location of the target, it is considered accurate.

Process-based TSA considers SA as a continuous perception, i.e., action process, rather than a cognitive product; perception follows the action and vice versa. The dynamic environment involves changes and responding to rapidly changing situations requires the adaptation process. Good TSA is more than each team member being individually aware. It is mainly about getting the right information to the right team member at the right time. The CAST measure was created to keep up with changes in the situation, focusing on how team members handle unexpected events that deviated from the common and valued trajectory (Gorman et al., 2006). CAST scoring procedure was composed of listening to team communications when the roadblock was first perceived and checking appropriate boxes on a CAST scoresheet (Figure3). The scoresheet consisted of four components: 1) who was the first team member to perceive the roadblock; 2) which team members discussed the roadblock; 3) which team members were involved in the problem-solving action; 4) whether the team overcame the roadblock or not. After the boxes were marked, the marks were compared to the optimal CAST score sheet, representing the minimum communication flow to solve the problem, and the hit and false alarm rate was calculated relative to ideal. The hits represented that there was a communication to the right person at the right time and the false alarm meant that there was a communication which was not needed. The hit rate was calculated by summing the elements in positions in which the communication should ideally be from the observed vectors and dividing by the total possible number of ideal communications. The false alarm was calculated by summing the elements in the other positions and dividing by the total number of ideal non-communication. The ratio of the number of roadblocks overcome out of total roadblocks were also recorded. Each score was compared by conditions.

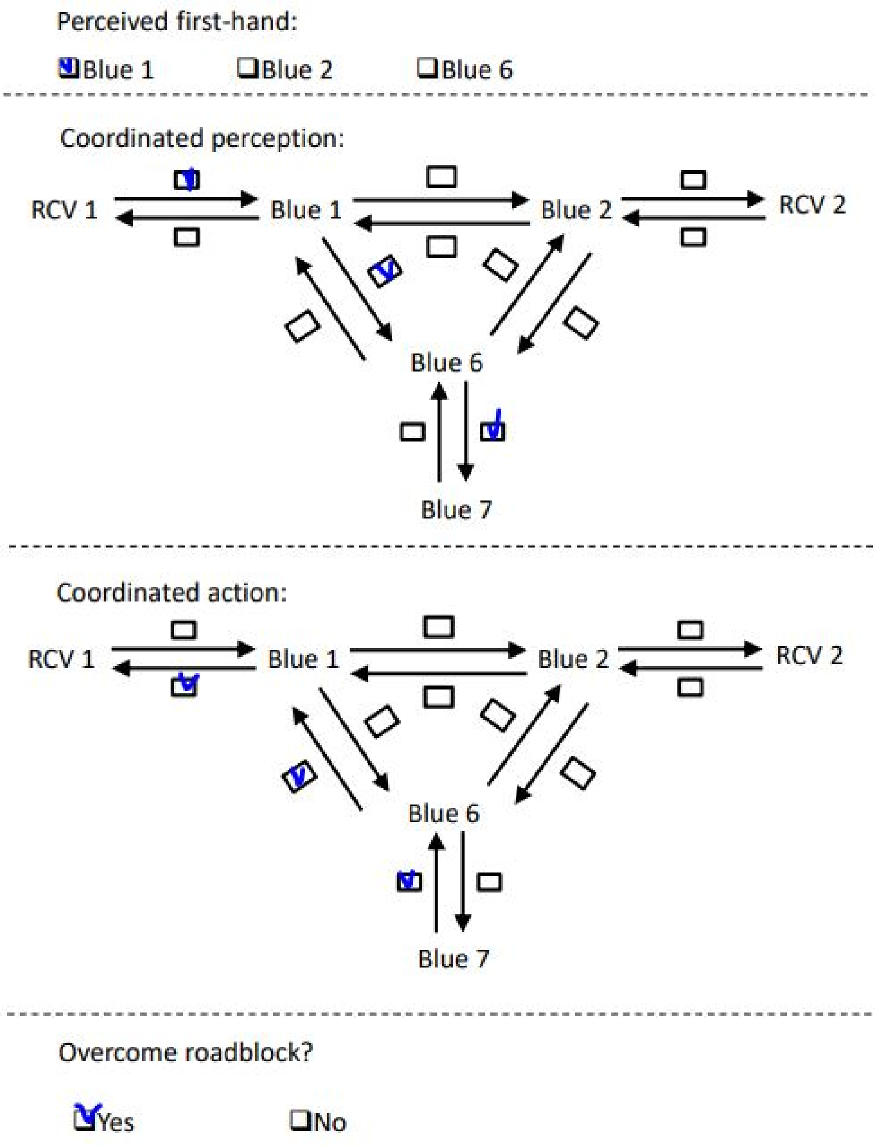

Figure 4. *Example of Scoring CAST*

Procedure

Every participant had a check-in session at least a day before the study to make sure that they did not have any technical problems. In the check-in session, the experimenter checked whether the participants' Zoom and Parsec worked well and that they could use the annotation function on Zoom. After confirming that participants had no technical problem conducting a remote experiment, the check-in session ended.

On the start of the experimental day, every participant was greeted by the research assistants and asked to sign the consent form. If participants agreed on participating, they were randomly assigned to one of two roles: *Coordinator* or *Operator*. The team was then randomly assigned to one of two conditions: the exploratory interaction strategy condition, or the procedural interaction strategy condition. Participants were divided by roles and went to breakout rooms in Zoom with trainers for the slide-based training. After participants understood their responsibility and tasks, they completed the hands-on training to practice the mission in the battlefield context.

Following training, the participants started missions (Figure 4).

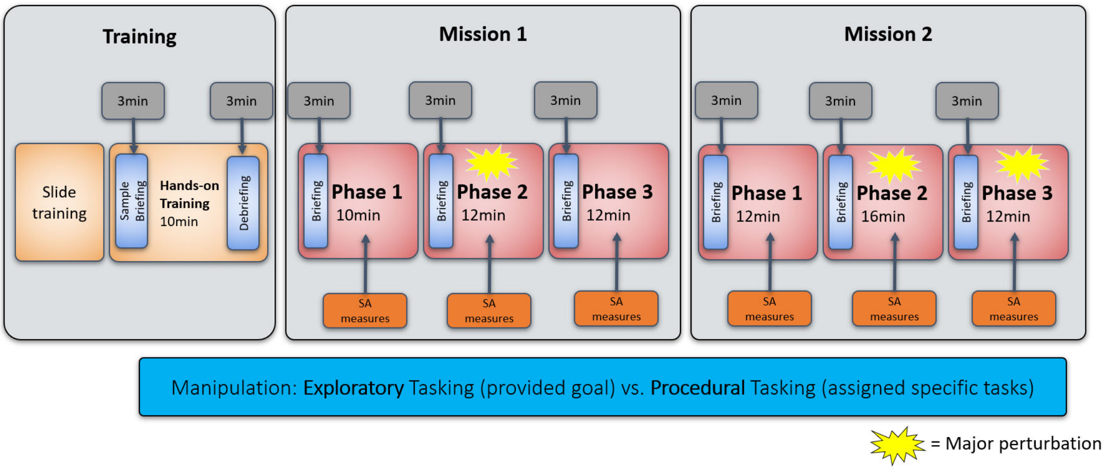

Figure 5. *Timeline of the Study*

Each mission was composed of 3 phases, and before each phase started, the team had a 3-minute briefing session in which they could discuss how to complete the tasks. Each phase lasted about 12 minutes and varied by complexity (and see Table 1). SAGAT was administered twice in total, once per mission, and the administrator paused all the participants during phase 2 on each mission and administered the SAGAT questionnaire. Following mission 2, the demographics questionnaire was administered with debriefing. CAST was scored in every artillery call and perturbation after the study, and the coordinator's map was captured at the end of every phase. Participants were provided a short break between missions if they wanted and compensated at the end of the experiment. After the study, CAST and coordinator's map were scored using the recording of the study, and SAGAT was scored in Qualtrics.

CHAPTER 5

RESULTS

Interaction Effect between the Interaction Strategy and Task Complexity

An interaction effect was expected between the procedural condition and high complexity and the exploratory condition and low complexity. The exploratory condition with low complexity was expected to have improved team situation awareness compared to the procedural condition with high complexity.

Coordinated Awareness of Situation by Teams (CAST)

A 2x3 mixed ANOVA performed on the CAST hit rate revealed that there was no main effect of the complexity ($F(2, 60)= .57$, $p> .05$, $\eta^2=0.02$), but there was a significant main effect of strategy ($F(1,60)= 4.84$, $p< .05$, $\eta^2=0.07$). No significant interaction effect between the strategy and complexity was found ($F(2,60)=1.28$, $p>.05$, $\eta^2=0.04$; see Table 3 and Figure 6).

Table 3. *Means and Standard Deviation of CAST Hit Rate by Task Complexity and Interaction Strategy*

Strategy	**Low**	**Medium**	**High**
Procedural	0.89(0.09)	0.94(0.07)	0.87(0.07)
Exploratory	0.86(0.08)	0.85(0.1)	0.86(0.07)

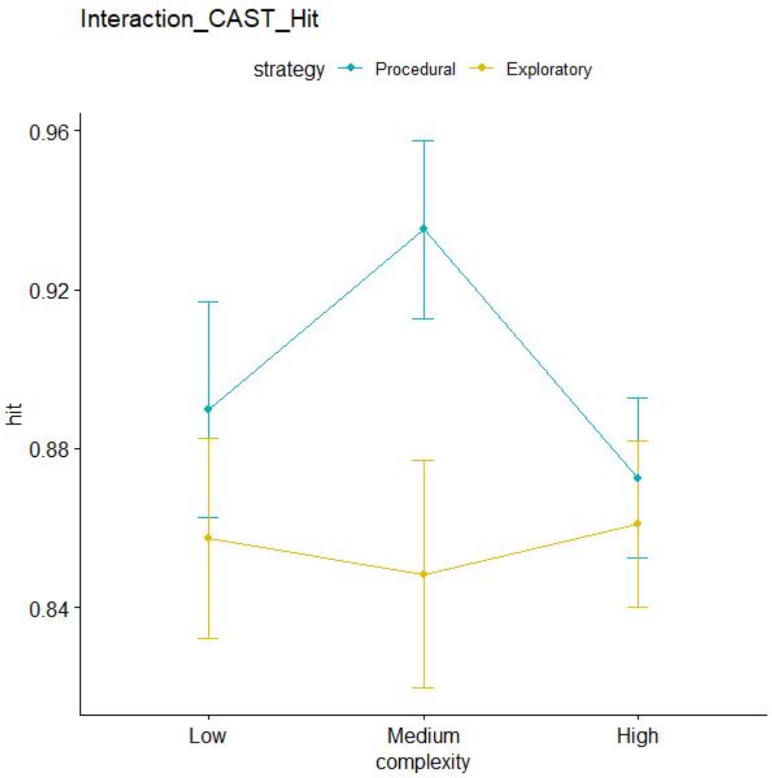

Figure 6. *Interaction Effect of CAST Hit Rate.*

Note. Error bars are standard error.

The 2x3 mixed ANOVA performed on the CAST false alarm data revealed that there is no main effect of the complexity (*F*(2,60)= 1.14, *p*>.05, η^2=0.04) or strategy (*F*(1,60)= .12, *p*>.05, η^2=0.002), and no significant interaction *(F*(2,60)=1.05, *p*>.05, η^2=0.34)(Table 4 and Figure 7).

Table 4. *Means and Standard Deviation of CAST False Alarm Rate by Task Complexity and Interaction Strategy*

Strategy	Low	Medium	High
Procedural	0.10(0.05)	0.11(0.07)	0.12(0.04)
Exploratory	0.14(0.07)	0.09(0.04)	0.12(0.07)

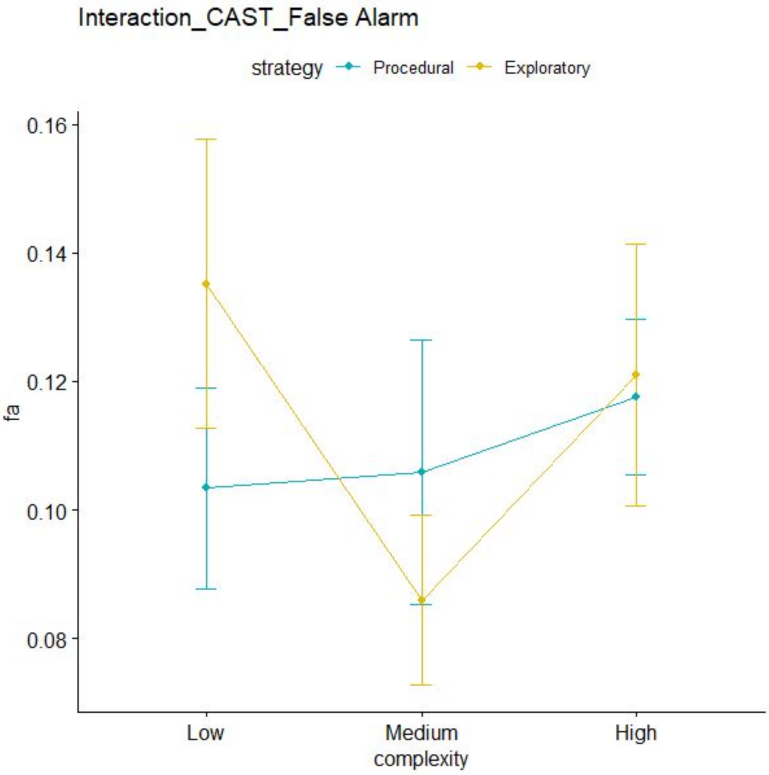

Figure 7. *Interaction Effect of CAST False Alarm Rate.*

Note. Error bars are standard errors.

Team Interaction Strategy. To investigate the main effect of team interaction strategy on CAST, CAST data was divided into the artillery calls, which are regular events and the perturbations, which are unexpected situations, and each CAST data was composed of the proportion of hit and false alarms. The hit implied there was a communication which should have happened, and the false alarm implied unnecessary communication occurred. Shapiro-Wilk's test indicated the artillery call hit and false alarm rate were normally distributed, and Levene's test showed homogeneity of variances across the teams. Two sample t-test performed on the CAST scores for artillery calls revealed the mean hit rate was significantly higher in the procedural interaction strategy

(M= 0.93, SD= 0.05) than the exploratory strategy (M=0.89, SD=0.06; *t*(42)= -3.73, *p*<.001; and see Table 5 and Figure 8).

Table 5.*Means and Standard Deviations for CAST Artillery Call Hit Rate (Averaged Across Teams Between Conditions)*

Interaction Strategy	**Mission**	**Mean (across teams) SA hit Rate**	**SD**	**Number of Events**
Procedural	1	0.96	0.04	5
	2	0.90	0.07	4
	Total	0.93	0.05	9
Exploratory	1	0.90	0.05	5
	2	0.89	0.07	4
	Total	0.89	0.06	9

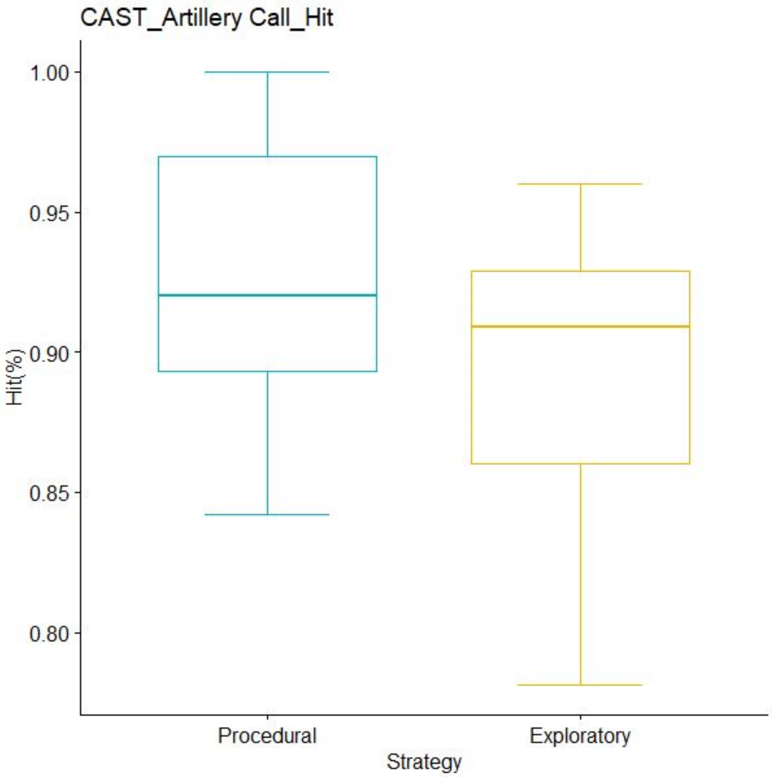

Figure 8. *Average Hit Rate of Artillery Call.*

Also, the mean false alarm rate was significantly different for the two groups. In the procedural condition (M=0.10, SD=0.05), the false alarm rate is lower than in the exploratory condition (M=0.09, SD=0.05; *t*(42)= 3.68, *p*< .001, and see Table 6 and Figure 9).

Table 6. *Means and Standard Deviations for CAST Artillery Call False Alarm Rate (Averaged Across Teams Between Conditions)*

Interaction Strategy	Mission	Mean (across teams) SA False Alarm Rate	SD	Number of events
Procedural	1	0.07	0.04	5
	2	0.13	0.06	4

	Total	0.10	0.05	9
Exploratory	1	0.09	0.05	5
	2	0.11	0.06	4
	Total	0.09	0.05	9

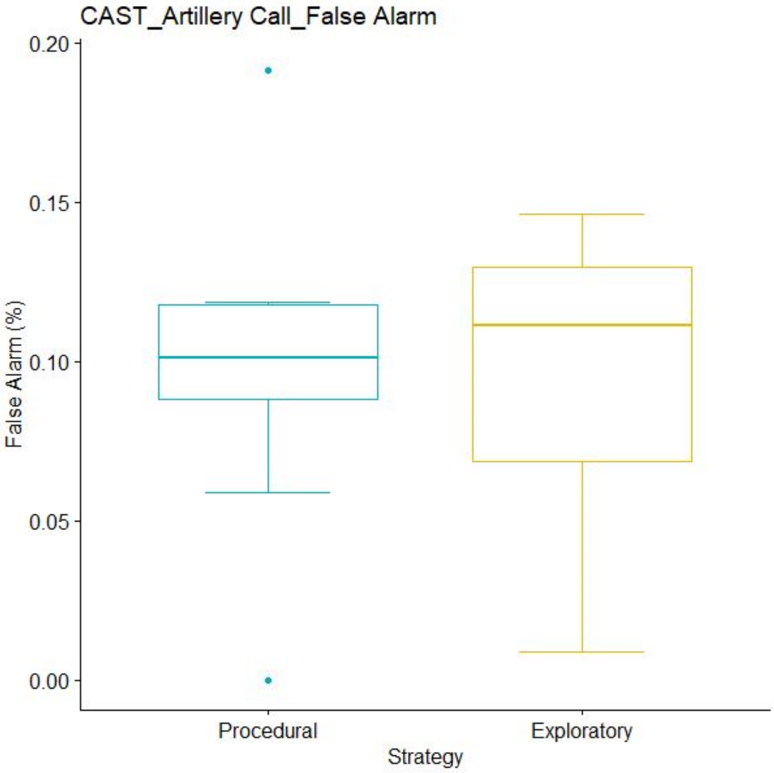

Figure 9.*Average False Alarm Rate of Artillery Call.*

Thus, when it comes to the artillery call, the team in the procedural condition showed higher team situation awareness on CAST than the exploratory condition.

The mean hit rate to perturbations violated normality (Shapiro-Wilk’s $p < .001$), so the Wilcoxon rank-sum test was used, and revealed no significant difference between the two interaction strategies (W=79.5, p>.05) on hit rate to perturbations (Table 7 and Figure 10).

Table 7. *Means and Standard Deviations for CAST Perturbation Hit Rate (Averaged Across Teams Between Conditions)*

Interaction Strategy	Mission	Mean (across teams) SA Hit Rate	SD	Number of Events
Procedural	1	0.79	0.13	1
	2	0.83	0.11	3
	Total	0.81	0.08	4
Exploratory	1	0.76	0.14	1
	2	0.76	0.15	3
	Total	0.69	0.25	4

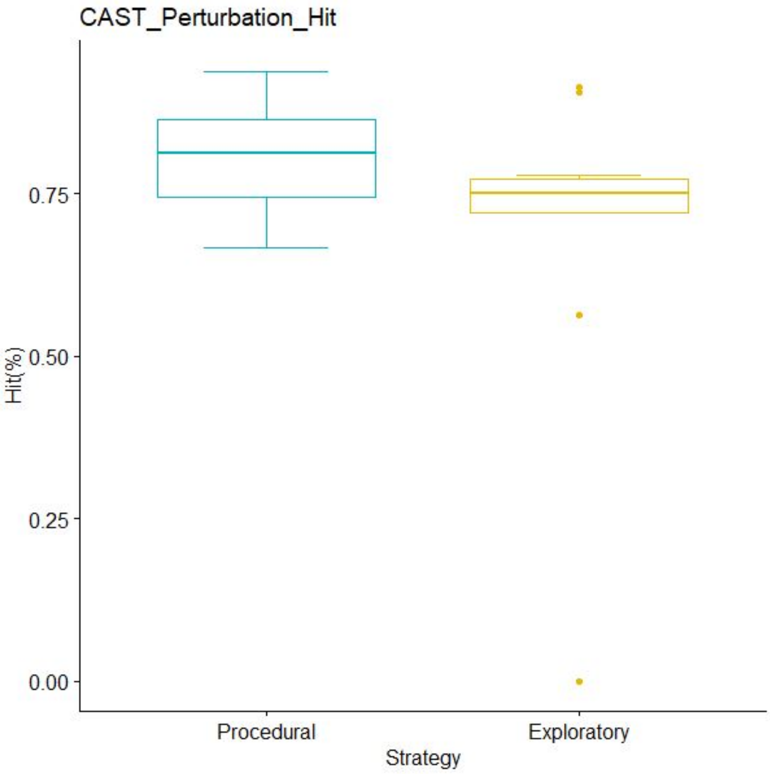

Figure 10.*Average Hit Rate of Perturbations.*

The mean perturbation false alarm rate met all normality and homogeneity assumptions. The result of t-test performed on the false alarm rate to the perturbations showed that the procedural condition (M=0.15, SD=0.05) had significantly lower false alarm rate than the exploratory condition (M=0.19, SD=0.07; *t*(42)= 2.97, *p*= .0049, Table 8 and Figure 11).

Table 8. *Means and Standard Deviations for CAST Perturbation False Alarm Rate (Averaged Across Teams Between Conditions)*

Interaction Strategy	**Mission**	**Mean (across teams) SA False Alarm Rate**	**SD**	**Number of Events**
Procedural	1	0.19	0.10	1
	2	0.12	0.08	3
	Total	0.15	0.04	4
Exploratory	1	0.22	0.09	1
	2	0.18	0.06	3
	Total	0.17	0.09	4

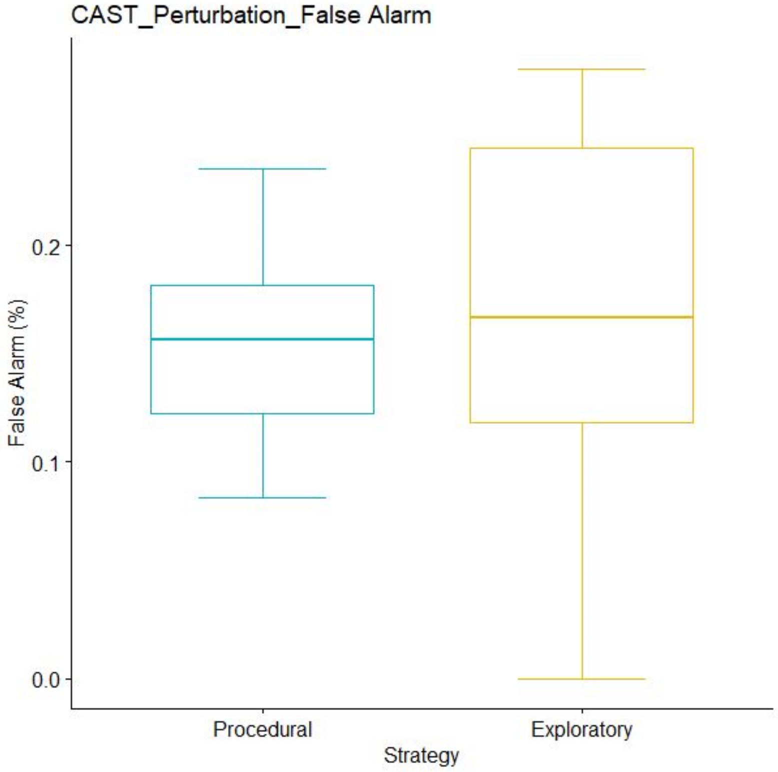

Figure 11.*Average False Alarm Rate of Perturbations.*

Map Accuracy

The 2x3 mixed ANOVA performed on the map accuracy revealed that there is no main effect of the complexity ($F(2,126)= .63$, $p<.1$, $\eta^2= 0.04$) or the strategy($F(1,126)= .13$, $p>.05$, $\eta^2<0.001$), and no significant interaction effect between the strategy and complexity ($F(2,126)=.44$, $p>.05$, $\eta^2=0.01$) (Table 9 and Figure12).

Table 9. *Means and Standard Deviation of Map Accuracy Rate by Task Complexity and Interaction Strategy*

Strategy	**Low**	**Medium**	**High**
Procedural	0.77(0.22)	0.83(0.22)	0.75(0.25)
Exploratory	0.80(0.26)	0.85 (0.23)	0.69 (0.26)

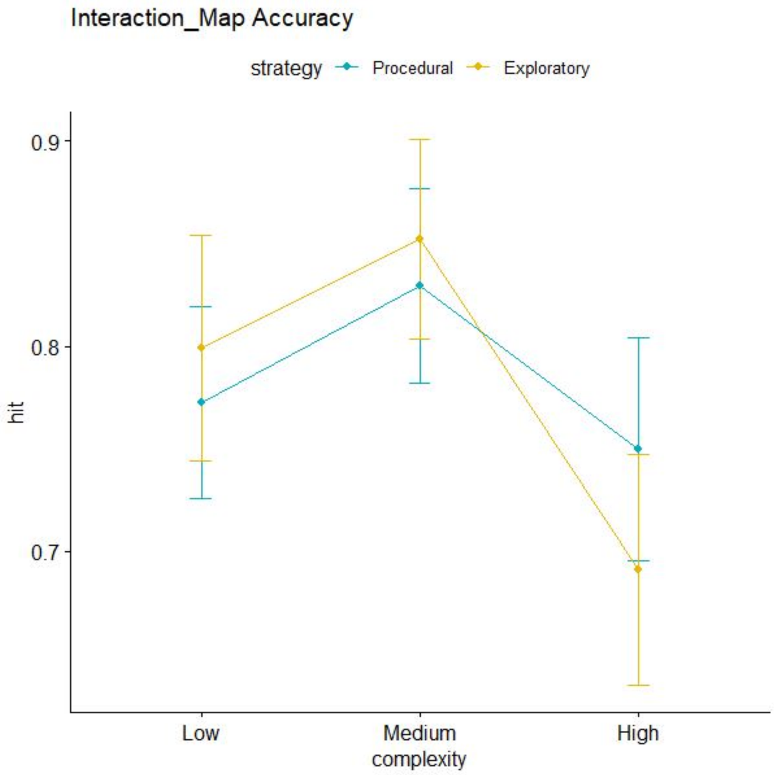

Figure 12.*Interaction Effect of Map Accuracy Rate.*

Note. Error bars are standard errors.

Situation Awareness Global Assessment Technique (SAGAT)

SAGAT scores were used to measure shared team situation awareness across the team interaction strategy condition. A summary of SAGAT scores are provided in Table 2. Shapiro-Wilk's normality test indicated that the scores had a normal distribution. And the result of Levene's test showed that the scores had homogeneity of variances across the teams. A two-sample t-test performed on the SAGAT scores revealed that the mean team SAGAT score was not significantly different when comparing the two communication strategies ($t(20) = .15$, $p>.5$; and see Figure 10 and Figure 13).

Table 10. *Means and Standard Deviations for SAGAT Score (Averaged Across Teams Between Conditions)*

Team Interaction Strategy	Mission	Mean (across teams) SAGAT score	Standard Deviation
Procedural	1	5.61	1.45
	2	7.48	1.05
	Total	13.09	1.54
Exploratory	1	5.00	2.04
	2	6.86	2.87
	Total	11.86	4.70

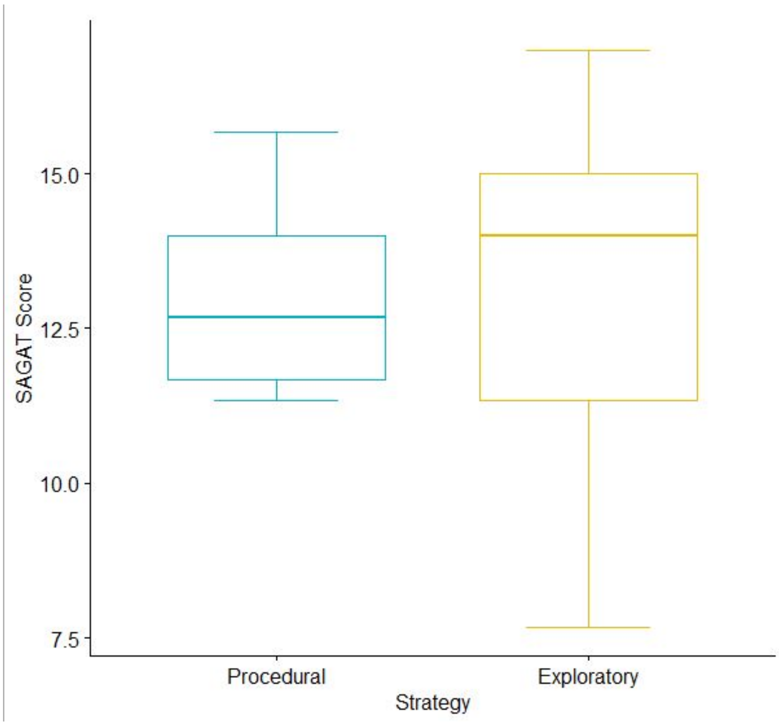

Figure 13. *Summary of SAGAT Scores by Interaction Strategy.*

Exploratory Analysis

Additionally, the correlation between the two situation awareness measurements was analyzed and the result showed that the team SAGAT score and CAST hit rate across the missions were not correlated (*r*(20) = -.22, *p*>.05, Figure 14).

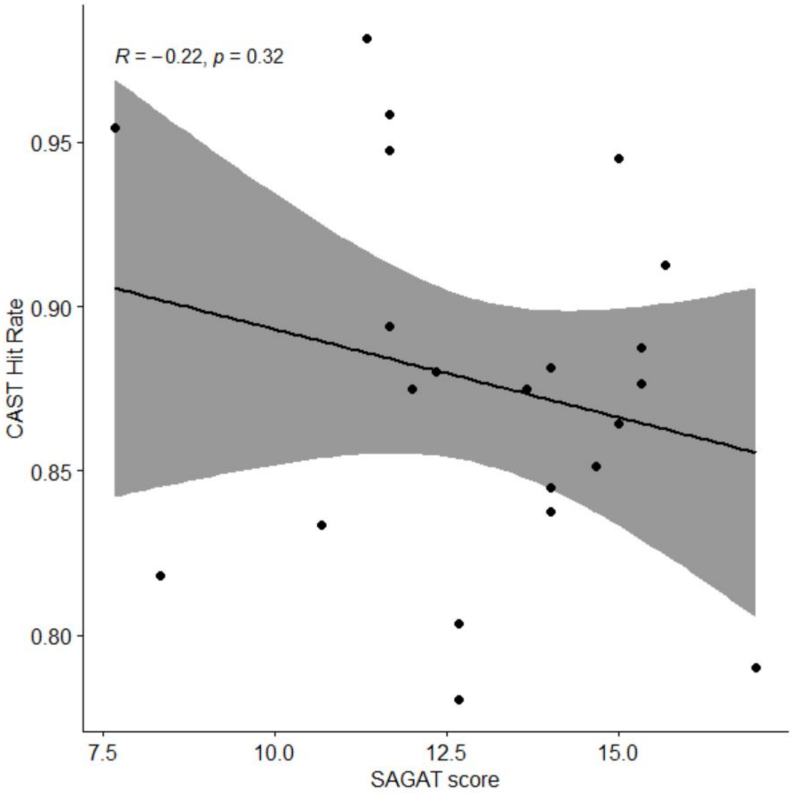

***Figure 14**. Correlation Between CAST Hit Rate and SAGAT Score*

Further correlation analysis was conducted to examine the measures capturing performance. The percentage of roadblocks overcome was used to represent performance, with a total number of 13 roadblocks across the missions. The CAST hit rate across the missions and the percentage of overcame roadblock were not correlated(*r*(20) = -.07, *p* >.05, Figure 15). However, the team SAGAT score and the percentage of overcame roadblock was found to be positively correlated (*r*(20)=.56, *p* <.01, Figure 16).

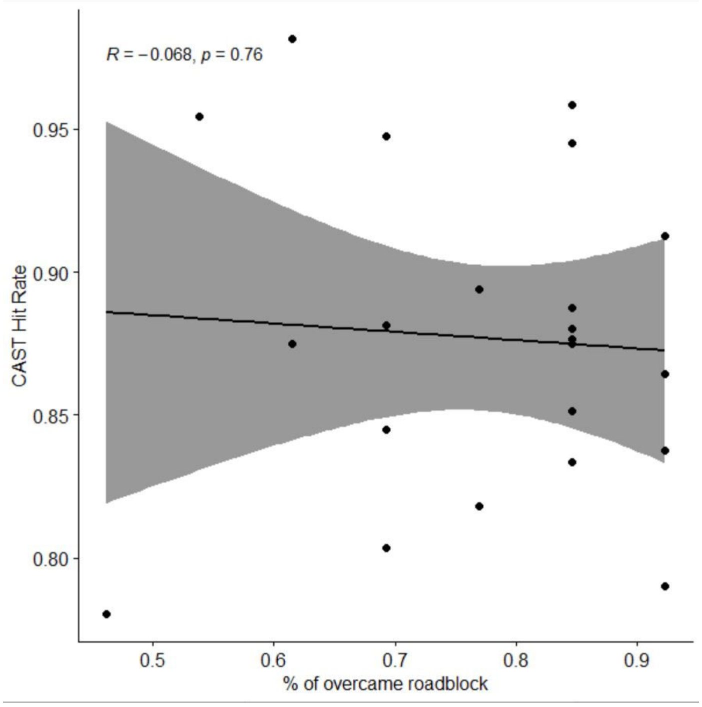

***Figure 15**. Correlation Between CAST Hit Rate and % of Overcame Roadblock*

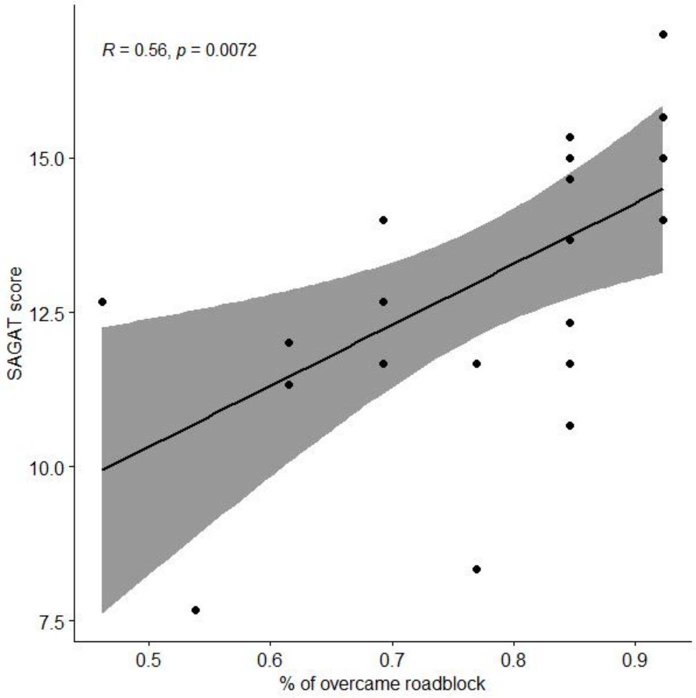

Figure 16. *Correlation Between SAGAT Score and % of Overcame Roadblock*

CHAPTER 6

DISCUSSION

This study aims to find which interaction strategies and levels of complexity help the team to improve their team situation awareness in the context of the Next Generation Combat Vehicle. It is important because the dynamic of environment and team interaction, which is susceptible to small variances, plays an essential role in team efficiency. In the human-autonomy teaming (HAT) context, the quality and frequency of communication affect team efficiency (Fan & Yen, 2011). Additionally, task characteristics affect team performance (O'Neill et al., 2020; Shaw, 1964). Thus, by combining communication networks with the task characteristics, team efficiency can be maximized in the HAT context. In the study, each interaction strategy was expected to provoke different types of communication networks that affect the team performance, e.g., team situation awareness. The exploratory interaction strategy, which was anticipated to produce the decentralized patterns, was expected to possess better team situation awareness than the procedural condition. Instead, better team situation awareness was found for procedural conditions, according to the CAST hit rate on the artillery calls, and the false alarm rate on both the artillery calls and perturbations. However, CAST hit rate on the perturbations, map accuracy, and SAGAT scores failed to reveal any difference between interaction strategies with respect to team situation awareness.

Task characteristics have varied impacts on the team performance. For example, time pressure, one of the components of task complexity, leads to higher workload and a negative impact on team performance (Fan et al., 2010). In this study, task complexity was composed of three levels: low, medium, and high. With the high complex task, the team was expected to show low team situation awareness. However, the CAST hit and false alarm rate and the map accuracy revealed that there is no significant impact of task complexity on team situation awareness.

A team with the centralized communication pattern performs better than the team with the decentralized pattern when the tasks are simple (Shaw et al., 1957). In the current study, the team in the exploratory condition that handles the easy tasks was expected to have higher team situation awareness than the team in the procedural condition that handles the complex tasks. However, no significant interaction effect of the interaction strategies and task complexity was found according to the CAST hit and false alarm rate, or map accuracy. In fact, the main effect of the CAST hit rate showed the procedural condition had better team situation awareness than the exploratory condition, the opposite of the predicted effect. To be specific, teams in the procedural condition shared essential information on right time with right teammates.

Limitations

There were several limitations for this study. Firstly, the task complexity was not properly manipulated when the experiment was designed. Instead, it was classified with the criteria mentioned after the fact. Even though the complexity was divided into three levels, the mean score difference between low and medium conditions was only 3 points, and it was 6 points between high and medium conditions (Table 2). Also, both the CAST rate and map accuracy for the task complexity did not satisfy the normality assumption, and both distributions were positively skewed. Thus, the complexity was not manipulated enough to bring about a significant difference among the complexity levels. Moreover, the complexity was mixed with procedural and exploratory strategies when the CAST rate was divided into the artillery calls and perturbations. The artillery call and perturbation themselves already possess the characteristic of task complexity. In other words, the task complexity was confounding when the CAST data were analyzed with respect to the interaction strategies. From the task complexity point of view, the artillery call and perturbation had different characteristics. The artillery call was a simple task because it was repeated, which means the teams had a chance to train themselves during the mission. On the other hand, the perturbation was a complex task because it was unexpected and required cooperation among team members. There is evidence that difficult tasks can cause less communication due to a lack of time to communicate (Wright & Kaber, 2005). Thus, it is plausible that the perturbation along with the time pressure disrupted any team interaction strategy effects on the team situation awareness.

Another limitation is the ceiling effect of the map accuracy. This effect was confirmed by the graph (Figures 17 and 18), and the distribution of the accuracy rate was positively skewed.

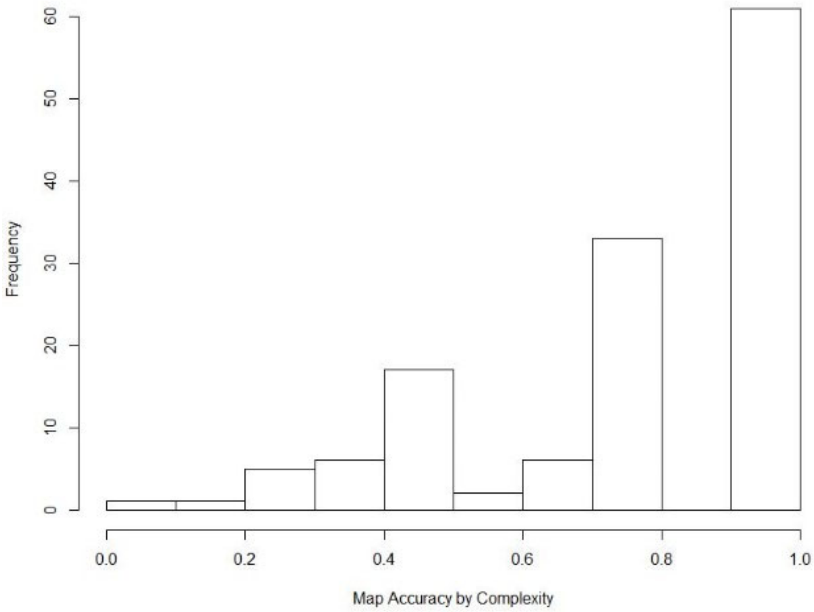

Figure 17. *Histogram of Map Accuracy by Complexity*

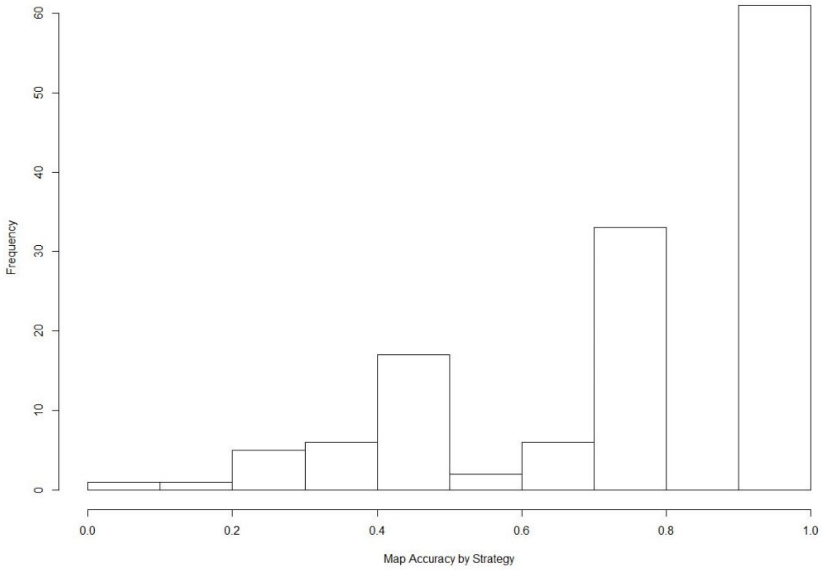

Figure 18. *Histogram of Map Accuracy by Strategy*

The map accuracy was measured by comparing the coordinator's marks on the map and the real battlefield, and each phase required an average of four marks. The map already had the location references, so the team just needed to confirm whether the map was correct or not. The reporting from the operator to the coordinator about the battlefield information was a regular task that gave the team a chance to get familiar with it. Moreover, regardless of the condition, all teams had the same training and direction about reporting responsibility. This means that, when it came to reporting, there was limited room for the interaction strategies to play a role in the team performance. After all, it made the job easy enough to cause the ceiling effect without making a difference between the variables of interaction strategies and task complexity.

Conclusion

Human-Autonomy Teaming is a burgeoning field of research. This new concept of the team includes an autonomy agent as a teammate, and it causes different aspects of team interaction compared to a human-human team, even though not all team members are not interacting with autonomy agents (Demir et al., 2016; McNeese et al., 2018). Even though this study focused on the communication and interactions among the human team members in the system, the operators interact to the artificial agents (RCVs) and it was expected to impact on the interaction among human teammates. Thus, new training methods and the measurement of performance for the HAT are needed. This study showed a significant effect of the interaction strategies on team situation awareness. Training methods with procedural interaction strategy will help to improve team situation awareness under some circumstances. Future studies should try various media for team communication. This study was conducted on one line of communication that overlapped frequently. The busy line caused a delay of reports and misunderstanding. If different media like chat or multiple independent lines are used, team interaction strategy might have a stronger impact on team situation awareness. Task characteristic is also an important factor of team performance. Even though the complexity did not show the impact on team situation awareness in this study, having levels of task complexity is helpful to see the varied interaction with other variables. For future studies, the complexity should be controlled at the experimental design level.

Given the characteristics of each measure—that CAST captures the process-based situation awareness and the others capture performance-based team situation awareness—the interaction strategies significantly affect team efficiency. The performance-based team situation awareness is considered the sum of the individual situation awareness. On the other hand, the process-based situation awareness represents the team process, and it is a more dynamic concept (Gorman et al., 2006). That is, the process-based situation awareness is closer to team efficiency because it captures more than just a sum of individual situation awareness. It is possible that the team that has a bad individual situation awareness possesses a good team situation awareness.

Additionally, it is helpful to consider increasing the role of the autonomy agent. In this study, the agents only interact with the operators in a limited function. If the team members, including the operator and coordinator, can actively communicate with agents, it is more suitable for the HAT concept. Further, the active engagement of agents will affect the team performance. The team interaction shown in HAT is different from the team interaction in a human-human team and it will show varied aspects depending on the role and the extent of participation of the agent. Future work should continue to pursue an understanding of team situation awareness focusing on the interaction and role of autonomy agent in a human-autonomy team with various performance measures.

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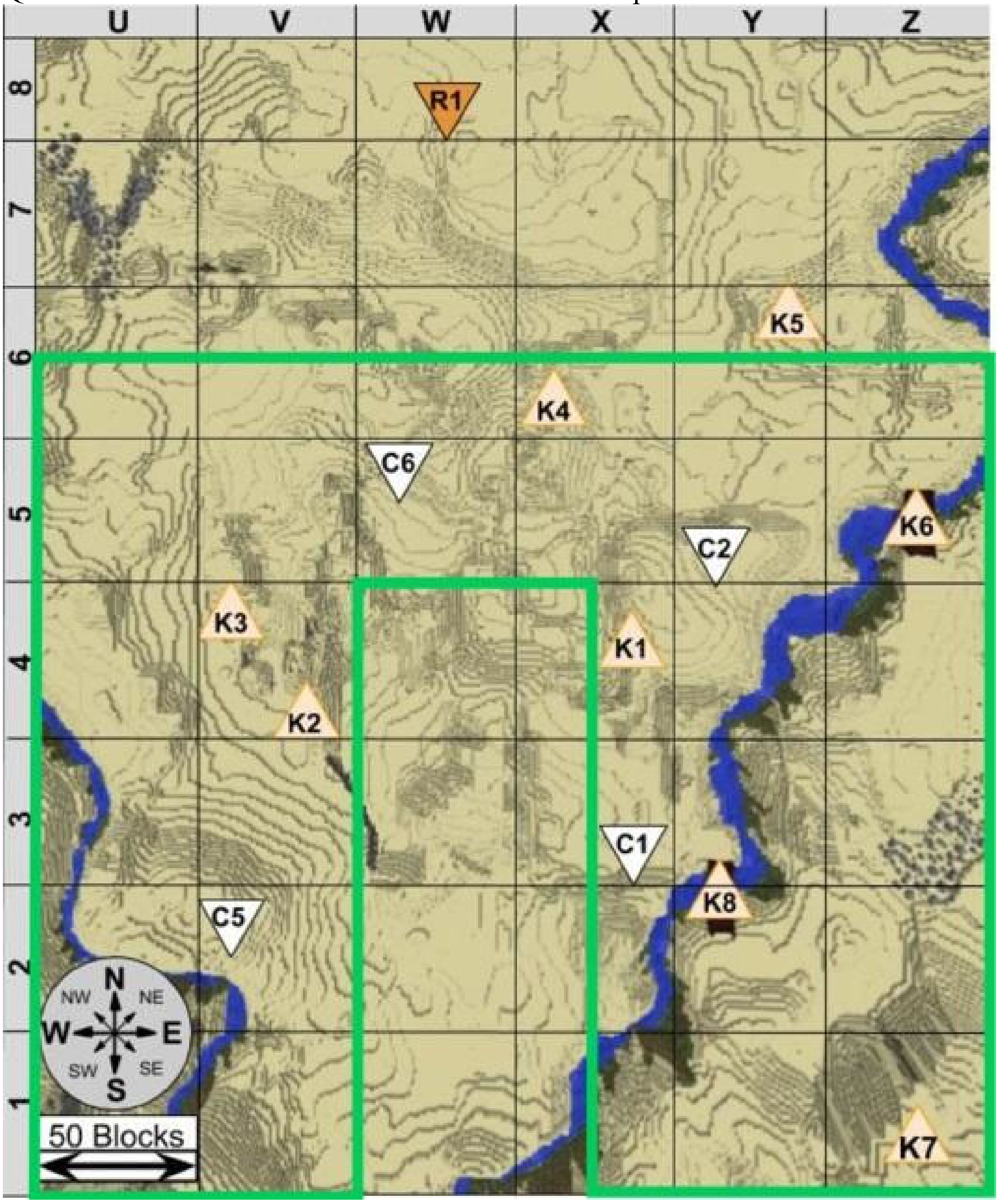
APPENDIX A

SAGAT QUESTIONAIRE

Mission 1 Map Questions

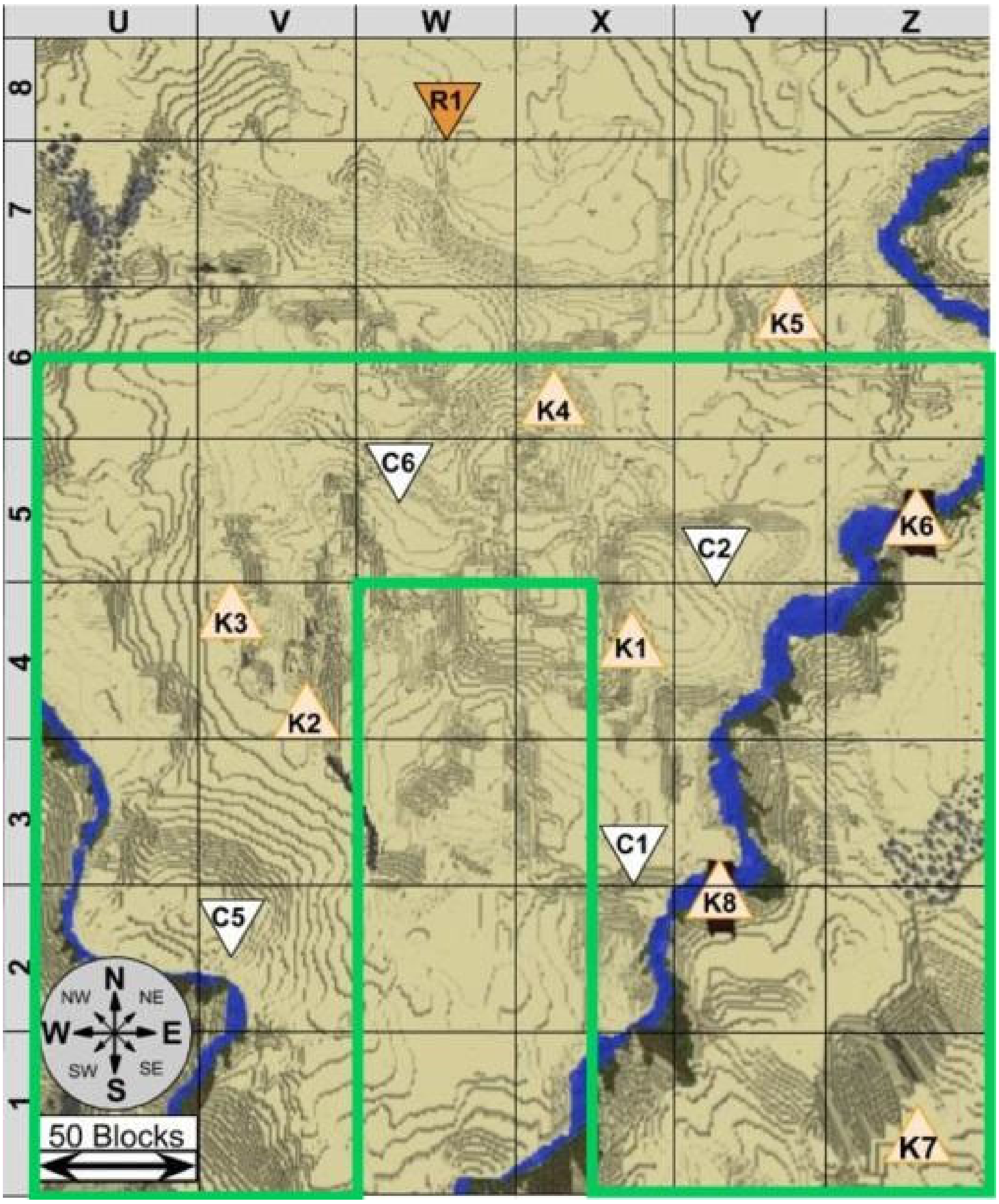
Q784 For the following questions you will be asked to estimate the location of objects within the mission environment on an interactive map. The green outline indicates the bounding box for the current phase.

Q787 Select the current location of **RCV1** on the map



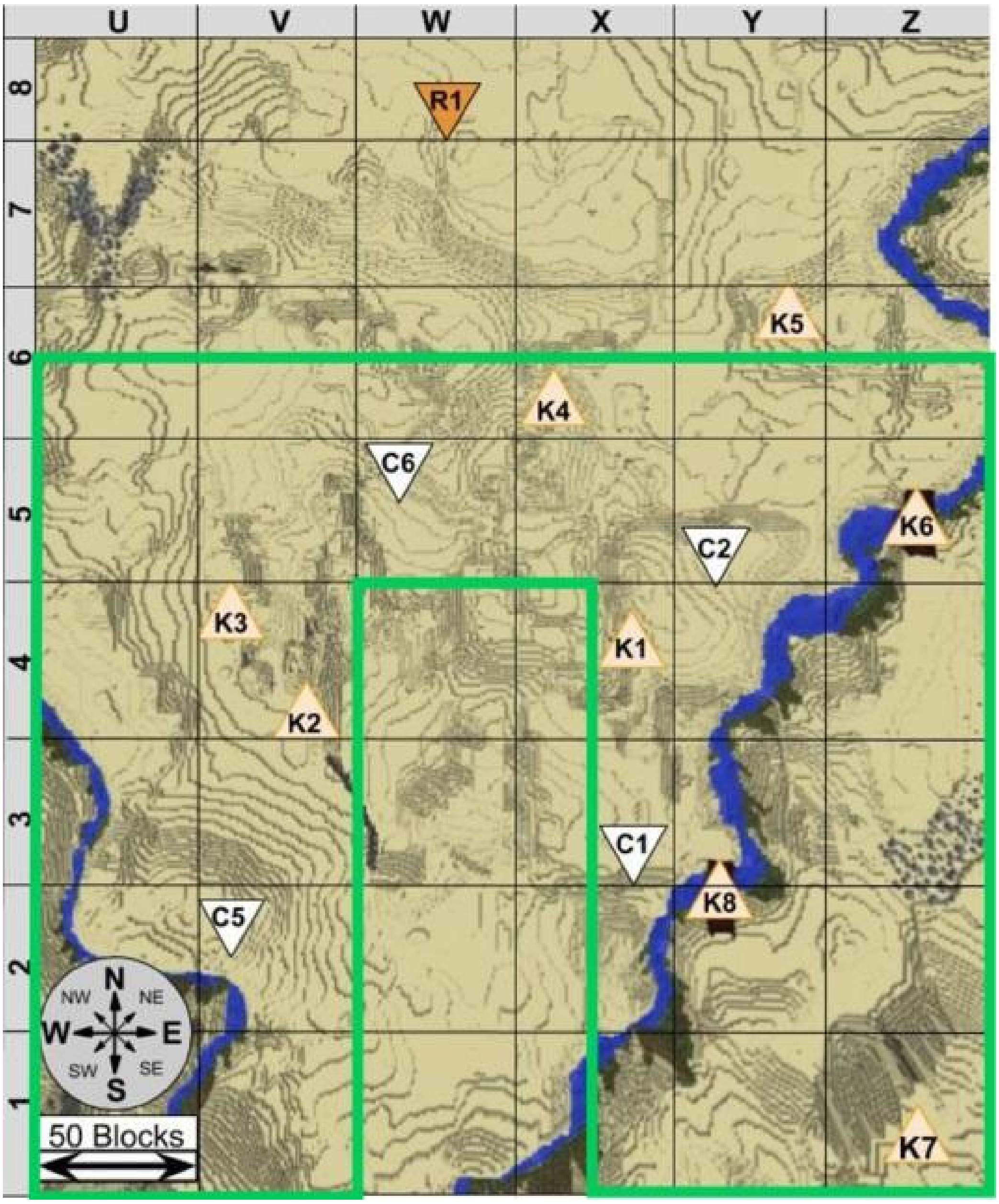
Page Break

Q1022 Select the current location of **RCV2** on the map



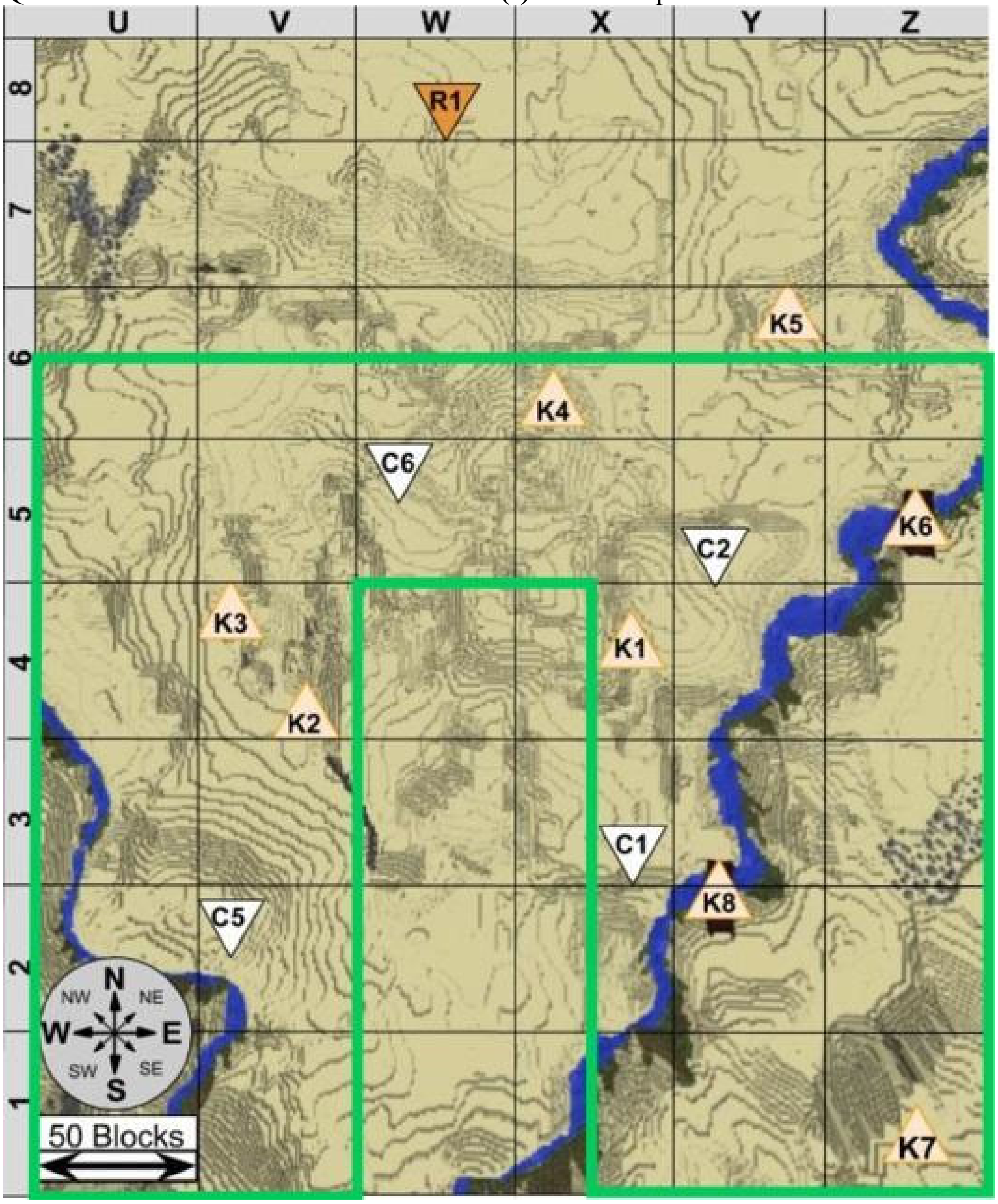
Page Break

Q1023 Select the location of the **passable obstacle(s)** on the map


U
V
W
X
Y
Z
8
7
6
5
4
3
2
1
R1
K5
K4
C6
K6
C2
K3
K1
K2
C1
K8
C5
N
NE
NW
W
E
SW
SE
S
K7
50 Blocks

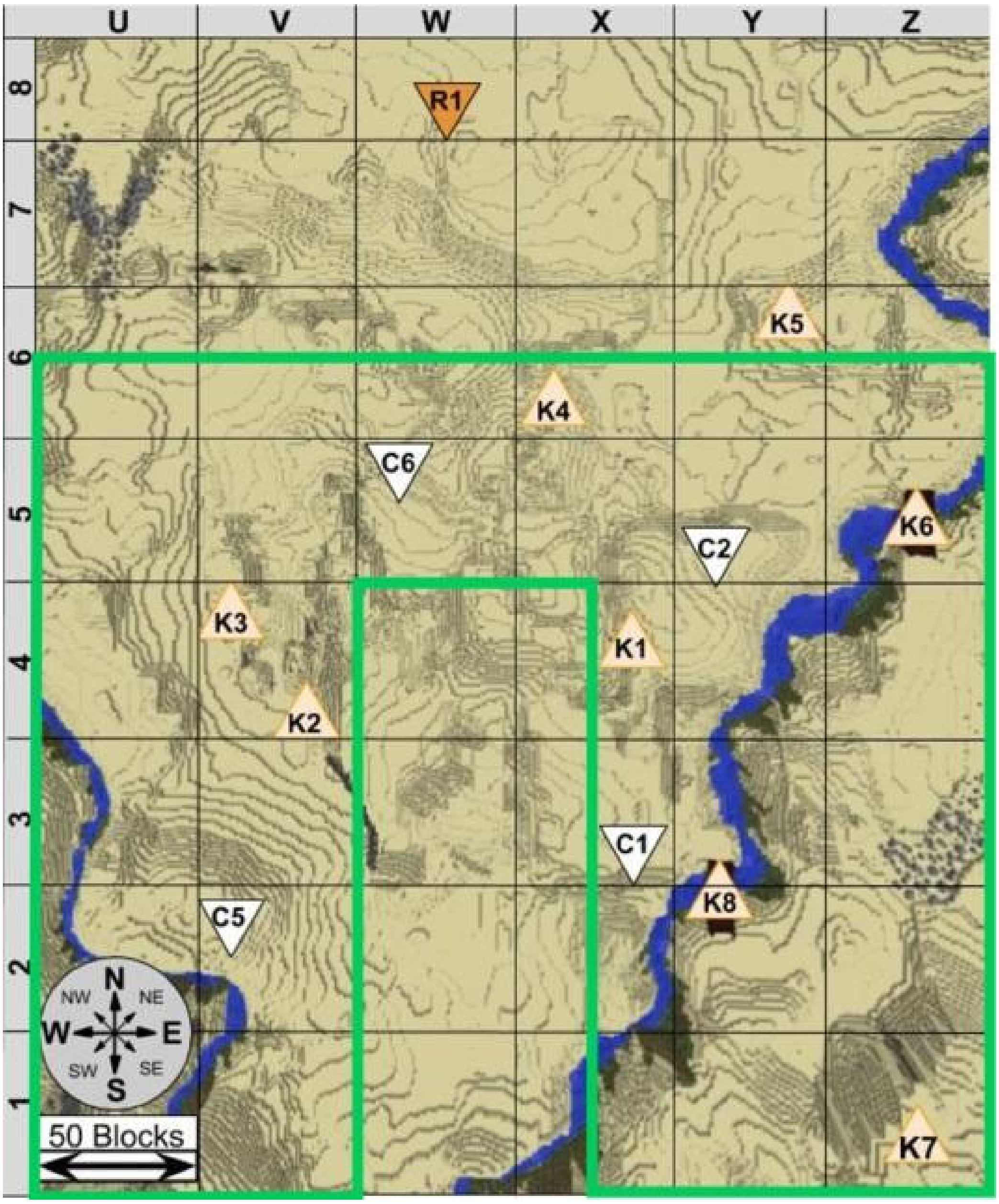
Page Break

Q1024 Select the locations of the **civilian(s)** on the map



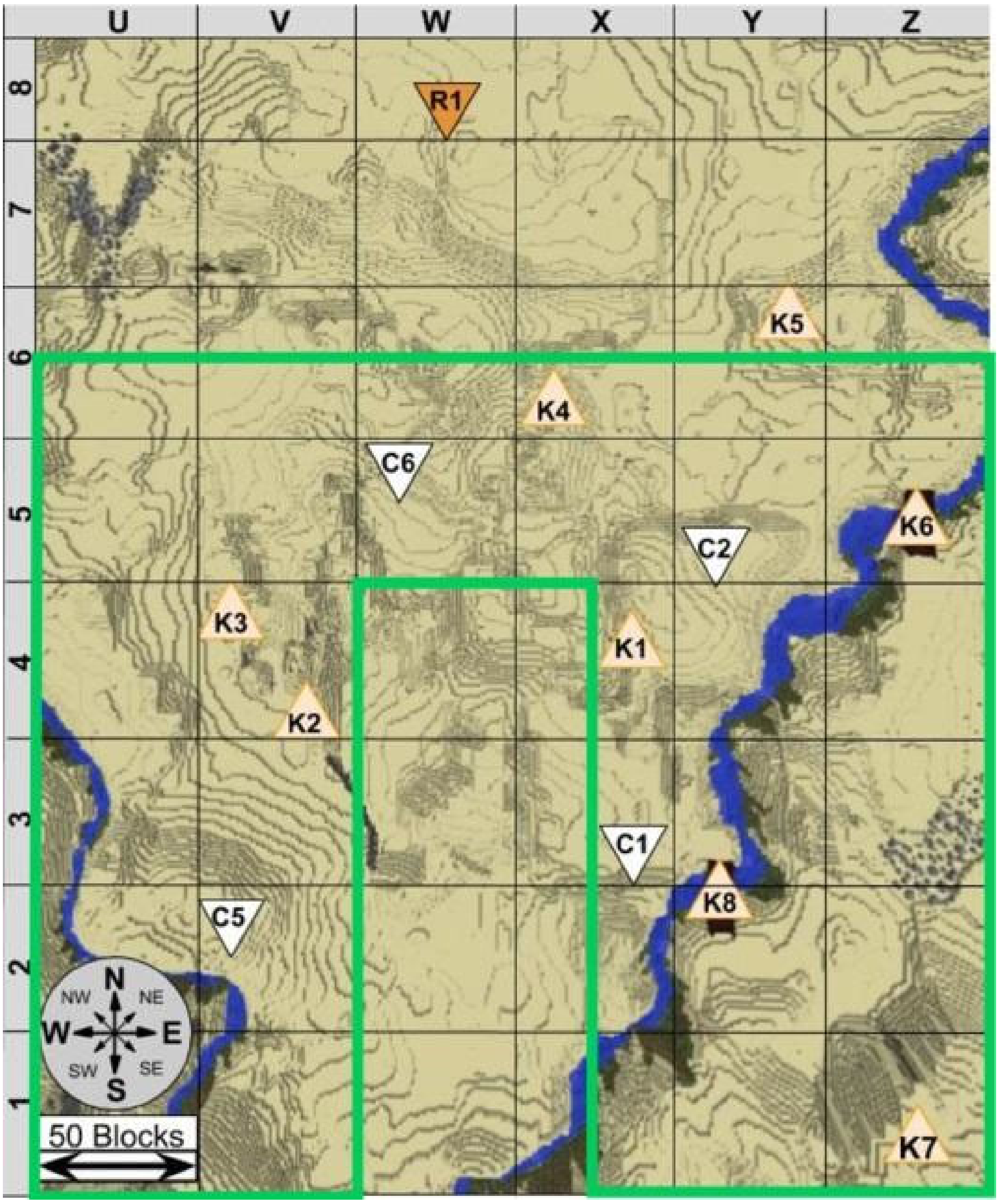
Page Break

Q1025 Select the locations of any **enemy(s)** on the map



Page Break

Q1028
Which previously selected enemy poses the most immediate threat to your team at this time?



Page Break

Q991 Which Operator will finish all of their tasks first?

○ Blue1 (1)

○ Blue2 (2)

Q994 Do you think your team will finish the phase before the time expires?

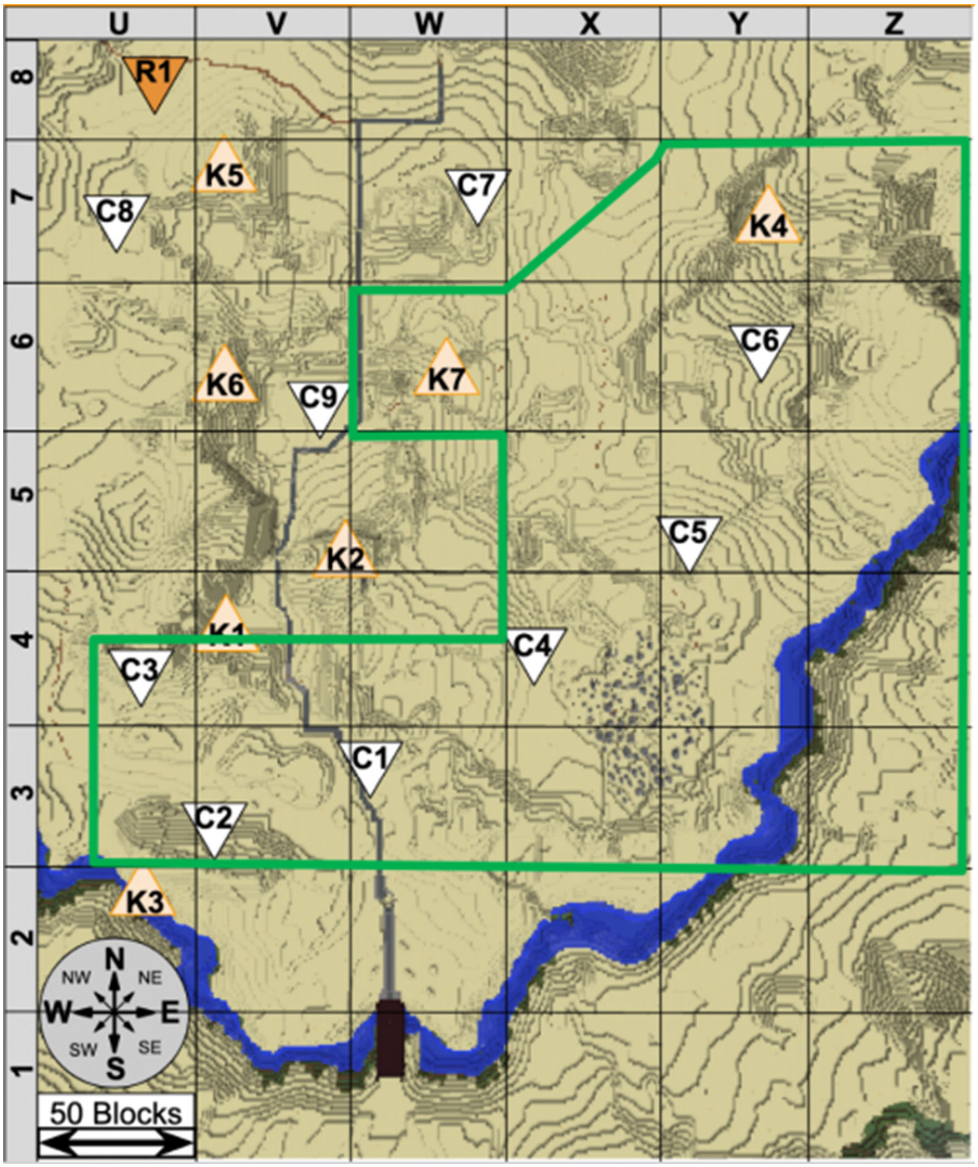
○ Yes (1)

○ No (2)

Mission 2 Map Questions

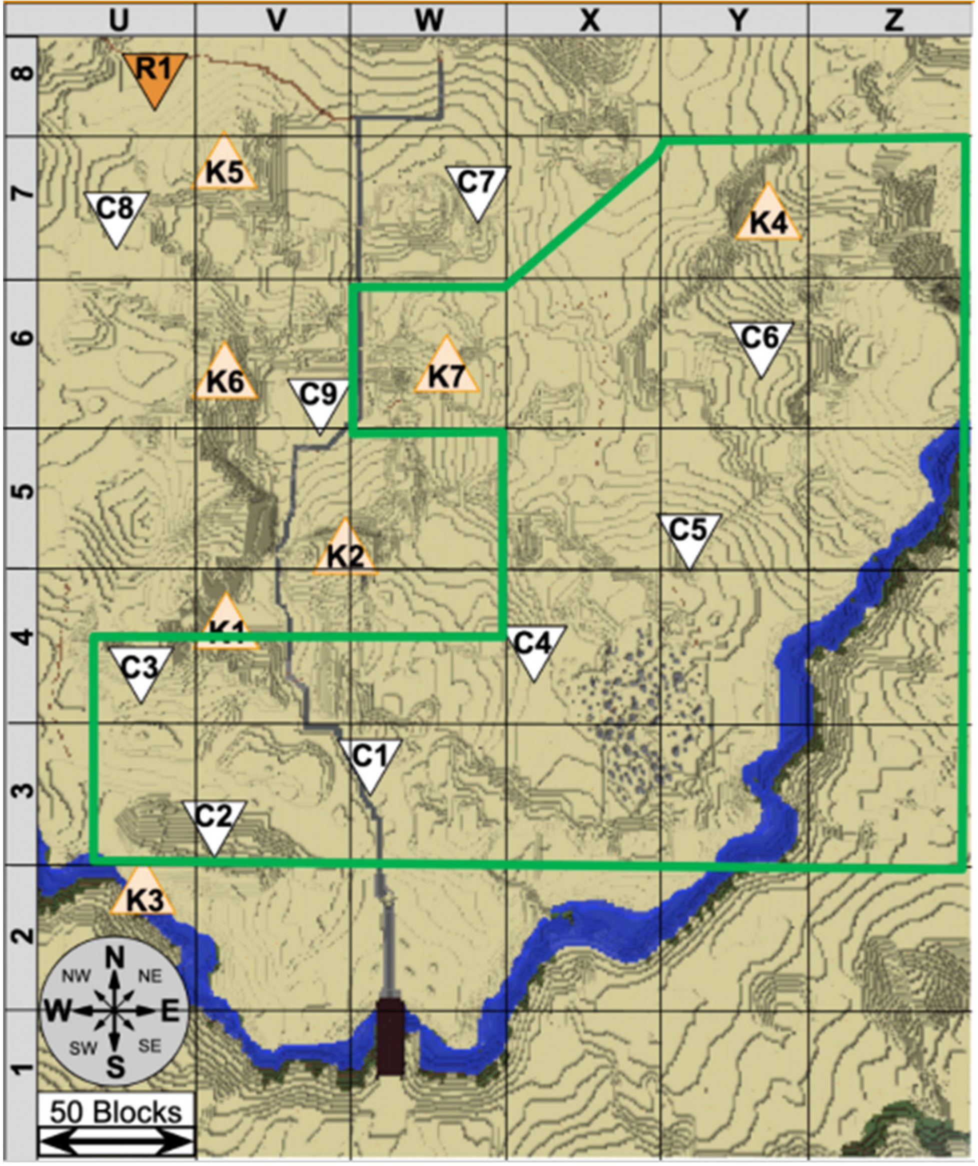
Q997 For the following questions you will be asked to estimate the location of objects within the mission environment on an interactive map. The green outline indicates the bounding box for the current phase.

Q1013 Select the current location of **RCV1** on the map



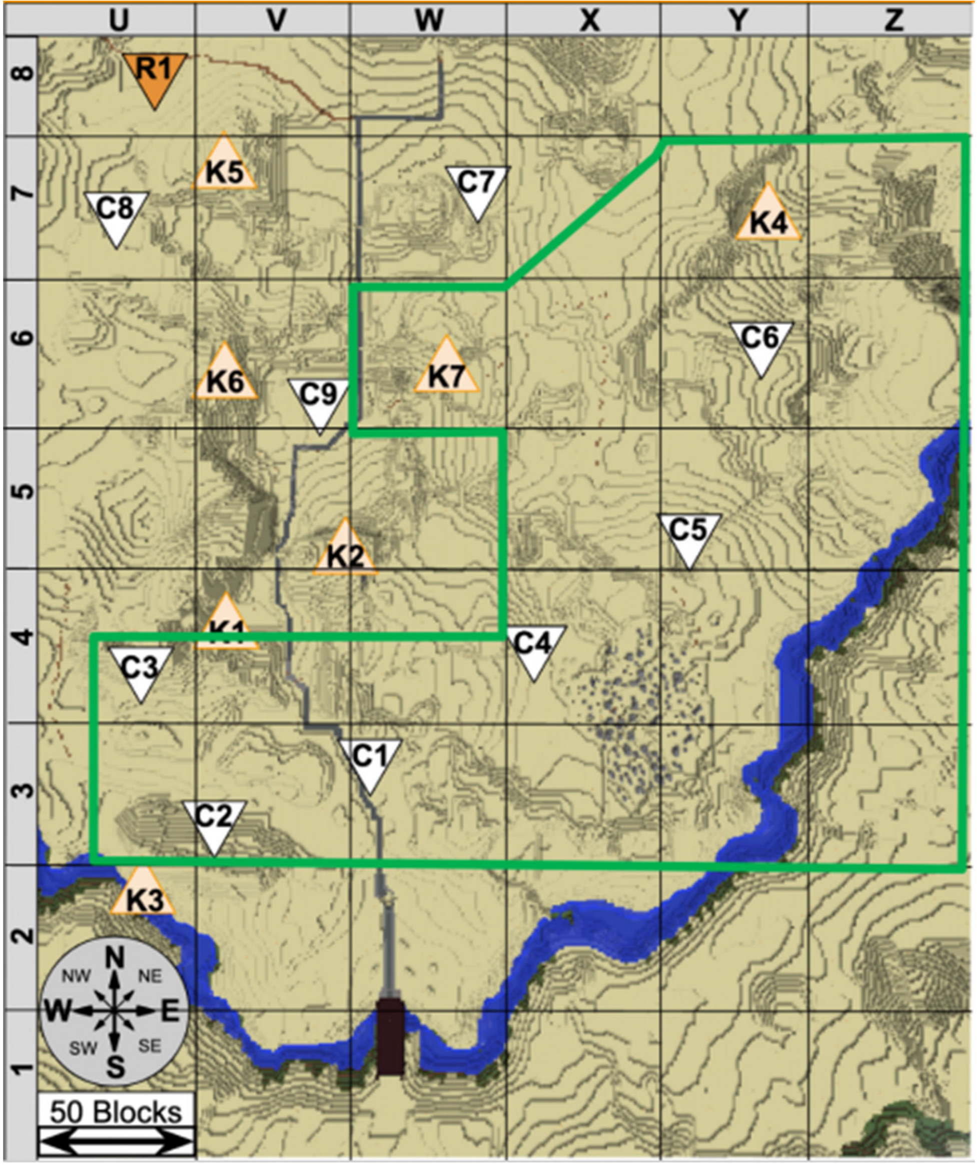
Page Break

Q1018 Select the current location of **RCV2** on the map



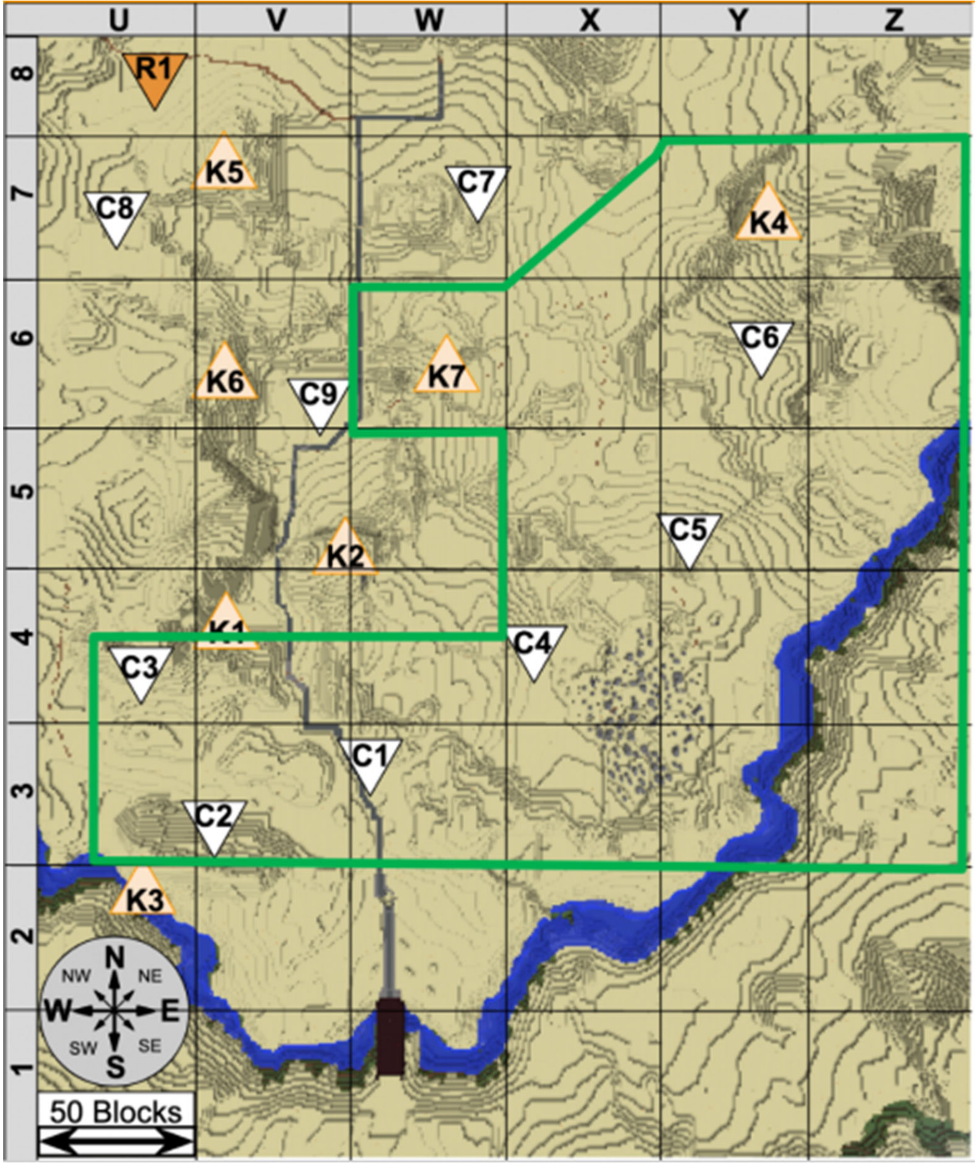
Page Break

Q1019 Select the location of the **impassable obstacle(s)** on the map



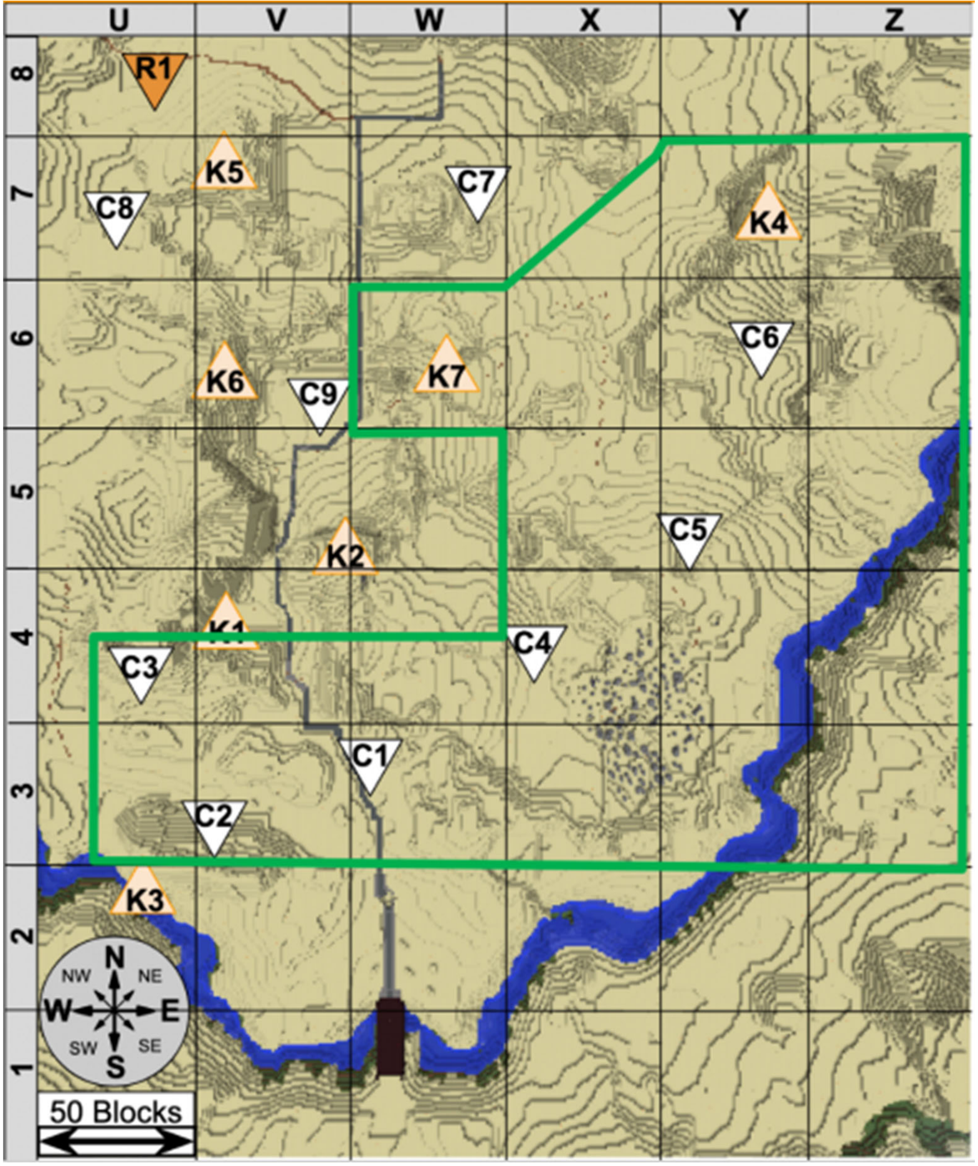
Page Break

Q1020 Select the locations of the **civilian(s)** on the map



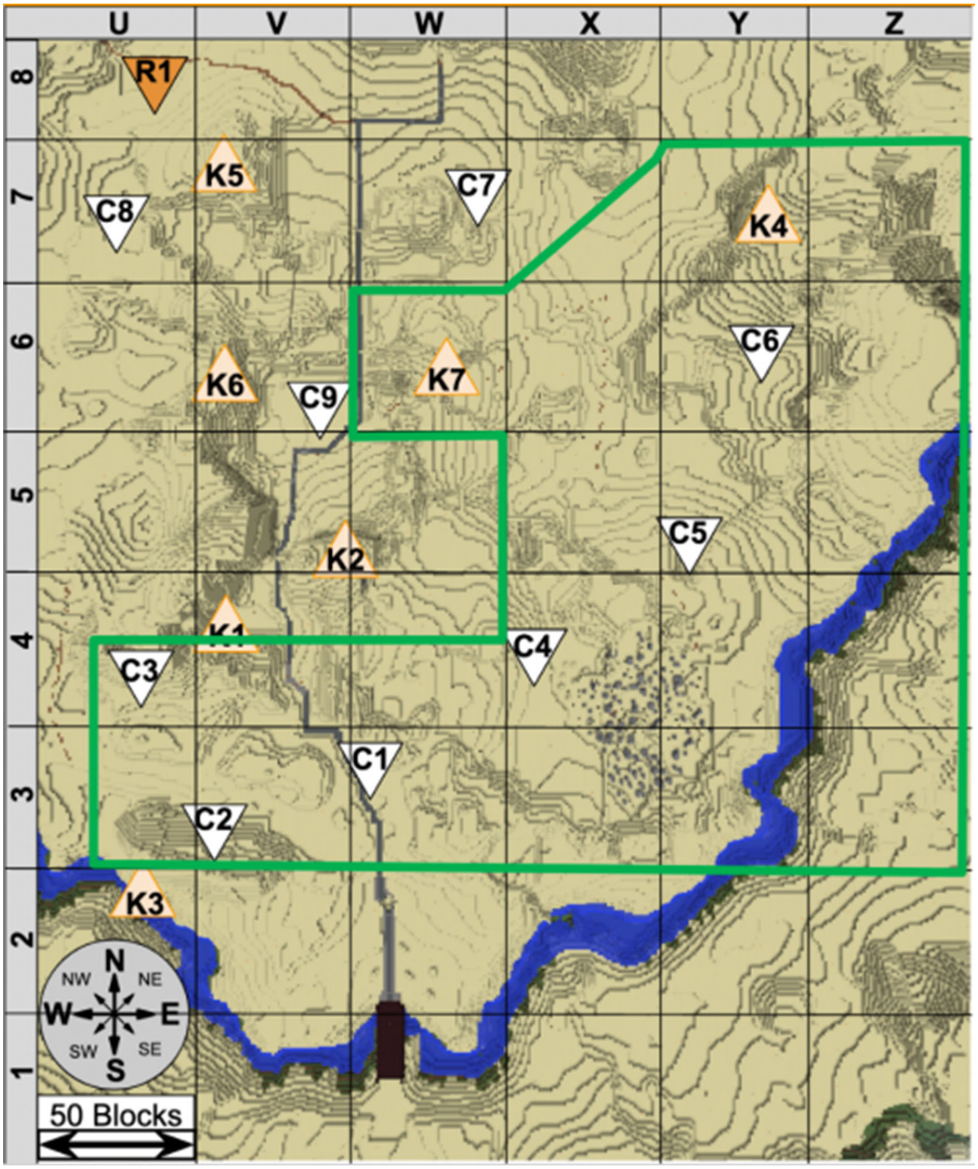
Page Break

Q1021 Select the locations of the **enemy(s)** on the map



Page Break

Q1029 Which previously selected enemy poses the most immediate threat to your team at this time?



Page Break

Q1004 Which Operators will finish all of their tasks first?

○ Blue1 (1)

○ Blue2 (2)

Q1005 Do you think your team will finish the phase before the time expires?

- ○ Yes (1)
- ○ No (2)

Page Break

Q1010 Describe the characteristics of an important civilian you are going to meet up with later in the following questions

Q1007 What will you do when you find this civilian?

- ○ Capture them (1)
- ○ Evacuate them (2)
- ○ Stay in place and guard them (3)
- ○ Unkown (4)

Q1008 What color was used to describe the civilian's clothing?

- ○ Red (1)
- ○ Green (2)
- ○ Blue (3)
- ○ Brown (4)
- ○ None (5)
- ○ I don't know (6)

Q1009 Where is this civilian supposed to be located?

- ○ To the north (1)
- ○ to the south (2)
- ○ To the east (3)
- ○ To the west (4)

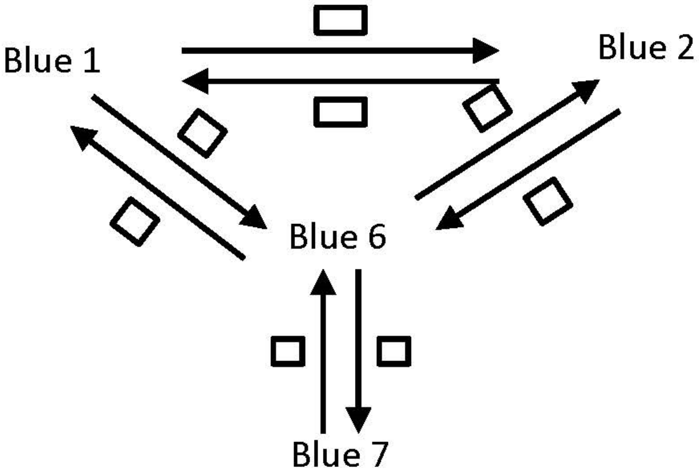
APPENDIX B

CAST SCORESHEET

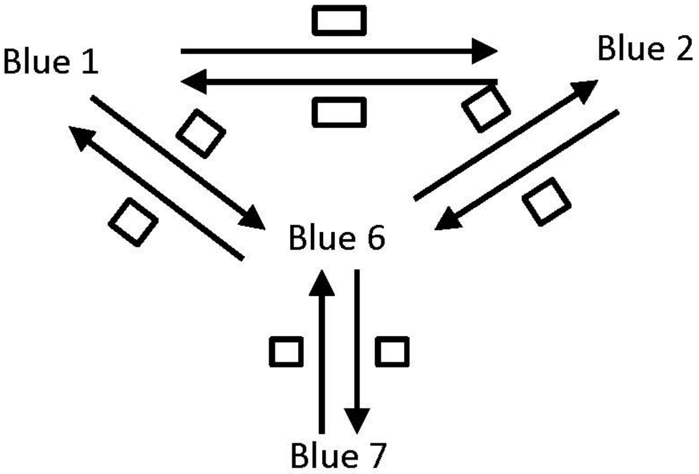
Perceived first-hand:

☐Blue 1 ☐Blue 2 ☐Blue 6

Coordinated perception:



Coordinated action:



Overcome roadblock? ☐Yes ☐No