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UNMANNED TACTICAL AUTONOMOUS CONTROL AND COLLABORATION (UTACC) HUMAN MACHINE COMMUNICATION AND SITUATIONAL AWARENESS DEVELOPMENT

by

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13. ABSTRACT (maximum 200 words)

The Unmanned Tactical Autonomous Control and Collaboration (UTACC) system seeks to integrate Marines and machine in a way that does not add to the cognitive load of warfighters. How do machines communicate with humans and vice versa when they are interdependent teammates, rather than following a framework of human operating the robot? Key to this capability, is the capacity to incorporate observability, predictability and directability into the interface designs. Previous research studied this question from a context of a Marine fireteam that had a robot as one of its members. Choosing the right type of interface to facilitate communications between members of a fireteam (be they human or machine) is essential to their ability to actually function as a team and trust one another. But those communications occur in the immediate proximity of the teammates. What changes when you seek to expand this concept beyond a small unit? Three essential focus areas are included in this thesis. First, what is the essential information required to maintain situational awareness between a UTACC fireteam and higher echelons of military units. In other words, this is the “what” of information being exchanged. Secondly, what are the interface design principles that will hold true no matter what type of information is being exchanged? Finally, this thesis presents proposed methods to evaluate these principles and the specific information exchange requirements.

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ABSTRACT

The Unmanned Tactical Autonomous Control and Collaboration (UTACC) system seeks to integrate Marines and machine in a way that does not add to the cognitive load of warfighters. How do machines communicate with humans and vice versa when they are interdependent teammates, rather than following a framework of human operating the robot? Key to this capability is the capacity to incorporate observability, predictability and directability into the interface designs. Previous research studied this question from a context of a Marine fireteam that had a robot as one of its members. Choosing the right type of interface to facilitate communications between members of a fireteam (be they human or machine) is essential to their ability to actually function as a team and trust one another. But those communications occur in the immediate proximity of the teammates. What changes when you seek to expand this concept beyond a small unit? Three essential focus areas are included in this thesis. First, what is the essential information required to maintain situational awareness between a UTACC fireteam and higher echelons of military units? In other words, this is the "what" of information being exchanged. Secondly, what are the interface design principles that will hold true no matter what type of information is being exchanged? Finally, this thesis presents proposed methods to evaluate these principles and the specific information exchange requirements.

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LIST OF ACRONYMS AND ABBREVIATIONS

AC	air carrier
BLOS	beyond line of sight
CO	company
COA	course of action
CJCS	Chairman of the Joint Chiefs of Staff
COP	common operational picture
CTP	common tactical picture
DoD	Department of Defense
DOT&E	Director, Operational Test and Evaluation
EM	electromagnetic
FT	fire team
GC	ground carrier
GUI	graphical user interface
HMI	human-machine interface
HPT	high priority target
IA	interdependence analysis
I&W	indications and warnings
JP	joint publication
LOS	line of sight
MAGTF	Marine Air Ground Task Force
MCDP	Marine Corps Doctrinal Publication
MCRP	Marine Corps Reference Publication
MCT	Marine Corps Task
MCTL	Marine Corps Task List
MCTP	Marine Corps Tactical Publication
MCWL	Marine Corps Warfighting Laboratory
MCWP	Marine Corps Warfighting Publication
MET	Mission Essential Task
METL	Mission Essential Task List
METT-TSL	mission, enemy, troops and fire support, terrain and weather, time, space, and logistics
MOE	measure of effectiveness
MOP	measure of performance
OCOKA-W	observation, cover and concealment, obstacles, key terrain, avenues of approach, and weather
OPD	observability, predictability, and directability
PLT	platoon

SA	situation awareness or situational awareness
SIGINT	signals intelligence
SOP	standard operating procedure
SoS	system of systems
SQD	squad
SSTM	sensory short term memory
STM	short term memory
T&R	training and readiness
TTPs	tactics, techniques, and procedures
UAS	unmanned aircraft system
UAV	unmanned aerial vehicle
UGS	unmanned ground system
UIS	user interface system
USJCS	United States Joint Chiefs of Staff
USMC	United States Marine Corps
UTACC	Unmanned Tactical Control and Collaboration
UxS	unmanned system

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I. INTRODUCTION

This thesis is an extension of two previous Unmanned Tactical Autonomous Control (UTACC) theses. The thesis by Kulisz and Sharp (2017) explored MOEs and MOPs for the UTACC program, while the thesis by Beierl and Tschirley (2017) evaluated situation awareness (SA) for the UTACC program. This thesis will evaluate methods to team humans and machines on the battlefield for maximum effectiveness. The research for this thesis will focus on MOEs and MOPs while accounting for SA for human machine teaming.

A. VISION OF UTACC

The UTACC program has been working with the Marine Corps Warfighting Laboratory (MCWL) to enhance the capabilities of the USMC through human-machine collaboration. The UTACC unmanned system (UxS) is a system of systems (SOS) approach to join human and machine capabilities to increase the overall effectiveness and efficiency of the force. Each individual component has strengths and weaknesses. UTACC, however, is attempting to leverage the strengths of each component in order to increase the overall strength and reduce deficiencies within a unit.

UTACC believes that the machine plays a vital role in future military conflicts. The ability to utilize a machine, in place of a human, enhances mission capability. The machine can be used when it may be too dangerous or unrealistic to employ a human for a certain task. A machine can be used to complete a task, just as a human can. The goal is to get the human and machine to work interdependently. The employment of unmanned aircraft systems (UAS) has been around for many years, with positive effects. The principles behind UAS can be leveraged to further the development of unmanned ground systems (UGS).

B. NECESSITY OF MOP/MOE

A Marine makes up a single component within a unit. That Marine develops a necessary skill set through training and education in order to become an asset to a particular unit. In order to determine his or her effectiveness, the Marine is evaluated based on standards that have been established by the Training and Readiness (T&R) manual. The T&R manual is developed through a deliberate process that will be further elaborated on in Chapter III. The point is that every Marine is evaluated by the same principles: does he or she meet the established standard, or not? The basis of the evaluation is through the use of MOEs and MOPs.

The requirement to integrate machines within a Marine unit brings about many questions. This thesis will try to determine how the machine can be evaluated on performance. The machine must be held to a standard that ensures that the team is improved by its addition. For this reason, the development of MOEs and MOPs for human-machine teams must be developed to establish the standard. As stated by the U.S. Joint Chiefs of Staff, "The assessment process uses MOPs to evaluate task performance and MOEs to determine progress of operations toward achieving objectives and ultimately the end state" (U.S. Joint Chiefs of Staff [USJCS] J-7, 2011, p. ix). The ability to evaluate the machine in the same manner as a human will make it easier for units to train and establish readiness for their tasks as described in the Marine Corps Task List (MCTL) 2.0.

C. NECESSITY OF SA

SA has been established as a critical factor in decision making for military infantry operations (Endsley, Holder, Leibrecht, Garland, Wampler & Matthews, 2000). The ability to develop SA will continue to be a key to sound decision making in the future for humans and machines alike. Technology makes some processes easier, but also creates a problem as the requirement for human-machine teaming is established. As the need for collaboration between humans and machines on the battlefield evolves, so does the need for team SA evaluation.

Each component, human and machine, possess individual SA. The ability to develop individual SA has been a challenge to the USMC for many years. The way to help with this process for Marines is to establish tactics, techniques, and procedures (TTPs) that are standardized throughout the USMC. This process ensures that the key principles of observability, predictability, and directability are understood throughout the unit. SA is enhanced when these principles are established. The implementation of machines within Marine units should be handled through the same standardization process as humans.

The combination of individual SA of members of a unit is the basis of the team SA. The interactions of the human and machine must be standardized, just as with human only teams, to effectively and efficiently build team SA in a human and machine team. A human possesses sensors that have necessary abilities and some shortfalls, depending on the task. A machine has the same dilemma, pros and cons depending on the task. The ability to join the human and machine in a single unit allows the strengths of both to be utilized while mitigating the deficiencies. Team SA needs to be established for this to work effectively. As such, SA will continue to be a key factor for decision making, regardless of the team composition. This is particularly true as we expand analysis beyond the fireteam level to that of SA between a fireteam and higher headquarters.

D. THESIS ORGANIZATION

This thesis is organized into four additional chapters. Chapter II is a literature review that explores human-machine interfaces (HMI) and SA models for human-machine collaboration. Chapter III describes the research methodology to incorporate machines into USMC units for increased mission capability, with an emphasis on communication and decision making through team SA. Chapter IV presents the findings of the research described in Chapter III. Chapter V summarizes the results of the thesis research and provides recommendations for further research in the field of HMI and robotics in the Marine Corps.

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II. LITERATURE REVIEW

This is the tenth Naval Postgraduate School thesis in a succession of related theses that support the development of the Unmanned Tactical Autonomous Control and Collaboration system. The theses that were previously written establish a foundation for the UTACC program and their conclusions will be used as a foundation for this effort. Additional applicable subject areas include military doctrine and concepts, situational awareness, and human-machine integration. Although there is substantial literature available for those topics areas, it is not applied to the issue in question: specifically, how to integrate a robot member of a fireteam-sized Marine unit with larger echelons of a military hierarchy. Another less developed but pertinent subject area includes the co-active design methodology and its application in this context.

A. UTACC CONCEPT

The Unmanned Tactical Autonomous Control and Collaboration system of systems has progressed through a series of theses. Rice, Chhabra, and Keim (2015) began the effort by developing a concept of operations that saw the UTACC system showing the most initial value as a decision support tool and mission planning capability that would reduce the cognitive load of its users, especially at the small unit level. Kirkpatrick and Rushing (2016) began the effort of defining those most critical measures of performance (MOP) and measures of effectiveness (MOE) for the UTACC program. Kulisz and Sharp (2017) then followed up this work by focusing on the human-machine communications required to successfully integrate a robot into a fireteam-sized Marine unit. Kulisz and Sharp (2017) developed and proposed MOEs and MOPs to evaluate those communications and concluded by recommending additions to the Marine Corps Task List. Although communications were analyzed between humans and robots, this was done in support of a small unit and not for those communications between a robot and higher echelons of military formations. The USMC is already testing and incorporating robots in tactical training scenarios. The groundwork has been underway for many years through the unmanned aerial vehicle (UAV) program and now with UxS. The intent of UTACC is not to develop a machine to be utilized by the USMC infantry unit, but to determine the requirements to make the human-machine team more effective. This thesis will expand upon earlier work to focus on the interface and situational awareness requirements for successful human-machine integration.

B. MARINE CORPS DOCTRINE

When developing a foundational theory for interactions between a robot member of a fireteam and higher headquarters organizations, the first principle observed is the use of already established military doctrinal concepts as a stepping off point. The capacity for supporting the Marine Corps' adherence to the principles of maneuver warfare and the organization's philosophy of command is foundational to the effort. Marine Corps Doctrinal Publication 1 provides the cognitive framework for characterizing the UTACC program as a technological capability to orient on enemy forces (United States Marine Corps [USMC], 1997b). A decentralized method of command and control, execution of mission tactics and incorporating Commander's Intent are all relevant concepts to this thesis (USMC, 1997b). This is not to say that current doctrine constrains the research; simply that it provides a point of departure.

Command and control is a concept of utmost importance in military operations. Marine Corps Doctrinal Publication 6 explains command and control as an iterative process of influences and authority made by a commander and the feedback or control received as the effect of command (USMC, 1996). Technology, such as a robot, potentially gives another mechanism of control to a commander, especially as a sensor that can provide information about the environment or current situation. Marine Corps Doctrinal Publication (MCDP) 6 also provides a definition of The Information Hierarchy as seen in Figure 1, and that will be adhered to when defining the types of information being exchanged (USMC, 1996). The concept of Image Theory will inform decisions based on the portrayal of information sent by a robotic system. Organization theory detailed in MCDP 6 will also inform limitations placed on the information and capabilities that an external organization should have over a robot in a subordinate fireteam (USMC, 1996). Additionally, principles of information management theory must inform decisions regarding whether information is exchanged as a “supply-push” or “demand-pull” manner (USMC, 1996).

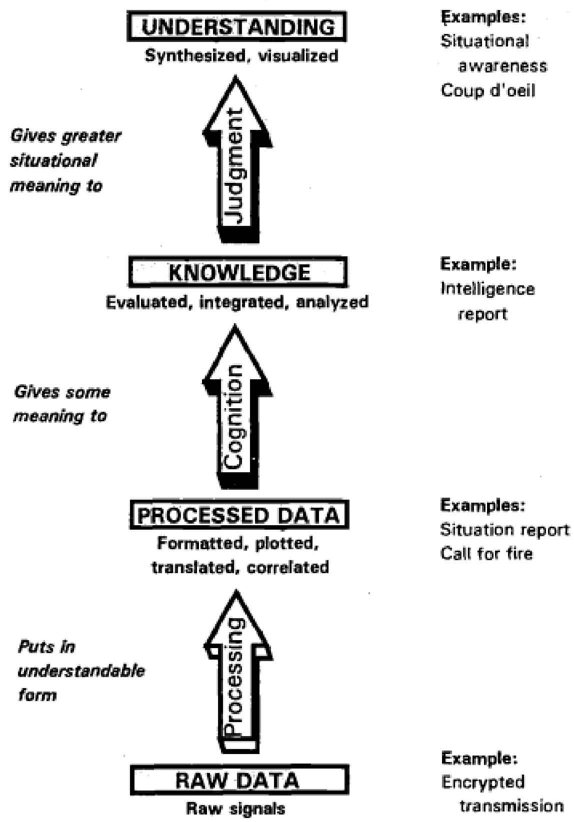

Figure 1. The Information Hierarchy. Source: USMC (1996).

More specifically, Command and Control systems must support the operational environment and methods that military units chose to employ to accomplish assigned missions. Features of command and control systems must allow for Marine units to conduct operations as dispersed, small units in environments that are degraded or denied before rapidly aggregating into larger sized units to deal with escalating crises (USMC, 2015). Current command and control concepts seek to obtain “widespread information-sharing, understanding of the commander’s intent, view of the operational environment, and collaborative situation assessments” (USMC, 2015). The Marine Corps’ Command and Control Concept (2015) identifies the promise of mobile technologies liberating commanders from command centers and allowing them to conduct essential command and control functions from anywhere on the battlefield. Again, command and control doctrine and recent concepts are well developed; the UTACC program is wise to adhere to their frameworks and align with their principles to be a realistic possibility as a contributor to command and control. In the future as the Marine Corps develops the ability to operate collaboratively with unmanned systems, such frameworks may require modification.

Another possibility for the UTACC program centers on the efficacy of utilizing a robot member of a fireteam as an intelligence asset for a higher headquarters and thus the objectives of intelligence inform the type of information that may be useful. The first objective of intelligence is to provide "accurate, timely and relevant knowledge about the enemy or surrounding environment" (USMC, 1997a). This type of information and its characteristics can help to scope the types of sensors and the information that must be conveyed by those sensors when designing the robot. The second objective of intelligence is protection of friendly forces through counterintelligence (USMC, 1997a); in this sense, the robot must include features (active or passive) that would deny intelligence to enemy forces. The desire to increase the number of reporting sensors on the battlefield will need to be balanced with the recognition that the future environment will be very much a "battle of signatures" (USMC, 2016d). In other words, special attention must be given to reducing robot transmission signatures. The Marine Operating Concept details a requirement to operate in contested-network environments as a critical task (USMC, 2016d). This critical task informs technology requirements to protect communications and limit the signatures of those communications.

C. CO-ACTIVE DESIGN PRINCIPLES

Co-Active design is an extension of standard systems engineering processes that enables a functional analysis of how machines and Marines expect to operate, so as to have effective interdependence. The central component of Co-Active Design is to conduct an interdependence analysis. That analysis results in an understanding of the observability, predictability, and directability (OPD) requirements supporting interdependence. The definitions of OPD, based on Matthew Johnson's (2014) work are cited below:

> Observability means making pertinent aspects of one's status, as well as one's knowledge of the team, task, and environment observable to others. Since interdependence is about complementary relations, observability also involves the ability to observe and interpret pertinent signals. Observability plays a role in many teamwork patterns e.g., monitoring progress and providing backup behavior.
>
> Predictability means one's actions should be predictable enough that others can reasonably rely on them when considering their own actions. The complementary relationship is considering others' actions when developing one's own. Predictability is also essential to many teamwork patterns such as synchronizing actions and achieving efficiency in team performance.
>
> Directability means one's ability to direct the behavior of others and complementarily be directed by others. Directability includes explicit commands such as task allocation and role assignment as well as subtler influences, such as providing guidance or suggestions or even providing salient information that is anticipated to alter behavior, such as a warning. Teamwork patterns that involve directability include such things as requesting assistance and querying for input during decision making. (Johnson, 2014, pp. 68–69)

Co-Active design allows the operator to understand the actions of the machine. This model adapted from Johnson (2014) and depicted in Figure 2 attempts to answer core issues in robotics providing support for humans. The answer to what the robot is doing, what the robot is going to do next, and how to get the robot to what needs to be accomplished is answered through OPD and the Coactive Design model. The answer to these questions provide confidence to the human and build trust for the human-machine team. It is equally as important that the robot is able to "understand" the same answers as well.

Human Needs	Issues
What is the robot doing?	Observability
What is the robot going to do next?	Predictability
How can we get the robot to do what we need?	Directability

Figure 2. Core issues in robotics providing support. Adapted from Johnson (2014).

The Coactive design method, with IA tables, provides UTACC the ability to analyze the interdependence of the Marine and machine team. The IA table is a tool developed by Matthew Johnson (2014) that assists designers in determining the specific requirements for OPD. The IA table supports the analysis of teaming by identifying tasks and subtasks of the team, the capabilities required to do the tasks and the "team role alternatives" describing different methods for completing the tasks (Johnson, 2014). The task required for a specific skill set can be analyzed to determine the most effective way to implement machines into a Marine unit to accomplish the mission. It is also a way to show how a higher headquarters can have observability, predictability and directability with a fireteam or the fireteam's unmanned systems.

D. MARINE MACHINE INTEGRATION AND INTERFACE DESIGN

There has been a traditional understanding of the interactive relationships between human and robots that can be described as "on the loop" or "in the loop" whereas the human operator has either supervisory control or is in direct and active control of the system (Chen & Barnes, 2014). A primary objective of the UTACC program is to limit the cognitive saturation that modern military operators are faced with. Thus far, Kulisz and Sharp (2017) proposed measures of performance and effectiveness for communications between an autonomous robot member of a fireteam and the team's human members. This work centered on humans and a system that would be in relative proximity of each other. In the question relevant to this research effort, the circumstances are very much different in that the human beings that make up a higher headquarters and the robot member of a fireteam would not be in such proximity to each other. Rather, it is most likely that there will be considerable distance between the two. This is a fundamental difference in the relationship between this group of humans and robots.

This does not mean, however, that there is not overlap from principles defined and developed in the context of an operator relationship between human and robot. For example, much of Goodrich (2004) describes preferred methods to interpreting human to machine commands and implied tasks. His first suggestion is that situational context determines the active human-machine interface. He provides an example where if a human starts operating a joystick, the interface should automatically switch to a mode in which the joystick is the active interface, rather than a manual process that needs to be initiated (Goodrich, 2004). Another proposed feature is to have the human use an interface to interact "with the world" or to "manipulate the relationship between the robot and world" rather than having the human use non-intuitive methods for doing so. So for example, if one wanted to send a command or information from the human to the robot side of the connection, it would be done automatically by translating human desires rather than having the human specifically needing to direct specific robot actions (Goodrich, 2004). An example of this would be a human selecting a representation of an interesting location on a display. The robot would interpret that command and automatically travel to the location rather than the operator needing to manipulate a joystick to manually direct the machine. An example of manipulating the relationship between robot and world is given by Goodrich (2004) where to send a UAV to an altitude, the operator does not increase the pitch until the new altitude is reached and then manipulate it to maintain the altitude, rather the display allows the operator to input the new required altitude and the robot automatically manipulates the required flight characteristics to bring itself to the desired altitude. This is all intended to reduce the cognitive load of the operator. These principles can be applied and in certain circumstances may be essential in the extended context of this research, and are the kinds of analyses that the interdependence analysis addresses. IA also addresses what happens if that method fails; that is, IA allows the developer to consider alternate means for task completion. This builds task resiliency.

Additionally, Casper and Murphy (2003) detailed a problem with the limited nature of information distribution that is common to robotics. These investigators recognize that the information provided by robots must be distributed to multiple echelons in a search and rescue operation but is currently technologically limited to information exchange between it and its operator (Casper & Murphy, 2003). This necessitates a manual information exchange between the operator and external echelons (Casper & Murphy, 2003). Casper and Murphy (2003) also recognized that information provided by robots is not simply a matter of broadcast but rather there is a requirement to filter and abstract information depending on the intended audience (in other words, "not all members…need the same information at the same time") (p. 381). Casper and Murphy (2003) also report that the lack of robot state information caused 54% of working time to be wasted and a lack of "state of the world" information had adverse effects on the ability of operators to work robots in environments suitable for them. The authors recommend that suitable "assistive roles" be identified to compensate for the heavy fatigue encountered in search and rescue operations and that "perceptual interfaces" that use auditory or haptic alerts be developed to reduce the overuse of the visual sense (Casper & Murphy, 2003). Identifying "assistive" roles is another hallmark of the interdependence analysis.

Murphy (2004) depicts a simple model for demonstrating the transformation of raw data into knowledge and the abstraction/filtering that happens as information flows from Robot/Operator to a second and third echelon of a search and rescue operation that is remotely located. Murphy (2004) notes that information in an urban search and rescue scenario "is generally one-way, flowing up from robot data to increasing levels of abstraction for the decision-makers in the hierarchy" (p. 148). Murphy (2004) also categorizes the raw data produced by robots as "robot's internal state…relationship to the environment… layout of the environment… [and] presence of victims" (p. 148). These are all examples of characteristics of the dynamic information that is necessary for exchange in the context of a robot member of a fireteam communicating with higher headquarters echelons. Furthermore, the ability to have "distributed communication networks offer the potential to both relocate a robot team member and immediately propagate information to all members of the rescue enterprise" (Murphy, 2004, p. 150).

The interface utilized for human-machine integration is a key to successful operations between humans and machines. The interface needs to be simplistic enough to be operated and understood while providing a real-world interpretation of the environment by the human operator/supervisor. In an environment in which the team (i.e., the robot and a human communicating from a distance) is not located in proximity, the interface becomes that much more important to the successful integration of the system. The interface must avoid the extremes of being either too simple or too complex:

> A well-designed operator interface presents the operator with enough context to quickly carry out a mission and the flexibility to handle

> unforeseen operating scenarios robustly. By contrast, an unintuitive user interface can increase the risk of catastrophic operator error by overwhelming the user with unnecessary information. (Marion, Fallon, Deits, Valenzuela, D'Arpino, Izatt, Manuelli, Antone, Dai, Koolen, Carter, Kuindersma, & Tedrake, 2017)

There are also several pitfalls that one must be aware of when incorporating machines into human teams. Chen and Barnes found that "research on human-automation has identified several issues with increased autonomy: tunnel vision, degraded situation awareness, misuse and disuse of automated systems, and complacency" (2014, p. 13). In some circumstances, the human is found to focus solely on the operations being performed by the machine and ignore the surrounding environment, which leads to tunnel vision and degraded situation awareness. The human has also been guilty of taking over control for a task that machine is more suited to perform without interaction, due to a lack of trust in the machine's ability. Conversely, the human may feel that the machine can do it all and disregard their role in the operation which leads to complacency. An interdependence analysis is designed to identify these kinds of issues.

The role of the human in the human-machine team is important to determine the level of effectiveness. The task required to be performed by the human will influence the number of UxS that may be supervised (De Visser & Parasuraman, 2011). With this focus on the nature of the tasks, De Visser and Parasuraman (2011) found that "it is not the number of UVs under supervision but the nature of the task carried out by each UV that is important in determining the load on the human operator" (p. 228). The interface used may be able to reduce the task of the human and lead to the ability to supervise multiple UxS.

Marion et al. (2017) created a graphical user interface (GUI), Director, to pilot a robot during a Defense Advanced Research Projects Agency Robotics Challenge. The GUI consisted of two user interface windows, the main window and the task panel. The task panel was the primary interface used by the operator and the robot to complete tasks. Marion et al. (2017) describe how "the main window contains a three-dimensional visualization environment to draw the robot's current state, perception sensor data, motion plans, and hardware driver status" (p. 8). Furthering their description of its capabilities, Marion et al. (2017) describe how "the interface also provides a teleoperation interface to support manual control by the operator" (p. 8). This design allowed for the robot to behave autonomously as well as the human to remotely control the robot to complete tasks (Marion et al., 2017). The GUI represents a process that could benefit UTACC for utilization of machines within a Marine unit and examples of it are depicted in Figures 3 and 4. Although the process used was preprogrammed for a specific task, it allowed operators to supervise or manually control the robot when deemed necessary. The UTACC problem is more extensive and requires the ability to respond to a complex and changing environment. Director is a user friendly interface that increases success due to ease of use and may serve as an example of what UTACC should strive for.

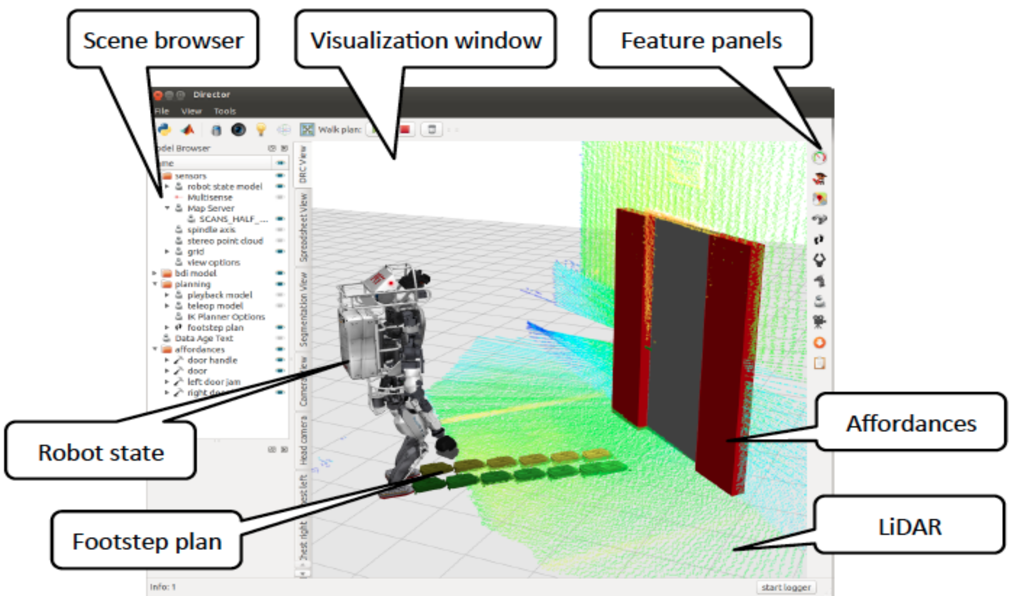

Figure 3. Director graphical user interface. Source: Marion et al. (2017).

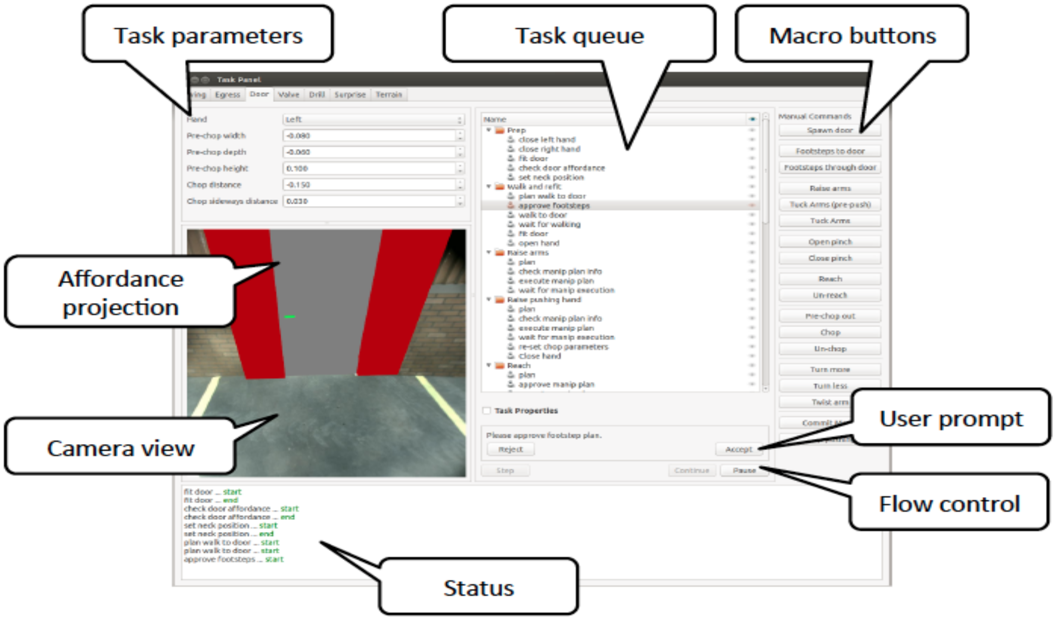

Figure 4. Task panel interface. Source: Marion et al. (2017).

E. ROLE OF SITUATION AWARENESS

A firm understanding for SA must be established, as there are many interpretations and definitions. Some researchers have defined SA as the "process of gaining awareness, the product of gaining awareness, or a combination of both" (Salmon, Stanton, Walker, Baber, Jenkins, McMaster, & Young, 2008). Fracker (1998) defines SA as "the knowledge that results when attention is allocated to a zone of interest at a level of abstraction" (pp. 102–103). The term SA is not the entire cognitive process for making a decision, rather it "pertains to the state of a dynamic environment" (Endsley, 1995, p. 36). Endsley's (1995) focus is on SA being a "state of knowledge" rather than a process to achieve a certain level of knowledge (p. 36). A number of models have been developed to evaluate and understand SA. Most notably Fracker (1988); Endsley (1995); and Smith and Hancock (1995) developed models that may be relevant and useful for the UTACC challenge for human-machine integration.

1. Fracker's Model

Fracker (1988) focused on the importance of SA required for military pilots to perform their duties. He developed the Model of Situation Assessment to explain how the long-term memory or "schemata" plays a significant role in SA development. The schemata can provide a pilot the ability to fill in the gaps in a given situation, "then the pilot need not attend to every detail of the environment to have a reasonably complete assessment of the situation" (Fracker, 1988, p. 103). The pilot only needs to develop patterns from incoming sensory data to identify schemata. The pilot then searches "the schema for items of information not currently in working memory" (Fracker, 1988, p. 104). The pilot is forced to increase the work load on "working memory" if the schema is not found in the long-term memory. The pilot would have to analyze the environment for information, "identify multiple schemata that may be appropriate, place information from these several schemata into working memory, and then integrate the information into a single result" (Fracker, 1988, p. 104).

Fracker's Model of SA relies heavily on the long-term memory of the pilot to develop SA. The pilot's "completeness" of long-term memory would result in less stress on the working memory and lead to a higher quality of SA. The "completeness" of long-term memory is likely to be broader in experienced pilots as compared to that of a "novice" pilot. A novice pilot must provide more attention to basic aircraft flight fundamentals and has less time for attention to sensory information to build SA. An experienced pilot, however, needs less time to focus on flight performance and less time required to build SA. Experience, through training and application, and knowledge are instrumental in developing SA quickly and accurately. A visual depiction of Fracker's Model of Situation Assessment was established by Beierl and Tschirley (2017, p. 8) and is depicted in Figure 5.

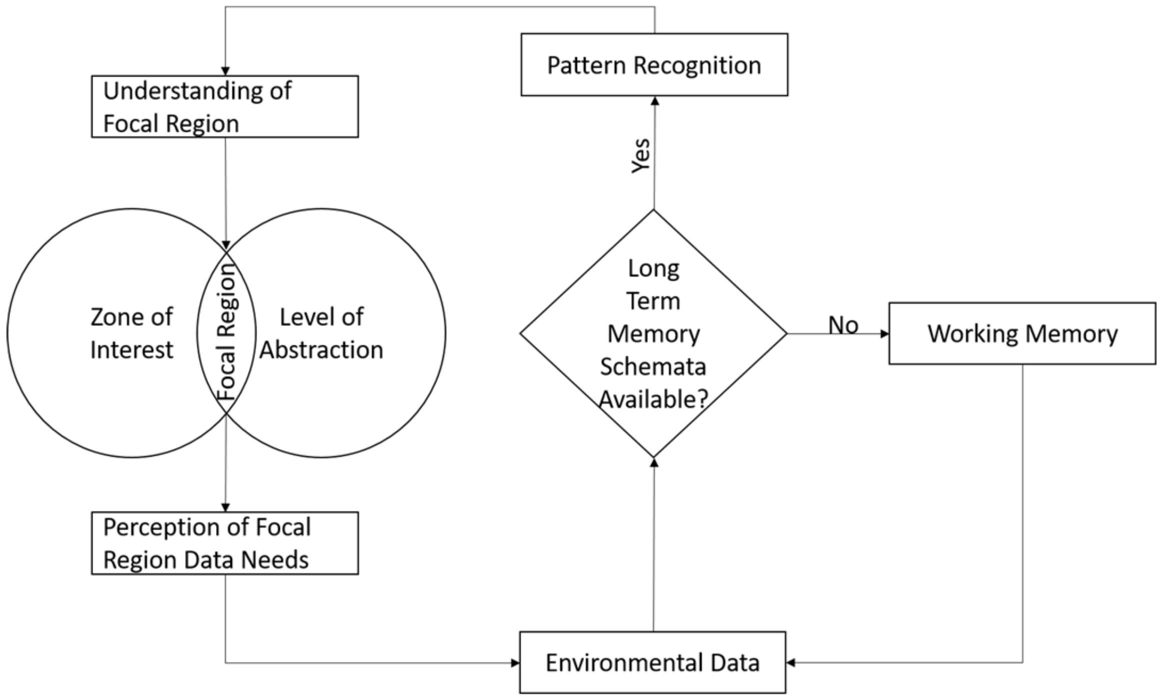

Figure 5. Fracker's Model of Situation Assessment. Source: Fracker (1988).

2. Endsley's Model

Endsley's (1995) Model for SA in dynamic decision making incorporates three levels of SA and the interactions involved for decision making; it is depicted in Figure 6. This concept is important in order to understand the various factors that contribute to decision making. SA is important for making appropriate decisions, but one should not lose sight of the fact that it is only a part of the decision-making process and not the sole factor as displayed in Figure 6 (Endsley, 1995, p. 35). The model suggest that a person's perception of the environment forms their SA. Endsley (1995) further elaborates on SA as consisting of:

- Level 1 SA: Perception of the Elements in the Environment.
- Level 2 SA: Comprehension of the Current Situation.
- Level 3 SA: Projection of Future Status.

The ability to understand what SA is and how it affects decision making is important for evaluation of the human-machine team. This basic understanding can help facilitate the understanding of team SA. The SA of each individual team member contributes to the overall team SA. Endsley (1995) thus concludes that “[a]s such, the quality of team members’ SA of shared elements (as a state of knowledge) may serve as an index of team coordination or human-machine interface effectiveness” (p. 39). This depiction of shared elements is depicted in Figure 7.

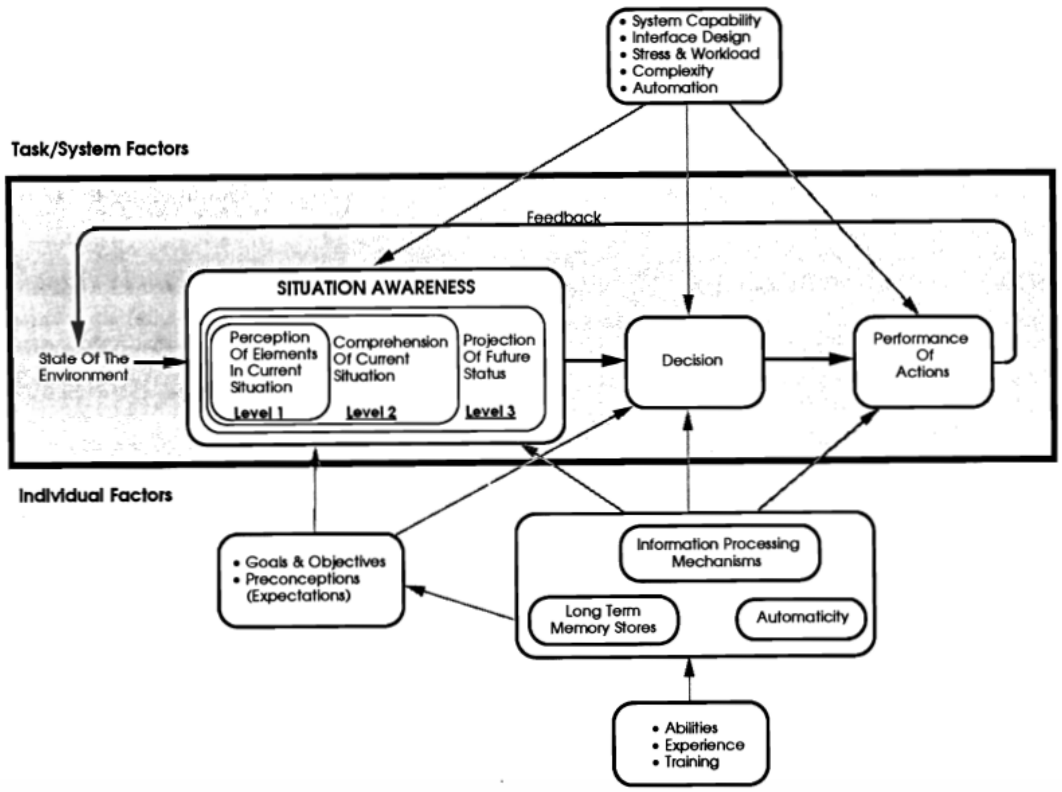

Figure 6. Model for Situation Awareness in dynamic decision making. Source: Endsley (1995).

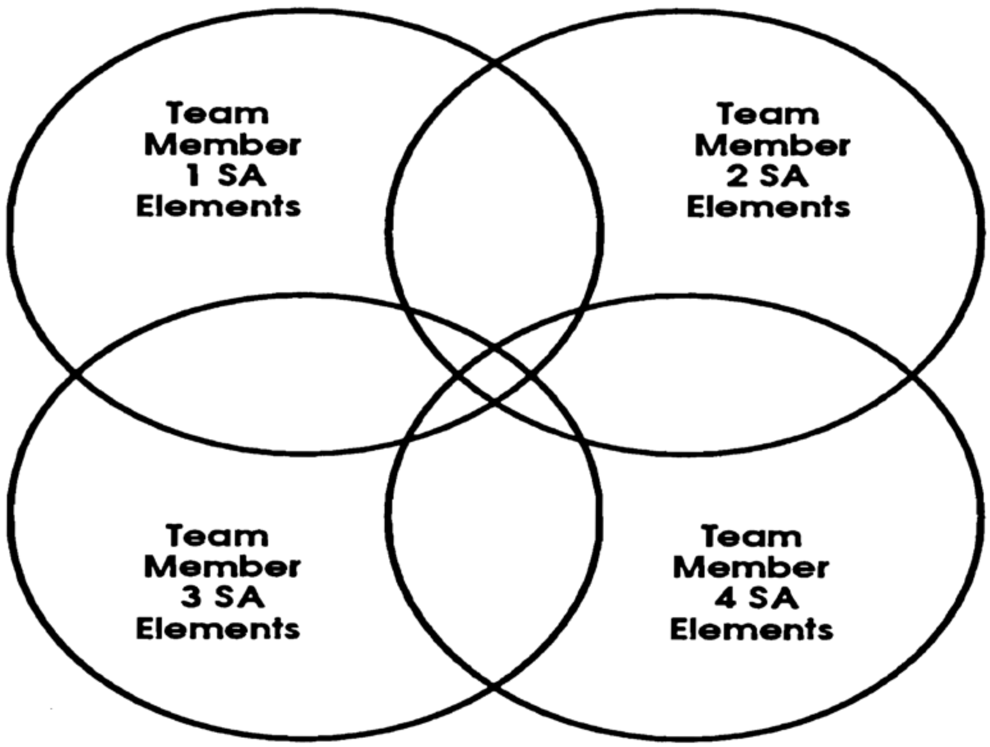

Figure 7. Team situation awareness. Source: Endsley (1995).

3. Smith and Hancock's Model

Smith and Hancock (1995) do not view SA in the same manner as Endsley, through the interrelationships of perception, comprehension, and projection. Rather, they view SA as a means to develop a "purposeful behavior" to accomplish a specific task. SA is "adaptive" to dynamic environments through the ability to "direct consciousness" to act in an acceptable manner. They used the perception-action cycle from Neisser (1976) as the framework for their model. They added the "invariant" as shown in Figure 8 (Smith & Hancock, 1995, p. 141) to account for interactions between the elements of the perception-action cycle. The invariant "codifies the information that the environment may make available, the knowledge the agent requires to assess that information, and the action the knowledge will direct the agent to take to attain its goals" (Smith & Hancock, 1995, p. 141).

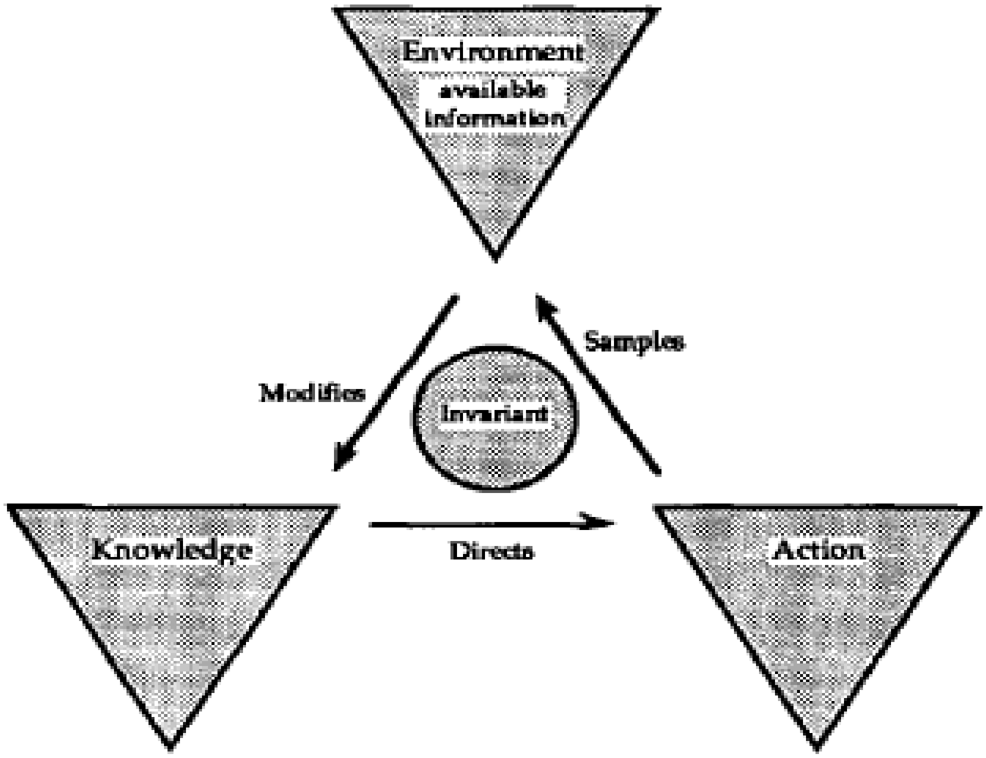

Figure 8. Perceptual Model of Situation Awareness. Source: Smith and Hancock (1995).

The idea that SA is adaptive gives way to the need to describe what allows it to change as the environment changes. Smith and Hancock (1995) explain that SA can only be developed if there is a goal to achieve. If an agent does not have a goal, they are merely observing the environment and not interacting towards a goal. Therefore, SA is not achieved for the agent. "To qualify for SA, the agent first must intend its goals, beliefs, and knowledge to match the task and performance specified by dicta from its environment and, then, must succeed to some degree in meeting those expectations" (Smith & Hancock, 1995, p. 139). The agent must have an idea of what is the "right stuff" or criteria required to evaluate performance toward a goal as indicated in Figure 9.

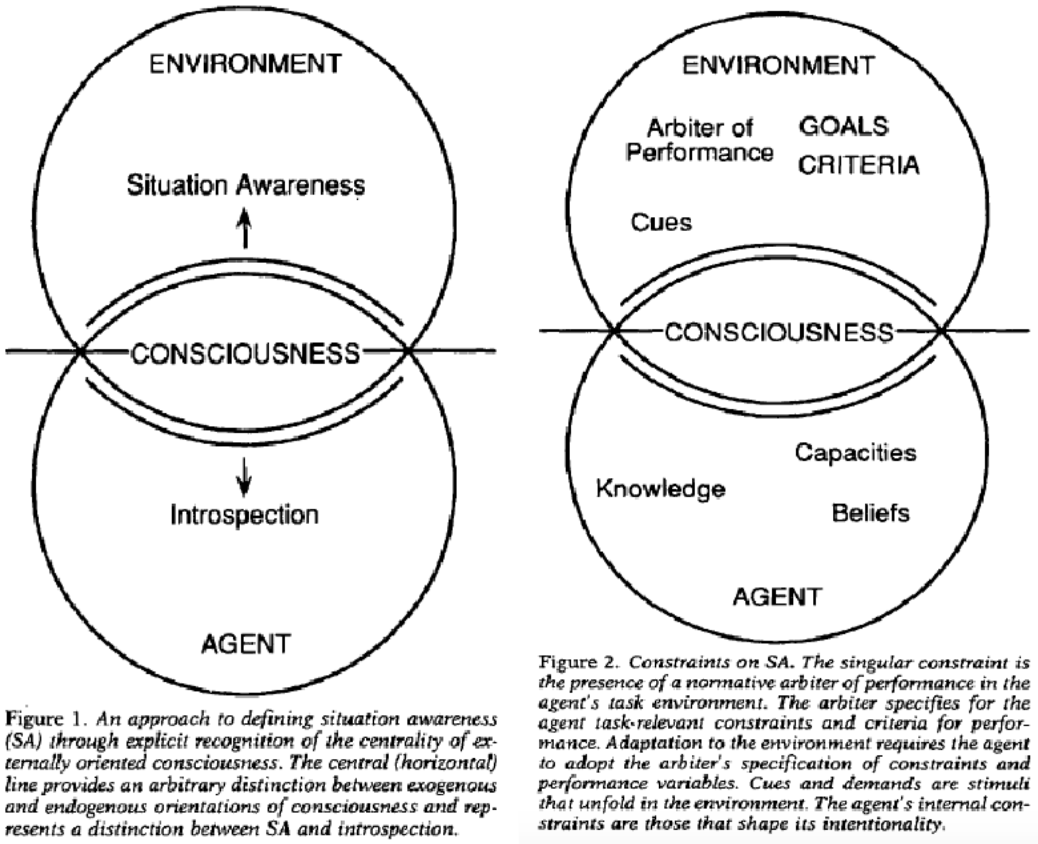

Figure 9. Environment and agent interaction. Source: Smith and Hancock (1995), as adapted by Beierl and Tschirley (2017).

The Department of Defense (DoD) (2018) describes SA through the use of a common operation picture (COP) or common tactical picture (CTP). The COP is “a single identical display of relevant information shared by more than one command that facilitates collaborative planning and assists all echelons to achieve situational awareness” (DoD, 2018, p. 46). The CTP is “an accurate and complete display of relevant tactical data link network, ground network, intelligence network, and sensor networks” (DoD, 2018, p. 46). The COP or CTP established at the tactical level is relayed to the higher echelon to further develop the situation awareness of all members of the team.

4. Team SA

Team SA plays an important role in the UTACC UxS program. The SA of the team must be understood in order to effectively incorporate machines into the team. Beierl and Tschirley (2017) determined that the team SA would be impacted by the SA deltas of the various team members. The team members may perceive the environment the same but comprehend the situation differently and therefore take different actions. UTACC is working toward the goal of incorporating a machine into the team and must take into account not only the SA of the humans toward the machine, but the machine's SA with respect to the team (Beierl & Tschirley 2017).

The transformation of individual SA into team SA, when a robot is involved, is more complex than human interactions alone. Murphy (2004) describes the nature of gaining team SA through a robot's sensors for interpretation "in order to enable safe and complete navigation," status of the mission and "communicate findings to other members" of the team (Murphy, 2004, p. 148) The SA, when incorporating robots, is "primarily about spatial relationships between objects and how that impacts robot navigation" (Murphy, 2004, p. 148)

Chen and Barnes reviewed human factors literature to determine the factors related to human supervision of robots, trust issues related to automation, and situational awareness in light of automation. Important considerations when taking the human out of the supervisory role include the appearance that situational awareness of an operator (or human supervisor) is degraded for tasks that are automated (Chen & Barnes, 2014). There is also awareness that interruptions in tasks will have a negative impact on situational awareness (Chen & Barnes, 2014). This concept is important when taken from the view of higher headquarters agents who by definition will have interrupted engagement with the information from individual, subordinate element robots. Additionally, this article examines effectiveness in variable attention capabilities, ability to develop and maintain spatial awareness and the effect of gaming experience on "visuospatial selective attention, multiple object tracking, rapid processing of visual information and imagery, and flexibility in attention allocation" (Chen & Barnes, 2014, p. 21). To improve transparency of automation, the "3P's (purpose, process, and performance) as well as the history" of those information elements should be available (Chen & Barnes, 2014, p. 22). It is also recommended that the information be simplified so as not to overwhelm a viewer. Among the conclusions of the article, the authors suggestion that “human factors design augmentation” be implemented to keep human agents situationally aware is directly applicable. (Chen & Barnes, 2014, p. 25)

Goodrich used particular mental models to develop principles in designing human robot interfaces. Using literature on attention and working memory, they created a model describing how humans process information. The model begins with short-term sensory memory capturing information from the environment. This sensory input is identified by the acronym SSTM (sensory short-term memory) (Goodrich, 2004). The inputs to this SSTM are human senses of hearing, seeing and touch. Goodrich also identifies the limited nature of humans to be able to apply attention to these inputs; in other words, not all sensory inputs are registered in SSTM. This information is then further processed into short-term memory or STM. The information in STM is information that will be used by the human for some purpose or to generate a response (Goodrich, 2004). Working memory is the next feature of this model which is defined as the information in STM that is also combined with some features of long-term memory; those features being “processes encoded as mental models” (Goodrich, 2004, p. 3) A mental model is defined by Goodrich as a representation that is internal to a person that is used to “encode, predict and evaluate the consequences of perceived and intended changes to the operator’s current state within a dynamic environment” (Goodrich, 2004, p. 4). Basically, the author defines a mental model as a mechanism from long-term memory that can modify the contents of short term memory as it is applicable to a certain situation. Figure 10 shows Goodrich’s interrelationships between short-term memory, working-memory, and long-term memory.

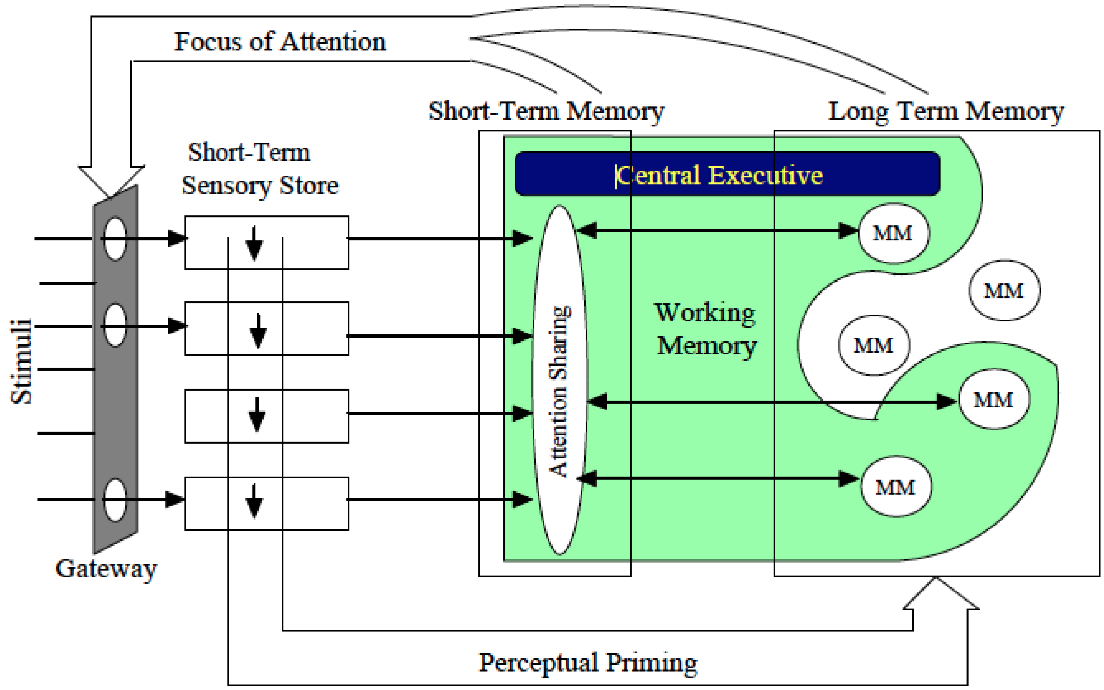

Figure 10. Interrelationships between computational elements. Source: Goodrich (2004).

F. CONCLUSION

This review offers several ways to consider Marine-machine teaming. For this research the key findings are five-fold. First, Johnson suggests that Marine machine teaming should be based on interdependence, where Marine and machine share common goals. Further, that those can be achieved by designing in observability, directability, and predictability between Marines and the machine. Interdependence analysis can help designers achieve this. Second, achieving OPD is based on understanding situational awareness. While many definitions exist, Endsley's model comes closest to defining a meaning applicable to our research question, especially the third level of SA, which has to do with projection. This relates well to Johnson's need for predictability.

Third, several researchers point out fundamentals of human machine interaction that seem obvious but are worth mentioning. That interface design is crucial. There also must be a set of tasks defined to develop an interface that builds SA for the team. A properly designed interface can be the difference between an effective and ineffective team.

Additionally, the interface needs to be user friendly in order to be a force multiplier in the battle space. The fourth key finding is that the need to build trust between the Marine and machine is vital to the success of teaming. The Marine must trust the machine to perform a task in a manner that is as effective as a human would. The machine must trust the human to act as the machine expects. OPD provides a baseline for trust to be established between human and machine.

Finally, the method of incorporating machines into a Marine unit needs to be adequate and feasible in order to be successful. The USMC utilizes doctrine as the baseline to perform all tasks. The use of TTPs which follow from doctrine, allows for Marine-machine teaming to be interdependent and builds trust within the team. For these reasons, the collaboration of Marine and machine must follow doctrine used by the USMC in order to be incorporated and increase the likelihood for success. There is substantial literature covering robotic autonomy and principles of designing interfaces for the operation of robots. Situational awareness is also a topic area that has established relevant theories for our research as it applies to military echelons external to a fireteam. There is not, however, an application of that research to the question that we are faced with. Namely, how does that exterior military echelon interface with an autonomous and interdependent robotic member of a fireteam? That synthesis will be the focus of this thesis.

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III. RESEARCH METHODOLOGY

This chapter outlines the process utilized by this thesis to determine what HMI MOEs and MOPs, if any, need to be established to allow for communication to higher echelons of command. The requirement to evaluate SA is important to enhance the communication flow and relevance of the information. To do this, the authors used a basic systems engineering process to evaluate the need for HMI in use for USMC applications. The next step was to determine how the Marine Corps establishes doctrine and evaluates the incorporation of the doctrine. The final step in MOE and MOP development was to use OPD as a basis for evaluation of the HMI to facilitate the decision making of higher echelons of command. This method is similar to Kulisz and Sharp (2017) as this thesis is expanding on their work for HMI MOEs and MOPs at the fire team level. The final step in the overall research process was to use SA models to ensure relevancy of the information content and to identify relevant properties of information display.

A. BASIC SYSTEMS ENGINEERING PROCESS

The analysis methods of the basic Systems Engineering Process as defined in "System Engineering Management 5th edition," (Blanchard & Blyler, 2016) was used in this thesis. The assessment by Kirkpatrick and Rushing (2016), based on the research of Rice, Keim, and Chhabra (2015), is accurate when Kirkpatrick and Rushing (2016) determined that "UTACC is a system of systems (SoS) capable of independent operations while operating within the Marine Corps' command and control model to ensure unity of effort when conducting operations" (Kirkpatrick & Rushing, 2016, p. 15). According to Kirkpatrick and Rushing's (2016) research, "the steps that were most applicable to this thesis were: definition of problem, operational requirements, and functional analysis. The entire process also incorporated feedback mechanisms as an important element of concept generations" (Rice et al., 2015, p. 21). These three steps were found to be of the most value for the given problem. Therefore, the focus was on the three steps to determine the feasibility of human-machine interaction within the Marine Corps' command and control structure. Figure 11 shows the basic Systems Engineering Model used for this thesis.

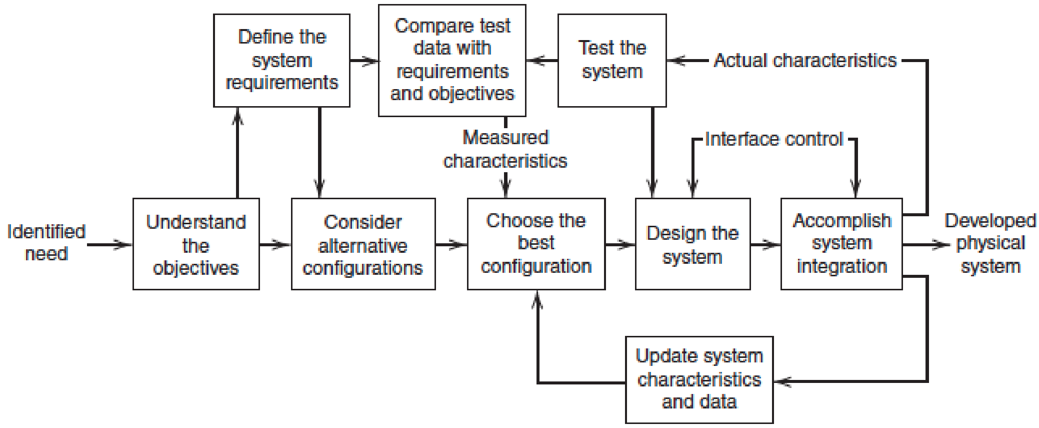


Figure 11. Systems Engineering Model. Source: Blanchard and Blyler (2016).

B. UTACC DEFINITIONS

The vast number of UTACC program theses makes it important to establish a baseline definition for terms. As such, the definitions below are directly sourced from Kulisz and Sharp's (2017) work:

Small tactical unit—a Marine Corps infantry fire team, infantry squad, or reconnaissance team.

UTACC—armed Marine(s) conducting operations with the assistance of a mix of semi-autonomous unmanned ground and air vehicles. One UTACC system is a triad of a human component, an air component, and a ground component.

Human Component—envisioned as a small tactical unit leader. UTACC should also be able to work with, provide input to, and receive direction from all members of a small tactical unit.

Air Carrier (AC)—an unmanned ground vehicle capable of carrying, launching, recovering, and refueling multiple unmanned air vehicles (UAVs). In addition, the AC will be capable of carrying additional supplies (e.g., ammunition, food) for the small tactical unit as well as acting as a communications relay for the UTACC components. In the future, this vehicle will be capable of high-speed travel over rough terrain and off-road areas.

Unmanned Air Vehicle (UAV)—an aerial platform capable of carrying any number of sensors to support mission specific intelligence, surveillance, and reconnaissance (ISR) requirements and capable of vertical takeoff and landing. The UAV will be capable of serving as a vital communications relay node between geographically separated ground components.

Ground Carrier (GC)—an unmanned ground vehicle capable of carrying, deploying, and recovering multiple unmanned ground vehicles (UGVs). In addition, the GC will be capable of carrying additional supplies (e.g., ammunition, food) for the small tactical unit as well as acting as a communications relay for the UTACC components. This vehicle will be capable of high-speed travel over rough terrain and off-road areas.

Unmanned Ground Vehicle (UGV)—mission specific unmanned systems capable of performing discrete ISR missions. The UGVs, similar to the UAVs, could have a variety of sensors to support mission specific ISR requirements.

Cue—is a notification issued by the UIS [defined immediately below] to the Human Component where human intervention is not required.

Alert—is a prompt issued by the UIS to the Human Component requiring human intervention. (Rice et al., 2015, pp. 26–27)

In addition to the preceding terms, it is necessary to update the definition of user-interface system from Kulisz and Sharp’s (2017) so that the concepts generated by this thesis can be accurately portrayed. Using Kulisz and Sharp’s (2017) user interface definition as a starting point, we adjust it for this thesis and also define the term headquarters element:

User Interface System (UIS)—a combination of devices that stimulate multiple senses in the human. In addition to presenting local information to the human component, the UIS will also present information to the headquarters element that may be local, geographically separated, or a combination of those circumstances. The devices also receive input from the human component and headquarters element.

Headquarters Element—a military unit of a higher echelon than the human component. This may include an echelon such as a squad, platoon and company etc.

C. UTACC ASSUMPTIONS

The lack of current USMC doctrine and research in the field of human-machine teaming has resulted in a number of assumptions by UTACC theses. These assumptions have been carried over from previous UTACC theses and most recently by Kulisz and Sharp (2017). They utilized a technologically agnostic methodology. The authors of this thesis used the same approach to further the evaluation of the human-machine interface.

The most noteworthy assumption made by Kulisz and Sharp (2017), which the authors used in this thesis, is that UTACC could evaluate the human-machine team through the use of the USMC Task List. This will ensure that the machine is being evaluated on the same standard as a Marine and, likely, will increase trust among the team. The machine is intended to perform the functions of a human and increase efficiency and effectiveness for the USMC. Therefore, the process of evaluation for the incorporation of a robot should be similar to that of the human operator.

Another assumption made by Kulisz and Sharp (2017) that is still viable is that the MCTL metrics used would "accurately reflect metrics applied to UTACC in future testing" (p. 21). The UTACC program may change over time due to personnel, budget considerations, and changes in priorities by sponsors; however, the end goal for UTACC is not likely to change in the near future.

D. UTACC CONSTRAINTS

The lack of physical resources (machines and Marines) to utilize for testing purposes is a significant constraint. The inability to gather a Marine infantry unit and machines to determine best practices provided a significant challenge. Therefore, current technology and research in the field of HMI was used to make informed decisions as to the best way to employ machines to increase effectiveness and capability of Marine units.

E. ROLE OF DOCTRINE AND TTPS

Marine Corps doctrine is at the root of everything that the USMC accomplishes. The backbone of the institution is founded on doctrine which is grouped into categories such as Marine Corps organization and standards, warfighting and Naval Operations. The foundation of USMC doctrine is comprised of the 10 Marine Corps Doctrinal Publications (MCDPs) which are "higher order doctrine containing fundamental and enduring principles regarding warfighting and the guiding doctrine for the conduct of major warfighting activities" (USMC, 2006). Following MCDPs are the Marine Corps Warfighting Publications (MCWP) which "describe how the [Marine Air Ground Task Force (MAGTF)] fights and subject matter that supports and enables MAGTF deployment and employment" (USMC, 2016f). Finally, there are Marine Corps tactical publications (MCTP) "focused on community-specific or functional tactics that support MAGTF operations" (USMC, 2016f) and their subordinate Marine Corps Reference Publications (MCRP) containing "general reference and historical material, or more specific/detailed" tactics (USMC, 2006).

The Marine Corps Task List (MCTL) is the next element that can be considered Marine Corps doctrine. The MCTL "allows for quantifiable measurement of proficiency in military skills and capabilities" (Kirkpatrick & Rushing, 2016, p. 19). The mission of the MCTL, as listed on the MCTL branch website, is as follows:

> MCTL is the authoritative, standardized, and doctrinally-based lexicon of USMC capabilities defined as Marine Corps Tasks (MCTs) and used by units, installations and the supporting establishments in the development of Mission Essential Tasks and Task Lists (METs/METLs). METs/METLs are the list of "essential," critical, discrete, externally-focused MCTs that directly enables the execution of the organizational mission. Capabilities, defined as "MCTs" and resident in MCTL enable Commanders to document their command warfighting operational abilities as METs/METLs, providing force sourcing planners, trainers and concept developers with single common language "tasks" articulating both Joint and USMC-specific, manpower, equipment and training requirements. ("Marine Task List Branch," n.d.)

Each Marine Corps Task (MCT) is comprised of pertinent MOPs and MOEs to evaluate a particular unit's ability to accomplish their warfighting functions. Table 1, from

Kulisz and Sharp (2017), provides an example of how a MCT is used to evaluate the readiness of a unit for a particular task.

Table 1. Excerpt from MCTL 2.0. Source: USMC (2018a).

MCT 5.3.1.2 Exercise Tactical Command and Control
Tactical command and control provides purpose and direction to the varied activities of a military unit. It is the means by which the Commander recognizes what needs to be done and sees to it that appropriate actions are taken. Tasks include: to order warfare degrees of readiness; to direct asset assignment, movement, and employment; and, to control tactical assets, including allied and joint forces assigned. **(JP 1-02, 3-0, 5-0, 5-00.2, MCDP 1-0, 6, NDP 6, NWP 3-21, 3-21.0 Rev A, 3-56.1 Rev A, 6-00.1, NTA 5.4.1.2)**

M1	Time	For units to respond to tasking.
M2	Time	Delay in response to orders.
M3	Percent	Of units responding appropriately to orders.
M4	Percent	Of mission objectives attained.

There are many MCTs that account for all mission capabilities across the USMC and many MOEs and MOPs to evaluate them. As identified by Kulisz and Sharp (2017), however, MOEs and MOPs do not exist for human-machine teaming. Kulisz and Sharp (2017) identified potential MOEs and MOPs which will be elaborated on later in this chapter.

F. DEVELOPMENT OF MOES AND MOPS

The development of MOEs and MOPs begins with the overarching guidance from the top. Kulisz and Sharp (2017) referred to this as the “developmental layers of analysis.” The “layers” provide the basis for MOEs and MOPs as depicted in Figure 12. The Chairman of the Joint Chiefs of Staff (CJCS) J-7 provided the top-level guidance to the authors by virtue of establishing the joint definitions and purposes of MOEs and MOPs. The next level to consider is the Director, Operational Test and Evaluation’s (DOT&E) approach to determine effectiveness. The mission of DOT&E, as listed on their website, is “responsible for issuing DoD OT&E policy and procedures; reviewing and analyzing the results of OT&E conducted for each major DoD acquisition program” (“DOT&E Mission,” 2018). They provide a detailed approach to determine the effectiveness of a particular system. The final consideration is the proposed UTACC MOEs and MOPs that were introduced by Kulisz and Sharp (2017) and further revised by MCTs of interest to the UTACC program and the OPD Interdependence Analysis (IA) Tables from Zach's Coactive Design thesis (Zach, 2016).

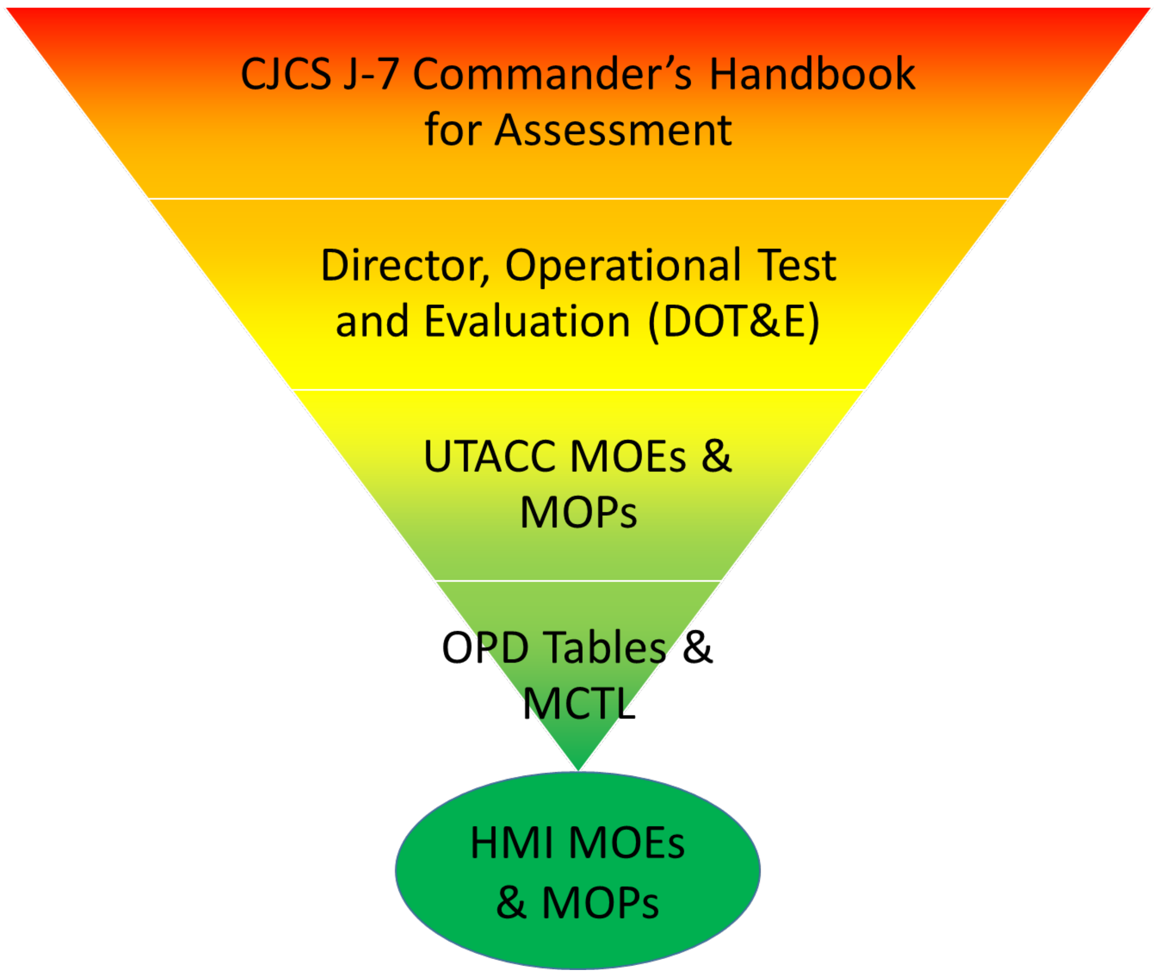


Figure 12. Framework for HMI MOE and MOP development. Source: Kulisz and Sharp (2017, p. 24).

1. CJCS J-7 Commander's Handbook for Assessment

The CJCS J-7's Commander's Handbook for Assessment Planning and Execution establishes a baseline for developing MOEs and MOPs for the UTACC systems. The MOEs and MOPs establish a metric to assess how the system is performing and if it is accomplishing the goals of a mission. Notably, this handbook is not an approved directive, but rather a supplemental document for the assessment process.

The CJCS J-7 Commander's Handbook states that "the assessment process uses MOPs to evaluate task performance and MOEs to determine progress of operations toward achieving objective, and ultimately the end state" (USJCS J-7, 2011, p. III-4). Figure 13 (USJCS J-7, 2011, p. III-5) shows how the MOPs and MOEs are utilized for assessment. The authors believe this to be an effective method to determine if new MOPs or MOEs are required or changes need to be made as the HMI is elevated to higher echelons of command.

ASSESSMENT MEASURES AND INDICATORS

MOE	*MOP*	*Indicator*
Answers the question, "*Are we doing the right things?*"	Answers the question, "*Are we doing things right?*"	Answers the question, "*What is the status of this MOE or MOP?*"
Measures purpose accomplishment	Measures task completion	Measures the data inputs to inform MOEs and MOPs
No hierarchical relationship to MOPs	No hierarchical relationship to MOEs	Subordinate to MOEs and MOPs
Often formally tracked in formal assessment plans	Often formally tracked in execution matrices	Often formally tracked in formal assessment plans
Typically challenging to choose the correct ones	Typically simple to choose the correct ones	Typically as challenging to choose as the supported MOE or MOP

Figure 13. Assessment measures and indicators for MOPs and MOEs. Source: USJCS J-7 (2011, p. III-5).

2. Director, Operational Test and Evaluation

As identified by Kulisz and Sharp (2017) "DOT&E is the primary agency responsible for the operational testing and evaluation of major DoD acquisitions programs"

(Kulisz & Sharp, 2017, p. 25). UTACC is in the early phase of research towards development of unmanned systems. It is important to follow the guidelines of established policy, as with DOT&E, to minimize the impact of problems that may arise later in the process.

Kulisz and Sharp (2017) identified the need to use the generic "Vee" approach, depicted in Figure 14, to ensure that the user and developer are both involved throughout the Systems Engineering Process. This is an effective and efficient way to ensure that the developer and customer can identify issues early in the design process to avoid setbacks and control costs. This will also allow the customer to be part of the design process.

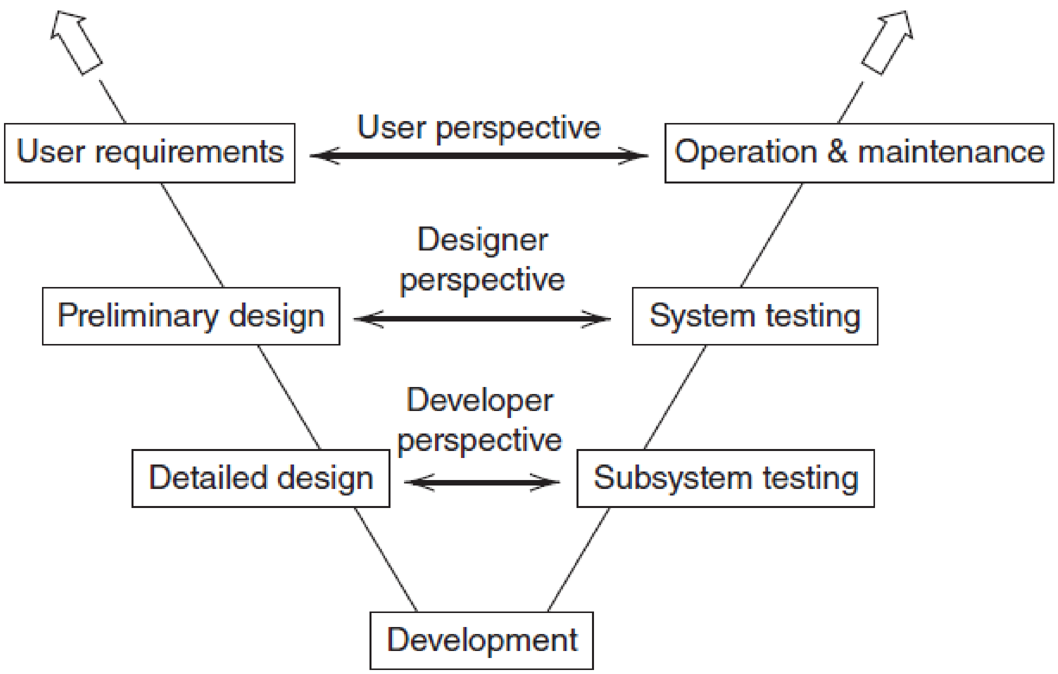


Figure 14. Generic "Vee" Developmental Model. Source: Blanchard and Blyler (2016).

As stated by Kulisz and Sharp (2017), metrics are invaluable to determine the success of testing. After a review and evaluation, the authors applied the same framework for developing metrics as used by Kulisz and Sharp (2017) which originated from DOT&E. Continuous or discreet metrics are generated based on the type of assessment mechanism that is intended. Continuous metrics rely on quantitative feedback into their outputs (Kulisz & Sharp, 2017). An example of the output is shown in Table 2. As Kulisz and Sharp (2017) state, the metric that causes the MOP to be continuous is the variable of 100 meters rather than the "meets threshold" evaluation of "Y."

Table 2. Continuous metric example. Source: Kulisz and Sharp (2017, p. 27).

Task	Variable	Meets Threshold
Relay information to Platoon Commander	100 meters	Y

Discrete metrics are measured by a pass/fail metrics. An example of discrete metrics is provided in Table 3.

Table 3. Discrete metric example. Source: Kulisz and Sharp (2017, p. 27).

Task	Meets Threshold
Relay information to Platoon Commander	Y

Continuous metrics provide a basis for measuring the effectiveness of a task. Discrete metrics, however, disregard the context and is limited in its ability to provide relevant information (Kulisz & Sharp, 2017). The discrete example does not provide pertinent information, such as, how far away the machine is from the Platoon Commander. The authors decided to follow the methods used by Kulisz and Sharp (2017), using discrete metrics for MOEs and continuous metrics for MOPs. Table 4 provides a visual directly from Kulisz and Sharp (2017) to solidify the idea.

Table 4. Discrete/continuous metric application to MOEs and MOPs. Source: Kulisz and Sharp (2017, p. 27).

MOE	Task		Threshold
1.0	Sensor is resilient to operating environment		Y
MOP	Task	Variable	Threshold
1.0.1	Sensor is waterproof	50 m	Y
1.0.2	Sensor is windproof	40 kts	Y
1.0.3	Sensor is temperature-proof	-30° to 180° F	Y

3. UTACC MOEs and MOPs

As stated, UTACC does not have approved MOEs and MOPs for human-machine teaming. Kulisz and Sharp (2017) developed a proposal for MOEs and MOPs by way of a recommended addition to the MCTL 2.0, depicted in Table 5.

Table 5. Recommended update to the MCTL 2.0. Source: Kulisz and Sharp (2017, p. 33).

MCT	Title
5	Exercise Command and Control
5.1	Acquire, Process, Communicate Information, and Maintain Status
5.1.1	Provide and Maintain Communications
5.1.2	Manage Means of Communicating Information
5.1.3	Maintain Information and Force Status
5.1.4	Maintain Two-Way Communication with Autonomous Robotics

The recommended addition was MCT 5.1.4, due to the unique nature of communication between human and machine. They further elaborated on MCT 5.1.4 as shown in Table 6.

Table 6. Recommended update to MCT 5.1.4. Source: Kulisz and Sharp (2017, p. 33).

MCT	Title
5.1.4	Maintain Two-Way Communication with Autonomous Robotics
5.1.4.1	Identification of Team Members
5.1.4.2	Explicit Human-Initiated Communication
5.1.4.3	Explicit Robot-Initiated Communication

The work done by Kulisz and Sharp (2017) directly relates to the subject of this research. As such, we have used the proposed changes to the MCTL 2.0 for further evaluation of applicability to communication beyond the scope of a Fire Team.

The ability to successfully create a human-machine team is dependent on creating observability, predictability, and directability (OPD). The human and machine need to have OPD to increase effectiveness, reduce cognitive load, increase SA, and achieve better decision making.

Table 7 demonstrates the framework employed by Kulisz and Sharp (2017) to use Coactive Design IA Tables to establish required technical parameters for evaluation. The tasks are in the left column. The tasks are then broken down by specific OPD requirements to determine the most effective method for mission accomplishment. The colors represent the extent of assistance either entity (man or machine) can provide to the other in the performance of the task. The end result is a focused MOP. This method facilitates effective development of MOEs and MOPs.

Table 7. Coactive design IA tables. Source: Kulisz and Sharp (2017, p. 30).

			Option 1			Option 2			Option 3			
Tasks	Subtasks	Capacities	UAS	UGS	M	UGS	UAS	M	M	UAS	UGS	OPD requirements
Maintain COP	Send Imagery and Data Back to COP and to Leaders											They may be positioned during this portion of the mission to extend the communication lines, where the UxVs serve as intermediate relay nodes in the communication link between the objective back to a HHQ or adjacently operating unit that would otherwise experience degraded or no communication links.
Tactical Alerts and Cueing	Provide Alert Message to Team When Critical Tactical Events Occur (Team Response Required)	Recognize Tactical Alert Scenario										The UxVs should always notify the team of critical tactical events, including: when in the vicinity of checkpoints and other important grids, when a high value target or be on the look out was spotted, direction and distance of enemy contact, etc.
	Provide Cues to Team When Less Than Critical Tactical Events Occur (Team Response Optional)	Recognize Cueing Scenario										The Team Leader may also want the UxVs to notify him of additional events like approaching traffic, or potential hot spots along the route where possible IEDs may be emplaced, etc.

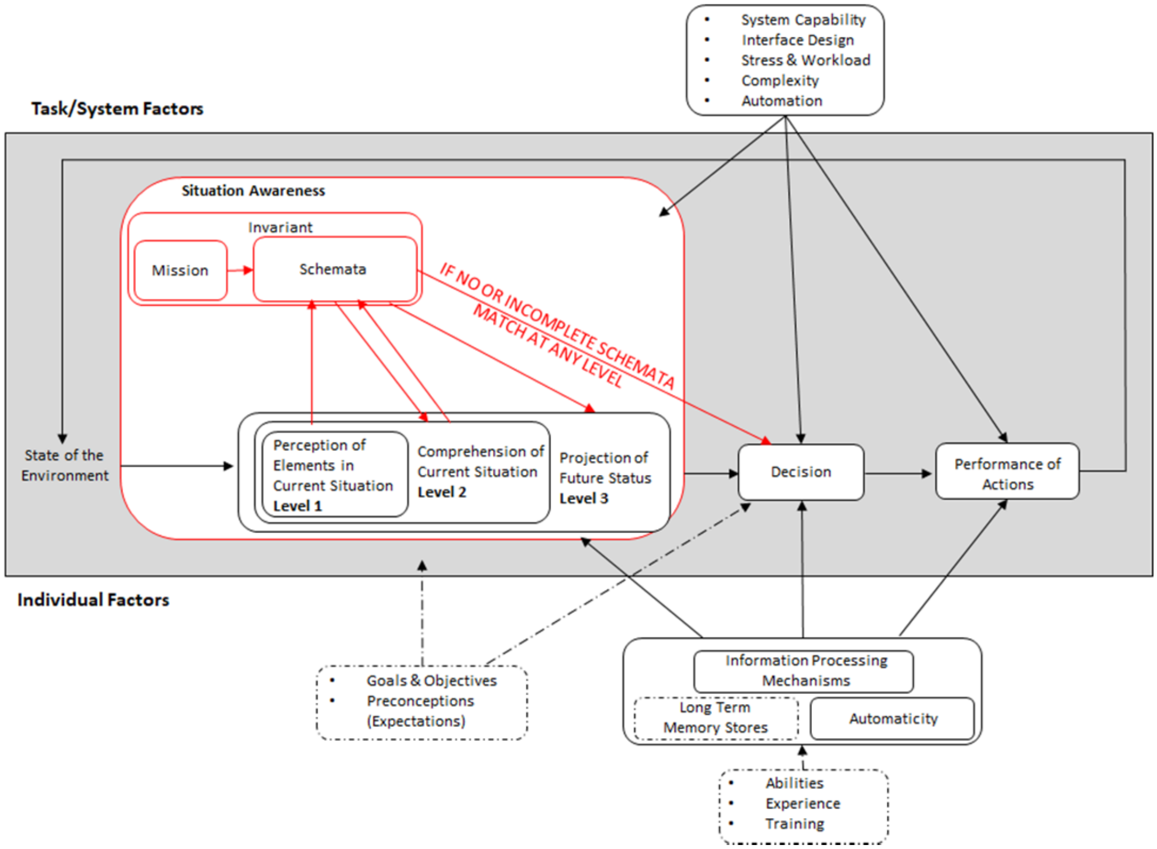
G. ROLE OF SITUATIONAL AWARENESS AS A METRIC

Situation Awareness is not easily measured with human subjects. As identified by Beierl and Tschirley (2017), however, "machine programming provides an opportunity to record and evaluate objective SA data. Specific SA assessments should seek to map the interactions between agent perception and the particular schema used to build comprehension and projection in order to improve programming" (Beierl & Tschirley, 2017, p. 64). The ability to measure SA of the UxS allows the human agent to better employ the machine for effective and efficient results.

The ability to measure SA of a machine can be accomplished with proper coding for a given situation. The machine can be programmed to perform a task while taking the environmental variables into account. The actions of the machine can then be evaluated in the same manner as is done for a human. The ability to code a machine for a specific task is similar to the training and education of a human. Additionally, though, the code for a machine can be verified and logs can be reviewed to provide an objective evaluation of performance. This is similar to the process of evaluating humans through a standardized metric. The authors believe that for this reason, the machine can be evaluated using similar types of MOEs and MOPs to which Marines are held accountable.

Beierl and Tschirley (2017) did extensive research on SA for human-machine teaming as it applied to a particular task. Their focus was on the USMC doctrinal Training and Readiness (T&R) event “INF-MAN-3001: Conduct fire and movement.” They used a combination of Hancock and Smith’s SA Model and Endsley’s SA Model to develop a suitable model for UTACC HMI. Beierl and Tschirley’s Model adapted from Endsley’s is shown in Figure 15.

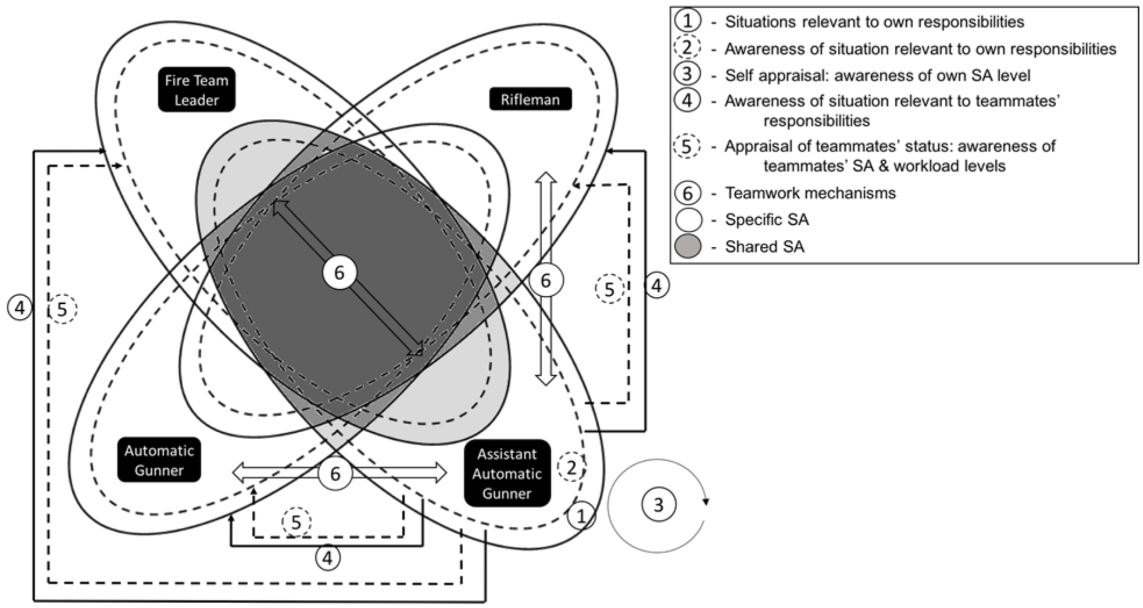
Beierl and Tschirley (2017) replaced Endsley’s “goals and objectives” with mission as the driving factor for SA. They proposed that “the mission should be the central starting point of the model because SA cannot exist without an externally oriented task, goal, or objective” (Beierl & Tschirley, 2017, p. 44).



Dashed boxes are subsumed into mission and schemata boxes

Figure 15. Proposed Model of Individual SA. Source: Beierl and Tschirley (2017, p. 45).

The need for individual SA is apparent. The need for team SA, however, is of more importance to the UTACC program. The interdependence of humans and robots relies on team SA and trust. Beierl and Tschirley (2017) noted this and adapted a team SA model from Sulistyawati, Chui, and Wickens (2009) with emphasis on specific and shared SA as shown in Figure 16. Beierl and Tschirley (2017) define specific SA in reference to an individual member of the team. Team SA is composed of the specific and shared SA (Beierl & Tschirley, 2017). The specific SA is shown within the ellipse while shared SA is shaded.



Ellipses were used as opposed to circles in order to display all possible iterations of shared SA. Circles suffice for depicting shared SA regions between three members, but not for teams of four members

Figure 16. Model of Team SA from a team member's perspective. Source: Beierl and Tschirley (2017, p. 47).

Beierl and Tschirley (2017) determined that the SA model would be different for the team leader due to the requirement that they be held accountable for the entire group. The team leader SA perspective is shown in Figure 17. The leader is concerned with not only their own SA or the specific SA of a team member, but also the overall team SA. This principle applies to all levels of command. The leader of a team, regardless of the size of the team, must account for individual SA and team SA. The Fire Team Leader in Figure 17 can be exchanged for a Platoon Sergeant, Platoon Commander, or anyone else in a leadership role. The ability of the team leader to quickly assess the team SA allows for quicker and more appropriate decision making.

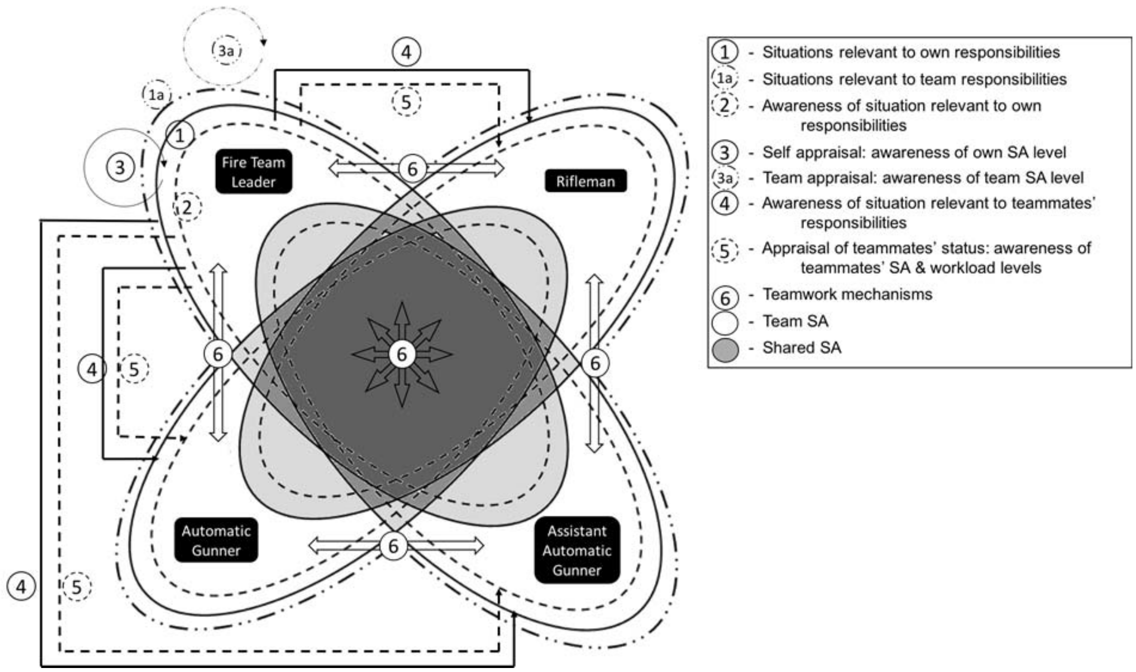


Figure 17. Model of Team SA from the Fire Team Leader's perspective. Source: Beierl and Tschirley (2017, p. 49).

As stated previously, the need for interdependence for the human-machine team relies on SA and trust. An effective method to increase SA and trust is through the use of OPD. The ability of the human and machine to observe, predict, and direct the actions of each other will lead to trust in what each member is doing. The human or machine will gain SA and trust through the process of OPD. Beierl and Tschirley (2017) noted this through the use of Endsley's three levels of SA to intrateam mechanisms shown in Figure 18. Beierl and Tschirley determined "application of OPD principles to team interface design will generate the intrateam visibility that is necessary in the infantry fire team" (Beierl and Tschirley, 2017, p. 50). This principle can be scaled accordingly and applied to higher echelons of military commands.

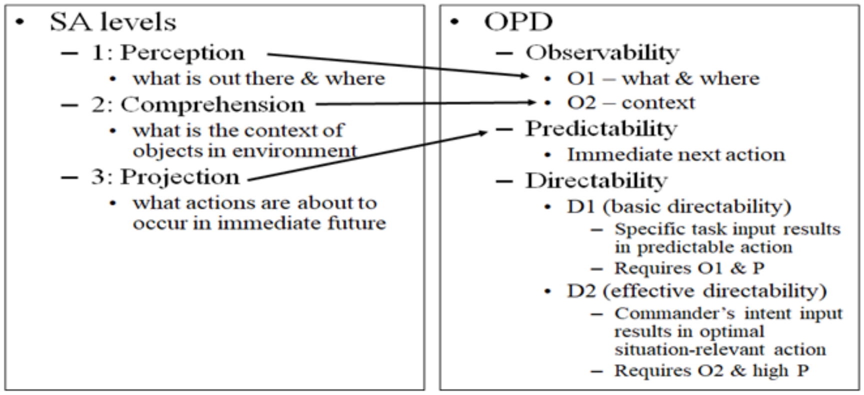


Figure 18. Levels of SA applied to OPD. Source: Beierl and Tschirley (2017, p. 50).

Beierl and Tschirley (2017) used the principles from the SA model to develop IA Tables for the first subtask, "suppress the enemy," of their selected T&R event, "conduct fire and movement" (USMC, 2016b, p. 7–56). They evaluated the task in regards to standard USMC TTPs for mission, enemy, terrain and weather, troops and fire support, time available, space, and logistics (METT-TSL). Table 8, shows the assessment for mission SA for the subtask "suppress the enemy." The fire team leader has to be able to communicate with the machine and the machine must be able to provide acknowledgement back to the team leader. The need for proper communication flow plays a significant role in team SA, OPD, and trust.

Table 8. IA table: Mission SA requirements. Source: Beierl and Tschirley, (2017, p. 52).

Tasks	Subtasks and Description	Capacities	Level 1 SA requirements (METT-TSL)	SA requirements justification	FTL	AR	AAR	RIF	FTL	UxS	AAR	RIF	OPD/common ground/shared mental model requirements & comments
(A) INF-MAN-3001 Conduct fire and movement. Fire and Movement is a technique of advance in which elements provide their own suppression and move by bounds. Elements and individuals alternate the firing and the moving so that movement is always covered by fire, and the assaults momentum is retained.	(A.1) Suppress the enemy. Suppress is an enemy-oriented tactical mission task that results in the temporary degradation of the performance of a force or weapon system below the level needed to accomplish the mission. "Fore" position 1) engages the enemy and 2) covers sector (if no enemy present).	-Aim weapon -Fire weapon	(A.1.M.1) Mission objective	Context: what is the larger mission objective and how does suppression support mission objective? At minimum, FT must understand the next higher level (squad) task.									Directability: FTL needs capability to issue orders to UxS. AR and UxS may receive orders from higher levels of chain of command for efficiency reasons, but at minimum FTL needs capability. Observability: FTL needs capability to confirm UxS receipt of orders Predictability: FTL needs capability to assess UxS comprehension of orders. True understanding of the objective may be extremely difficult for a machine. Use of OSMEAC mission order format, tactical tasks (seize, screen, destroy, etc) and success criteria (1st platoon occupies hill 512, 25% of enemy armor assets K-kill, etc) will allow machine to "understand" mission objective. Mission orders received via chain of command through FTL, but AR may assist with interpretation of mission orders. UxS incapable of that assistance role - mission parameters must be programmed. Interface examples: Mission map interface with standard military ops terms & graphics would allow FTL to confirm robot has downloaded mission parameters. Map walkthrough played by robot would confirm for FTL that robot understands the intended COA. Read back or visual display of mission parameters and constraints would allow FTL to confirm robot settings are correct for mission (ROE, weapon conditions, information requirements, etc). AAR & RIF can assist with orders process if they have ability to interface with UxS (this may depend on system security, access permissions, and chain of command programming).
			(A.1.M.2) Location of objective	Where is the objective in relation to suppression?									Directability: FTL needs capability to communicate objective location to UxS. Observability: FTL needs capability to confirm UxS receipt of absolute/relative objective location. Predictability: FTL needs capability to assess UxS navigable routes to objective location. Robot can't know until programmed but once programmed it can track objective location better than Marines and assist team with navigation. UxS could plot possible routes that are navigable by UxS and humans (dependent on quality of navigation system data and navigability programming).
			(A.1.M.3) Commander's intent	Context: why conduct this mission?									Machines may never understand this, or at least take a long time
			(A.1.M.4) Course of action / scheme of maneuver	Context: how does this task fit into scheme of maneuver?									Directability: FTL needs capability to communicate COA to UxS. Observability: FTL needs capability to confirm UxS receipt of COA. Predictability: FTL needs capability to assess UxS understanding of COA (i.e., COA impact on route selection, navigability of COA routes, etc). May be similar to boundaries in terms of machine tacking of COA, but these are soft guidelines, not hard rules like boundaries. COAs are oftentimes communicated visually through ops terms and graphics on a map or imagery. Could be implemented with software that interprets ops terms and graphics drawn onto a touchscreen map interface, but interpretation of physical maps/imagery with COA diagrams would be ideal.
			(A.1.M.5) Priority of targets	Which types or specific targets are high value/payoff? If multiple targets present themselves, which should be engaged first? (Automatic gunners would typically focus on enemy automatic weapons over riflemen).									Directability: FTL needs capability to communicate target priorities to UxS. Observability: FTL needs capability to confirm UxS receipt of priorities. Predictability: Confirmed when UxS selects targets based on priorities. Achieved through training/experience with dynamic targets of varying priorities. Doctrinal for human AR. Current UxS could be programmed with priority targets but may struggle with application during execution. If machine can identify and distinguish targets by function/capability, it could execute this task with less or without assistance. Machine learning can overcome ability to identify enemy uniforms, vehicles, weapon systems visually/aurally. If machine could assess priority targets during execution and had access to distributed target data or camera feeds from other team members, could dramatically assist with assessing priority targets based on larger picture of the whole team.
			(A.1.M.6) Assignment of targets	Which targets did the FTL assign to the AR? Which targets are assigned to other FT members?									Directability: FTL needs capability to assign targets to UxS. Observability: FTL confirms receipt of target assignment by observing UxS fires - no different than with Marine. Predictability: Built through training and experience of target assignment & resultant actions. UxS should expect target assignments from FTL & needs to monitor FTL for assignments/updates during actions. If machine could process enemy targets, friendly locations, boundaries, COAs, etc. then machine may be able to optimize target assignments and feed info to other members. If UxS is currently incapable of identifying targets and implementing target assignments independently, a "gun buddy" UxS that follows a particular Marine and shoots what that Marine shoots may achieve intermediate progress (could be conducting machine learning for future capability at same time). Gun buddy UxS could feed Marine information from its sensors through various heads up interfaces that could support a hybrid Marine/machine buddy team that optimizes combination of robotic gains with Marine cognition and decision-making.

The ability to incorporate SA into a metric that can be objectively evaluated is a tough task for the UTACC program as it applies to HMI. The need to evaluate SA is relevant to the use of machines as part of USMC teams and the ability to exchange information between various levels of command. The ability to evaluate SA will lead to enhanced team SA and better informed decisions. The end result is a more effective and efficient Marine Corps unit. The authors feel that the most logical method is to apply UTACC SA models to a subset of relevant MCTL 2.0 items. This will allow for the objective evaluation process that the USMC currently uses for assigned tasks.

H. INFORMATION DISPLAY

The final level of analysis required when formulating interface design requirements is the manner of information display. As the analysis progresses further up the level of military hierarchy, the importance of display increases as the proximity of UTACC actors become farther separated. Individual members of a fireteam will be relatively close to one another while individual members of a company could be spread over large distances. The authors use Wickens, Lee, Liu and Becker’s (2004) categories of display design based on perception, mental model, attention, and memory to identify key characteristics depending on the information presented. A survey of the thirteen principles described by Wickens et al. (2004) is listed in Table 9. All thirteen principles do not apply to every element of information, but they were used to screen those elements to recommend how they should be presented.

Table 9. Categories of display design. Source: Wickens et al. (2004).

Perception	**Mental Model**	**Attention**	**Memory**
Legible / audible	Pictorial Realism	Minimize access cost	Replace memory with visual information
Avoid absolute judgement limits	Moving Part	Proximity Compatibility	Predictive Aiding
Top-down processing		Multiple resources	Consistency
Redundancy Gain			
Discriminability			

I. CHAPTER CONCLUSION AND SUMMARY

The need for a HMI that can be held accountable to the standards set forth by the USMC is required in order to build a successful human-machine team. The most logical way to do that is by expanding the current standards to account for the actions required by a machine. The machine needs to be objectively evaluated on its ability to perform the required tasks as a member of a team. The use of OPD, MOEs and MOPs make a human-machine team on the battlefield a realistic goal for the USMC.

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IV. UTACC INTERFACE DESIGN

The interface design is critical to ensure that a human-machine team can collaborate towards common goals. Chapter III discussed the methods used to evaluate the methods for HMI requirements. Chapter IV leverages the USMC method for evaluation, MCTL 2.0, to determine interface design specifications. The implementation of interface design requirements will increase the likelihood of positive human-machine teaming.

A. INTRODUCTION

A preliminary screening of MCTL 2.0 developed the basis for the expansion of UTACC HMI MOEs and MOPs with an emphasis on SA. The need to create standards for the HMI is crucial to the successful incorporation and collaboration in any USMC unit. As with human members of a military team, an ability to evaluate the way robots perform in the context of a group is essential. Unfortunately, the method by which the evaluation takes place for machines is much harder to determine. The USMC uses MCTL 2.0 as the current basis to evaluate force readiness. As such, the implementation of machines should be evaluated in the same manner to avoid confusion and maintain the standards that have already been established. Kulisz and Sharp (2017) evaluated Marine Corps Tactical Task (MCT) 5 to determine some baseline needs for HMI evaluation. This thesis takes a broader approach by evaluating MCTL 2.0 and determining where the machine may be useful and needs evaluation.

The requirement to account for SA while integrating machines is a critical component to ensure collaboration is effective. The ability to evaluate SA in this context can be incorporated in the applicable tasks that make up MCTL 2.0. For this reason, UTACC related MCTs within the MCTL 2.0 need to be crafted so that they allow for objective evaluation. This ensures that SA is enhanced by the use of the HMI. SA degradation defeats an important factor in the use of the machines: their use as a force multiplier. The need for an interoperable machine is apparent, as the machine can perform tasks that a human may not be able to perform or have risks that are too high to make the task feasible by a human. The loss of SA, however, may impact the task to a level where the machine is not a viable option. This is a crucial factor for incorporating UTACC-enabled SA within MCTL 2.0 and a robot into a human team.

B. PRINCIPLES OF THE INTERFACE

At a UTACC-enabled small unit, there will be one or more robots that will have a user interface system (UIS). The possibilities for the UIS at a small tactical unit are well defined by Kulisz and Sharp (2017) as they survey the sensory modes possible for implementation: visual, audio, haptic and electromagnetic. We do not repeat their analysis. We look only at those characteristics required to team across military echelons: namely, information exchanged between a higher headquarters element and the smaller tactical unit.

There will be principles of interface design that will hold true no matter the type of information being exchanged. The determining factor in establishing these principles is the form factor and capabilities of the devices chosen to relay the information that is being exchanged. The characteristics of the information being exchanged will also inform the interface design, but that will be tied specifically to the type of information. There are also two "ends" of the communication link that must be analyzed to determine the appropriate principles: the higher headquarters and the small tactical unit. Another way to describe this is by asking two questions. First, what information is required to maintain situational awareness? Secondly what are the other, common characteristics required by the interfaces?

1. Situational Awareness

There are certain elements of information that must be exchanged to establish or maintain situational awareness in a military environment. Beierl and Tschirley (2017) identified the ability to tie Endsley's levels of situational awareness to OPD principles to generate necessary visibility between teams. Figure 19 depicts the situation, status and teamwork mechanisms intersecting between a company commander and platoon commanders. This is simply applying the Model Beierl and Tschirley (2017) adapted for the fireteam level to a higher military echelon. This usage along with applying Endsley's level of situational awareness to OPD principles provides us with specific information elements required to be exchanged.

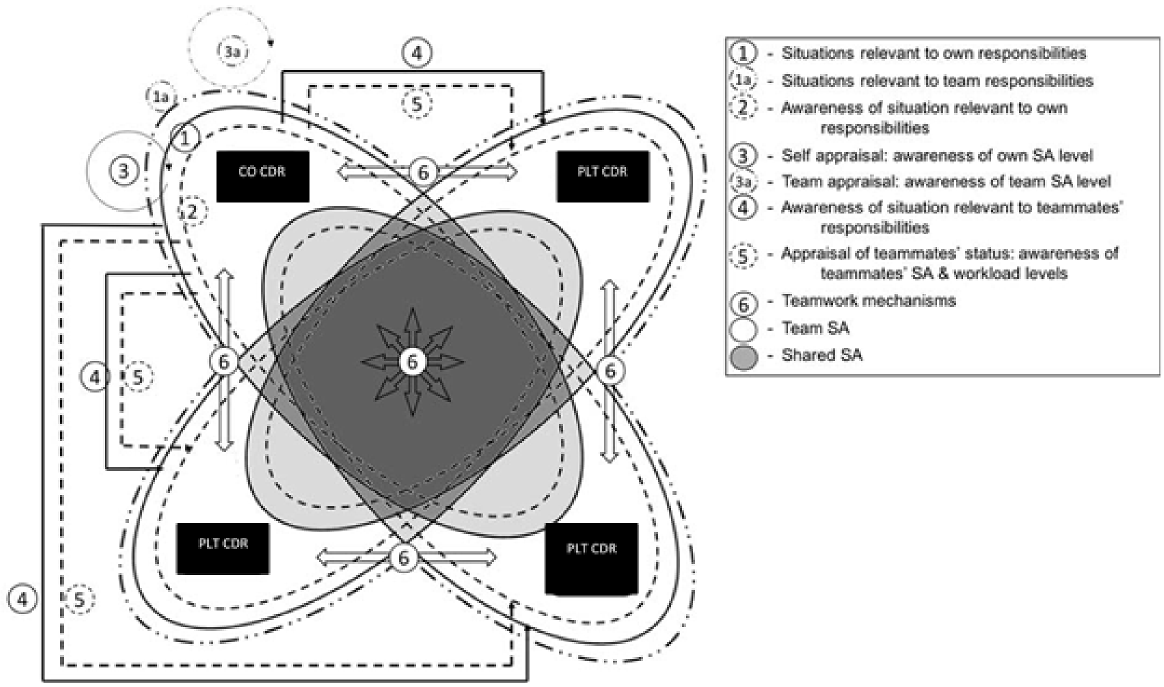

Figure 19. Model of Team SA from Company Commander's perspective. Adapted from Beierl and Tschirley (2017).

There are three essential elements of information that are required to be exchanged for the purposes of establishing or maintaining situational awareness. They are information regarding mission and Commander's Intent; the operational environment; and information regarding enemy and friendly forces. This information is derived from the application of UTACC situational awareness models and the planned incorporation of the systems into a military hierarchy.

a. Mission and Intent

The first essential element that contributes to situational awareness is information regarding the mission. The mission is articulated in a mission statement that includes the information elements who, what, where and when (USMC, 2016e). The UxS must have the ability to receive this information from the headquarters (Beierl and Tschirley, 2017) and also must have the ability to acknowledge its receipt. A higher headquarters must also be capable of receiving the mission of the smaller unit and interact with them about the content. The information should be able to be presented in text format and by a visual graphic depicting standard military topographical map information and operational terms and graphics.

Equally important is the inclusion of Commander's Intent which includes the information elements of "purpose of the operation and the desired military end state" (DoD, 2018, p. 44). This information should be inputted and presented to the UIS in text format, to allow for commanders to articulate the intent flexibly and suitable to the situation. An example of how the information might be portrayed is presented in Figure 20. This information must be presented to the UxS in a format understandable to the machine. Although an UxS may not be capable of understanding the meaning of the content, it must at least recognize if there is an update and alert its human counterpart. The intent therefore must also be capable of being "translated" to a human-readable format for viewing by other members of the small tactical unit team. Note that both affect predictability and observability, and are closely related to directability within the OPD construct.

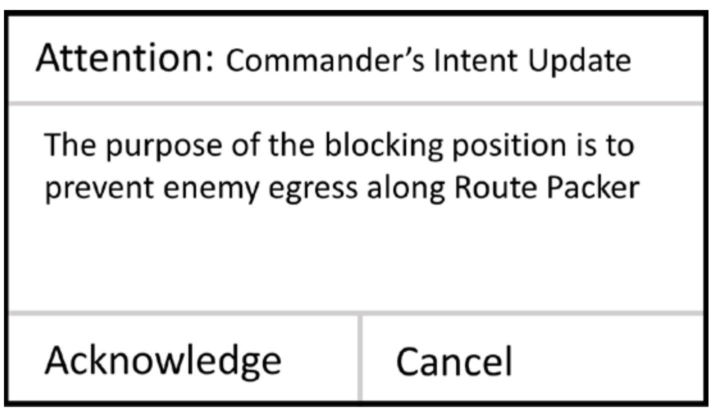

Figure 20. Example update of Commander's Intent

b. Forces and Environment

The second category of essential information that contributes to situational awareness in this context is information about forces (either friendly or enemy) and the environment. The UIS must thus be able to transmit and receive relevant combat and intelligence data. The UIS must have the capability to identify and present location information of military targets. The ability to transmit and receive imagery related to targets is also a requirement. The interface should be able to show or receive enemy disposition, strength and activity (either recent or ongoing) (USMC, 2018a). The same information regarding friendly forces should be included as a capability of the interface. This information could be presented as textual information or utilizing standard military iconography and geographic data.

In addition to information about forces, there must be the capability to exchange information about the environment. The well-known doctrinal acronym OCOKA-W describes those elements of the environment: “observation and fields of fire, cover and concealment, obstacles, key terrain, avenues of approach and weather” (USMC, 2016a, p. I-28). The interface must be able to present and alert to the presence or update of any of these specific elements of information. We hypothesize that this acronym may need to be altered when used in the context of UxS, due to the inherent capabilities and limitations of robotic systems. An example of this is related to the different ways in which humans and robots perceive long grasses. Long grass is easily recognized by Marines, while an UxS might “see” it as an obstacle.

2. Common Principles

The first general principle is that the information sent to and from a unit must increase understanding of Commander’s Intent and the operational environment (USMC, 2015). This principle is primarily focused on the reduction of unnecessary information. Therefore, the UIS must automatically abstract and filter information to an appropriate level. For example, if a fireteam is located outside of the vicinity of a significant event so much so that they are unable to influence it, they should not automatically receive that information. This is not to say that the information should be restricted, just that it should not be presented as a cue or alert. This would limit the cognitive processing required by the small tactical unit. An example of this abstraction process is depicted in Table 10. Here, the detail of information is filtered as it transitions up or down the unit hierarchy.

Table 10. Example information abstraction across echelons

Title	FT	SQD	PLT	CO
Identification of Fireteam members	Green	Black	Black	Black
Identification of Fireteams	Green	Green	Black	Black
Identification of Squads	Black	Green	Green	Black
Identification of Platoons	Black	Black	Green	Green

TABLE KEY: FT – Fireteam, SQD – Marine Squad, PLT – Marine Platoon, CO – Marine Company

Green – information automatically presented

Black – information not automatically presented

In this example, the automatic identification of individual fireteam members remains at the fireteam level. The human element at the fireteam is the only one who needs this information to be automatically presented. At the squad level, the squad leader cares about the location of whole fireteams and other squads. This abstraction and filtering continues in this manner as you progress to higher echelons in the military hierarchy. We also note that this abstraction process might be done by an intelligent software component. In this case, the software should be treated with the same OPD approach and analysis to ensure it is appropriately designed to support the mission.

The second general principle is that the alerting or presentation of important information must be done in a redundant manner and be discriminable between the different types of information (i.e., it must incorporate resilient features). This also includes the practice of utilizing multiple communication paths if possible. The redundancy requirement presents important information in more than one way to reduce the possibility that it will be missed or misinterpreted (Wickens et al., 2004). A popular example for depicting this concept is a traffic stoplight where both the color of the light and its position indicate the information rather than just one or the other as depicted in Figure 21. For example, if the UTACC unit receives updated Commander’s Intent, the alert or cue could come in the form of a haptic response and an audible tone in the earpiece of the fireteam leader. This is essential for both transmission of information and acknowledgement of the receipt of interactions.

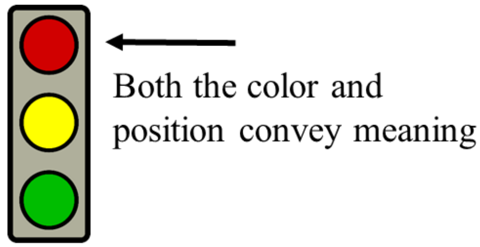

Figure 21. Example of Information Redundancy

Furthermore, the alert or cue for that specific information should be different or distinguishable from other pieces of information, if it is important that the information be distinguished (Wickens et al., 2004). This prevents confusion due to similarity of the alerts or cues. This distinguishability could be enforced depending on message content or priority. For example, a critical priority alert might generate repeated vibrations on a fireteam leader's communication interface whereas one of less priority might only generate a single vibration. In an environment where sound discipline is not a factor, different frequencies of audible tones could be generated.

The final common principle is that the UIS must also be able to prepare, exchange and present standard intelligence products. Required and standardized formats should be automatically generated from data entered by the human component or headquarters element. Examples of reports include reconnaissance exploitation reports, casualty report, contact report and enemy sighting report et cetera. Depending on the sensors operating on the UTACC, additional intelligence information and reports might be generated such as signals intelligence (SIGINT) products and imagery intelligence. The automatic generation of standardized reports will reduce the cognitive load of both the preparer and recipient of the intelligence.

C. MCTL 2.0 EVALUATION

The collaboration between Marine and machine provides unique capabilities and challenges. The machine has the potential to be a force multiplier and provide the commander with more tools to accomplish the mission. The requirement exists to place machines into units to increase the chance for mission success. Poor collaboration and utilization of machines, however, can be a detriment to unit cohesion and success. Utilizing the standards that already exist, MCTL 2.0 is the most efficient way for the USMC to incorporate the change into man-machine teaming.

The MCTL 2.0 is a tool that allows for a standardized method of evaluating and describing requirements for training and operations. MCTL 2.0 does not currently account for an autonomous machine's ability to enhance readiness as envisioned by the UTACC program. In order to describe the contributions of the machine, MCTL 2.0 has been reviewed with emphasis on individual ability, teaming ability, and SA. The recommendations for additions, or adjustments based on the design principles above, are listed in the following tables.

1. Recommended MCT Updates

Table 11 depicts an excerpt from MCTL 2.0 and the MOPs associated with MCT 2.1.1.3- *Provide Indications and Warnings.*

Table 11. Excerpt from MCTL 2.0. Source: USMC (2018a).

M1	Days	Prior to operation for useful information.
M2	Y/N	Intelligence requirements identified and prioritized to address I&W.
M3	Y/N	Named Area of Interest identified.
M4	Percent	Of indicators necessary to reassess enemy COA identified.
M5	Time	To disseminate I&W.
M6	Y/N	I&W information passed in accordance with SOPs and direction.
M7	Percent	Of critical and system up-time availability.
M8	Y/N	Organic teams have the capability to collect, process, and disseminate information meeting I&W criteria.
M9	Y/N	Enemy fails to achieve tactical surprise.

Table 12 depicts the recommended update to MCT 2.1.1.3 with the addition of M10 and M11 in order to account for the ability to measure the machine's ability to provide indications and warnings.

Table 12. Recommended update to MCT 2.1.1.3. Adapted from USMC (2018a).

M1	Days	Prior to operation for useful information.
M2	Y/N	Intelligence requirements identified and prioritized to address I&W.
M3	Y/N	Named Area of Interest identified.
M4	Percent	Of indicators necessary to reassess enemy COA identified.
M5	Time	To disseminate I&W.
M6	Y/N	I&W information passed in accordance with SOPs and direction.
M7	Percent	Of critical and system up-time availability.
M8	Y/N	Organic teams have the capability to collect, process, and disseminate information meeting I&W criteria.
M9	Y/N	Enemy fails to achieve tactical surprise.
M10	**Y/N**	**UxS passes environmental hazard information.**
M11	**Y/N**	**UxS transmits enemy information.**

Another MCT that required updating based on our analysis was MCT 2.1.1.5 *Support Targeting*. This task details what is required for intelligence to support the targeting process by "identifying target systems, critical nodes, and high-value and high-payoff targets, as well as, by providing the intelligence required to most effectively engage these targets" (USMC, 2018a, p. 129). Table 13 depicts an excerpt from MCTL 2.0 that presents the current MCT.

Table 13. Current MCT 2.1.1.5 Support Targeting Measures. Source: USMC (2018a).

M1	Y/N	Targets assigned relative value.
M2	Percent	Of prioritized targets collected upon.
M3	Percent	Of failed attacks on high priority targets (HPTs) attributed to incorrect enemy location data.
M4	Y/N	Maintain display of current enemy situation with target locations and priorities.
M5	Y/N	Maintain country files, technical databases, and deployment tech kits for geographic locations and functional areas.
M6	Number/Day	Targets administratively processed during a given phase or time requirement.
M7	Y/N	Perform I&W, processing, analysis exploitation, production, and reporting on SIGINT information.
M8	Percent	Of targets susceptible to non-lethal kill allocated to non-lethal attack systems.
M9	Y/N	Blue-on-Blue engagements conducted.
M10	Hours	After receipt of Orders to review FSC Measures Guidance.
M11	Hours	Before ATO-cycle begins, JTCB Guidance is passed to targeting agencies (e.g., JFACC).
M12	Percent	Of selected high priority targets (HPTs) have coordinates available.
M13	Hours	For the targeting cycle to be completed.
M14	Time	Blue Print procedures initiated by ADC for unknown or suspect tracks in the CIEA.
M15	Percent	Of desired results achieved by expected conclusion of a given phase or time line.
M16	Percent	Minimum of intercepts CID prior to engagement.
M17	Y/N	HPT/HVT identified.
M18	Y/N	Target folders with Precision Geolocation (PGL) developed as required.
M19	Y/N	ID Electronic Warfare threats.
M20	Y/N	ID Cyberspace threats.
M21	Y/N	Threat to aircraft identified.
M22	Y/N	BHA collected via ISR or MISREP.
M23	Y/N	Re-Strike recommendations made.
M24	Y/N	Theater Net-Centric Geolocation (TNG) / Hostile Integrated Targeting System (HITS) provided as required.
M25	Y/N	Direction Finding (DF) capability provided.
M26	Y/N	Conduct organic logistics in order to enable Communications Intelligence Support.

M27	Y/N	Establishment of tactical communications; man packable, team portable, palletized, and mobile high bandwidth communications and information systems connectivity, up to the TS//SCI level, with organic assets, other services, joint, theater, and multi-national intelligence organizations and assets.
M28	Y/N	Automatically disseminate releasable information across multiple security level domains.
M29	Y/N	Capable of acquiring hand held still images ISO targeting requirements (e.g., COMCAM, Intel, etc.).
M30	Y/N	Capable of acquiring hand held video ISO targeting requirements (e.g., COMCAM, Intel, etc.).

Table 14 depicts an update to the MCTs with M18, M21 and M24 added to incorporate the UTACC system.

Table 14. Recommended update to MCT 2.1.1.5. Adapted from USMC (2018a).

M1	Y/N	Targets assigned relative value.
M2	Percent	Of prioritized targets collected upon.
M3	Percent	Of failed attacks on high priority targets (HPTs) attributed to incorrect enemy location data.
M4	Y/N	Maintain display of current enemy situation with target locations and priorities.
M5	Y/N	Maintain country files, technical databases, and deployment tech kits for geographic locations and functional areas.
M6	Number/Day	Targets administratively processed during a given phase or time requirement.
M7	Y/N	Perform I&W, processing, analysis exploitation, production, and reporting on SIGINT information.
M8	Percent	Of targets susceptible to non-lethal kill allocated to non-lethal attack systems.
M9	Y/N	Blue-on-Blue engagements conducted.
M10	Hours	After receipt of Orders to review FSC Measures Guidance.
M11	Hours	Before ATO-cycle begins, JTCB Guidance is passed to targeting agencies (e.g., JFACC).
M12	Percent	Of selected high priority targets (HPTs) have coordinates available.
M13	Hours	For the targeting cycle to be completed.

M14	Time	Blue Print procedures initiated by ADC for unknown or suspect tracks in the CIEA.
M15	Percent	Of desired results achieved by expected conclusion of a given phase or time line.
M16	Percent	Minimum of intercepts CID prior to engagement.
M17	Y/N	HPT/HVT identified.
M18	**Y/N**	**HPT/HVT identified, labeled and transmitted by autonomous robot**
M19	Y/N	Target folders with Precision Geolocation (PGL) developed as required.
M20	Y/N	ID Electronic Warfare threats.
M21	**Y/N**	**Electronic Warfare threats identified, labeled and transmitted by autonomous robot**
M22	Y/N	ID Cyberspace threats.
M23	Y/N	Threat to aircraft identified.
M24	**Y/N**	**Threat to aircraft identified, labeled and transmitted by autonomous robot**
M25	Y/N	BHA collected via ISR or MISREP.
M26	Y/N	Re-Strike recommendations made.
M27	Y/N	Theater Net-Centric Geolocation (TNG) / Hostile Integrated Targeting System (HITS) provided as required.
M28	Y/N	Direction Finding (DF) capability provided.
M29	Y/N	Conduct organic logistics in order to enable Communications Intelligence Support.
M30	Y/N	Establishment of tactical communications; man packable, team portable, palletized, and mobile high bandwidth communications and information systems connectivity, up to the TS//SCI level, with organic assets, other services, joint, theater, and multi-national intelligence organizations and assets.
M31	Y/N	Automatically disseminate releasable information across multiple security level domains.
M32	Y/N	Capable of acquiring hand held still images ISO targeting requirements (e.g., COMCAM, Intel, etc.).
M33	Y/N	Capable of acquiring hand held video ISO targeting requirements (e.g., COMCAM, Intel, etc.).

Table 15 depicts an excerpt from Kulisz and Sharp (2017) for a recommended change to MCT 5.1.4.1.3 Electromagnetic Identification of Team Members.

Table 15. MCT 5.1.4.1.3 Electromagnetic Identification of Team Members. Source: Kulisz and Sharp (2017, p. 38).

5.1.4.1.3	Metric	Electromagnetic Identification of Team Members
M1	Percent	Of fire team members UTACC can identify electromagnetically
M2	Percent	Of time UTACC can electromagnetically identify the primary human (fire team leader)
M3	Time	To electromagnetically identify the primary human (fire team leader)

Table 16 depicts the recommended update to MCT 5.1.4.1.3 with the addition of M4 and M5 in order to account for the ability to identify team members beyond-line-of-site and the time required to relay that information.

Table 16. Recommended update to MCT 5.1.4.1.3. Adapted from Kulisz and Sharp (2017).

M1	Percent	Of fire team members UTACC can identify electromagnetically
M2	Percent	Of time UTACC can electromagnetically identify the primary human (fire team leader)
M3	Time	To electromagnetically identify the primary human (fire team leader)
M4	**Y/N**	**Able to identify higher, adjacent or subordinate teams using beyond-line-of-site (BLOS) means.**
M5	**Time**	**To identify higher, adjacent or subordinate teams using beyond-line-of-site (BLOS) means.**

2. Recommended MCT Addition

In addition to the recommended updates to the MCTL 2.0, an additional task is necessary to fully allow for evaluation of a UTACC system. The addition of a task labeled 2.2.6 *Conduct Autonomous System Intelligence Collection Activities* is logically placed under 2.2 *Collect Data and Intelligence* in the hierarchy. Table 17 depicts the newly proposed hierarchy.

Table 17. Recommended update to MCTL 2.0. Adapted from USMC (2018a).

MCT	Title
2.2	Collect Data and Intelligence
2.2.1	Collect Tactical Reconnaissance
2.2.2	Conduct Engineer Reconnaissance
2.2.3	Conduct Terrain Reconnaissance
2.2.4	Conduct Sensor Operations
2.2.5	Conduct Aviation Intelligence Collection Activities
2.2.6	Conduct Autonomous System Intelligence Collection Activities
2.2.7	Collect Battle Damage Assessment (BDA)
2.2.8	Collect Combat and Intelligence Data
2.2.9	Collect Medical Intelligence Data
2.2.10	Conduct Reconnaissance and Surveillance
2.2.11	Collect Tactical Intelligence on Ordnance and Munitions
2.2.12	Collect Signals and Intelligence Data
2.2.13	Conduct Armored Reconnaissance and Surveillance

This is a natural location for the new task and requires simply the renumbering of the follow-on tasks depicted as 2.2.7-2.2.13 in Table 17. Table 18 depicts possible metrics associated with the additional task.

Table 18. Proposed metrics to evaluate task addition. Adapted from USMC (2018a).

M1	Percent	Of equipment ready and available to provide intelligence collection operations.
M2	Y/N	Product (sensor) dissemination/distribution network available.
M3	Y/N	Able to communicate relevant reconnaissance information using line-of-site (LOS)/beyond-line-of-site (BLOS) means.
M4	Y/N	Capable of employing visual observation to acquire intelligence information.
M5	Y/N	Capable of employing sensors to acquire intelligence information.
M6	Y/N	Capable of providing electronic reconnaissance.

Table 18 adapts language associated with current MCT 2.2.5 *Conduct Aviation Intelligence Collection Activities* and applies it to the newly proposed 2.2.6 *Conduct Autonomous System Intelligence Collection Activities*.

3. MOEs and MOPs

The MOEs and MOPs are the baseline to determine mission readiness. The USMC relies on MCTL 2.0 as the guiding principles for evaluation of a unit towards their ability to conduct their assigned mission. The need to evaluate a machine is not currently well defined and must be considered as the USMC changes the approach to combat with the incorporation of machines on the battlefield. This analysis begins that process by establishing what would be considered the minimum essential metrics.

The proposed changes to MCTL 2.0 are preliminary and based on theoretical abilities and requirements of the machine. The requirement to utilize a machine brings about the necessity to develop methods to evaluate the machine. Additionally, testing of the machine will bring about the need to update, change or delete some of the proposed adjustments. The need to reassess capabilities will be based on the proficiencies of the machine, requirements and restraints or constraints of the unit to which the machine is assigned. Consistently utilizing the principles of observability, predictability and directability is crucial to this endeavor.

It is clear that more detailed work will be required to fully adapt these changes to an effective interface. This can be done utilizing the framework presented in this thesis. For example, the recommended update to MCT 2.1.1.3 in Table 12 is a baseline for which additions can be made to fully incorporate the UxS. M10 may be further elaborated to account for the ability of the UxS to transmit weather information in the area, obstacles, and man-made structures; these are just a few of the possibilities. M11 can be expanded upon to include enemy location, size, and composition. The need to fully incorporate and evaluate the UxS exists, however this is not a simple task. There exists the requirement to determine who needs the information, how quickly they need it, and what method will be used to transmit the information. What do the receivers do with the information and is there an override feature that allows a small unit leader to prevent the transmission of it in certain circumstances? Conducting further interdependence analysis will be useful in answering these types of questions. The end result will be a more useful UxS for collaboration on the battlefield.

D. CONCLUSION

The need to change the ways by which the USMC fights has been identified by key leadership through their public statements and organizational documents such as the Marine Corps Operating Concept (2016d). The requirement is described in the Marine Operating Concept when it argues for us to “streamline our ability to evaluate and acquire advanced technologies to ensure we gain advantages from innovations faster than our competitors and adversaries” (USMC, 2016d, p. 5). This change will not be easily implemented due to the bureaucratic nature of the military. It is important to note though, the easiest way to implement change is through minimizing the disturbance to the organization. This is achieved by utilizing the doctrine that is already in place and accepted: MCTL 2.0. The groundwork for UTACC implementation is in place and needs only be modified. The proposed changes to MCTL 2.0 utilizes the foundation for evaluation and accounts for man-machine integration. This allows for the easiest method in which to incorporate machines for use in future conflict.

V. SUMMARIZING RESULTS AND RECOMMENDATIONS FOR FURTHER RESEARCH

This chapter summarizes the authors' findings based on the collaboration of man-machine teaming utilizing MCTs. The most beneficial way to evaluate machines within a USMC unit was determined to be through current methods, such as MCTL 2.0. The evaluation of MCTL 2.0 defined a number of machine tasks that could be accomplished. The tasks were modified to account for the implementation of a machine within the unit while enhancing team SA. The chapter will close with recommended follow on research that will guide future UTACC program development activities.

A. SUMMARIZING RESULTS

1. MOP and MOE Final Tables

The tables provided in Chapter IV provide a baseline for evaluating a machine for implementation within a Marine unit. The tables allow for objective evaluation of the machine, which provides a number of functions. The evaluation ensures that the machine is capable, enhances mission capacity, and helps instill trust in the machines for the humans in the unit. This provides evidence to ensure that the machine is a force multiplier on the battlefield.

2. Limitations of MOP and MOE Tables

MOP and MOE tables provide a baseline for collaboration between Marine and machine. The ability to encompass the capabilities of a machine within a table, however, cannot provide all of the answers. The greatest challenges that UTACC faces for man-machine teaming are the operational environment, denied/restricted access to the electromagnetic (EM) spectrum, and unrealized complexities involved with human machine interaction.

The operational environment is constantly changing throughout a theater of armed conflict. This may be the weather changing from day to day or the environment changing due to the military movements of operational forces. No matter the reason, the machine needs to adapt to the environment in which it is required to operate. A MOP may be able to evaluate the machine in the desert environment, but may not have the same capability in the mountains. This could be catastrophic if a machine is utilized in an environment that it has not been evaluated in. The USMC does seek to train in environments that it intends to fight. Therefore, this potential risk may be mitigated through normal training evolutions of deploying units. The potential that exists for problems due to the environment, however, must not be overlooked.

The USMC has had the luxury of operating in places that allowed for full and uncontested usage of the electromagnetic spectrum during recent conflicts. This may not be the case in future endeavors. In this case, there may be serious problems when using machines to enhance operational capabilities. Current methods to communicate rely heavily on the EM spectrum and the ability to utilize machines to increase SA provides a significant capability. A denied EM spectrum environment would hinder the capacity of the machine to perform this function. The questions become, what does the machine do for me now and how does this affect the complex interactions between man and machine? This problem is not limited to the machine, but rather is a concern for the USMC as a whole. For this reason it should not slow implementation, but needs to be considered while the USMC looks at the problem holistically.

B. RECOMMENDATIONS FOR FURTHER RESEARCH

1. Communication Methods

The ability to communicate is a vital component to a successful military operation. Various communication methods have been successfully employed throughout the history of military operations. These methods range from word of mouth, radio communications, satellite communications, and various data transmission methods. The U.S. military has recently been able to use these communication methods with little resistance. The U.S. military’s freedom of movement in the electromagnetic spectrum will be challenged as technology continues to improve and is proliferated across the globe. The ability to communicate will continue to be vital in the future. The need to have an UxS with redundant and resilient communication methods will play a significant role in future conflicts. The communication methods require significant research to be a strength of UxS.

2. Communication Exchange beyond the Company Level

This thesis focused on information exchange from the fire team to higher echelons of command. The authors, however, did not go beyond the company level. The types of information exchanged between higher levels of command needs evaluation. The types of information and the amount of information changes as it moves up the military hierarchy. Research should identify what the higher level commander requires and desires to make better informed decisions while not detracting from the mission at hand. A poor information exchange may degrade from the mission and result in the lack of UxS incorporation.

3. Training and Readiness Manual Implementation

The authors concentrated the efforts of this thesis on the MOPs and MOEs for UxS collaboration by evaluating MCTL 2.0. The MCTL 2.0, however, is a high level evaluation tool. The MOPs and MOEs should be further elaborated for implementation at the tactical level. Training and Readiness (T&R) manuals are used by units to measure their ability to accomplish subordinate tasks that contribute to their overall mission. The MOPs and MOEs for UxS need to be tailored to the T&R manual in the same manner. The suggested MOP changes, referenced by this thesis, need to be further refined to the T&R manual to ensure that implementation and evaluation is accomplished completely to the smallest tactical level.

The concept of trust also repeatedly emerges throughout this thesis as being a necessity between humans and machines. We offer several different ways of understanding machine functions, that we suggest increases the trust a Marine has of the machine. There are, however, likely many other aspects of trust that should be researched in support of the UTACC program. For example, does a machine calibrate the level of trust it places in a human based on previous reliability? Should trust be incorporated into a robot "T&R manual?" Both questions that should be explored in the program.

C. CHAPTER CONCLUSION

The use of machines in combat is not a new concept within the United States military. Machines have been helping to increase mission capability for hundreds of years, from the rifle to the tank to aircraft. The use of unmanned aerial vehicles (UAVs) is a more recent example of successful machine integration on the battlefield. The UAV increases capability in a similar manner to what a robot integrated within a USMC infantry unit can accomplish. There are differences in the implementation of the ground robot. Most notably is the close teaming and interactions between humans and robots at the small unit level. A UAV is operated by a team with standoff distance to increase survivability of the operators while conducting operations.

A ground robot can provide similar capabilities as the UAV, however the UTACC robot cannot require a team to operate it. This would degrade capabilities and take Marines out of the fight; this directly contradicts goals of the program. The robot has to be a force multiplier to be an asset on the ground. The principle is that the robot takes the place of a member within a fire team and perform the functions of the Marine that it replaced. The force multiplier is that the robot can be loaded with sensors and capabilities that a Marine does not organically bring to bear against the adversary. The robot can also be tasked to perform a task that has risks associated with it that would not make it feasible for a Marine to perform. The need is best explained by the Marine Corps Operating Concept: "[l]earn how to use unmanned systems and automation at all echelons and in every domain-because mastering the man-machine interface offers a revolution in military operations" (USMC, 2016d, p. 9).

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