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MISSION COMMAND FOR AUTONOMOUS SYSTEMS (MCAS)

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ABSTRACT

As the number of robotic systems on the battlefield increases, the number of operators grows with it, leading to significant cost burden. Autonomous robots are already capable of task execution with limited supervision, and the capabilities of autonomous robots continue to advance rapidly. Because these autonomous systems have the ability to assist and augment human soldiers, commanders need advanced methods for assigning tasks to the systems, monitoring their status and using them to achieve desirable results. Mission Command for Autonomous Systems (MCAS) aims to enable natural interaction between commanders and their autonomous assets without requiring dedicated operators or significantly increasing the commanders' cognitive burden. This paper discusses the approach, design and challenges of MCAS and present opportunities for future collaboration with industry and academia.

INTRODUCTION

The US Army's Communications-Electronics Research, Development and Engineering Center (CERDEC) Command, Power and Integration (CP&I) Directorate and its research partners execute Mission Command for Autonomous Systems (MCAS), with the aim of extending the mission command warfighting function [1] to allow autonomous systems to support commanders and their staff during operations. To that end, MCAS is developing a platform-agnostic mission command architecture and prototype that allows autonomous systems to decompose mission orders to specific tasks; plan, prepare, and execute these tasks; and assess the outcomes. The goal is to evolve toward a natural interaction between warfighters and their autonomous assets, allowing one soldier to use numerous unmanned systems, requiring neither dedicated operators nor significant cognitive burden on the part of commanders.

BACKGROUND

Mission Command

Historically, US Army unit commanders have exercised command and control (C2) through a concept called Battle Command. Defined as the art and science of battlefield decision-making and leading soldiers and units to successfully accomplish a mission, Battle Command focuses on decision-making, leading, and controlling [2]. Historically, Battle Command is a centralized model, where information was provided to a commander, who made decisions and gave specific instructions to subordinates.

The complexity of the modern warfighting environment, combined with the net-centric nature of today's military, has changed the way warfighters engage in battle, however. Around 2013, the Army recognized that future environments would be too complex for centralized C2. Drawing from the WWII German command philosophy of *Auftragstaktik,* the Army moved to a decentralized model: mission command [3]. The philosophy behind mission command is "the exercise of authority and direction by the commander using mission orders to enable disciplined initiative within the commander's intent to empower agile and adaptive leaders in the conduct of unified land operations" [1]. Figure 1 compares Mission Command to Battle (Detailed) Command.

Detailed Command		Mission Command
• Deterministic • Predictable	Assumes war is	• Probabilistic • Unpredictable
• Order • Certainty	Accepts	• Disorder • Uncertainty
• Centralization • Coercion • Formality • Tight rein • Imposed discipline • Obedience • Compliance • Optimal decisions, but later • Ability focused at the top	Tends to lead to	• Decentralization • Spontaneity • Informality • Loose rein • Self-discipline • Initiative • Cooperation • Acceptable decisions Faster • Ability all echelons • Higher tempo
• Explicit • Vertical • Linear	Communication types used	• Implicit • Vertical and horizontal • Interactive
• Hierarchic • Bureaucratic	Organization types fostered	• Organic • Ad hoc
• Directing • Transactional	Leadership styles encouraged	• Delegating • Transformational
• Science of war • Technical/procedural tasks	Appropriate to	• Art of war • Conduct of operations

Figure 1: Battle command and mission command. [4]

Mission command is also a warfighting function, defined as the "related tasks and systems that develop and integrate those activities enabling a commander to balance the art of command and the science of control in order to integrate the other warfighting functions" [1]. The commander and his staff conduct these tasks through the framework of the operations process. While commanders drive the operations process, their staff are responsible for conducting the process that supports the operations [1]. In other words, the commander provides constraints, objectives, and critical information requirements to the staff who then develop products that the commander uses to make decisions and execute mission command. As seen in Figure 2, the operations process comprises planning, preparing, executing, and continuously assessing the situation. These activities are defined as follows: [5]

- *Planning* is the art and science of understanding a situation, envisioning a desired future, and laying out effective ways of bringing that future about.
- *Preparing* comprises those activities performed to improve operational success.
- *Executing* is the act of putting a plan into action by applying combat power.
- *Assessment* is the continuous determination of the progress toward accomplishing a task, creating an effect, or achieving an objective.

Critical thinking skills, flexibility, proper training, and experience allow Army commanders to understand intent and take the disciplined initiative necessary to execute mission command. MCAS aims to extend the principles of the mission command philosophy to the operation of autonomous assets and to improve the way that commanders and their staff use these assets to execute tasks.

Figure 2: The operations process. [5]

The History of Command and Autonomy

Autonomy is a rapidly growing field in academia, industry and government, with technology driving a wider application to everyday life. A Google Scholar search for "autonomy" yields over 19,600 articles published in 2015, 13,900 of which are focused on military applications. The scope of this paper will mirror the scope of CERDEC CP&I's efforts. While a number of entities across the Army focus on research and development across a number of areas, and CERDEC leverages this work, CP&I's work centers on the interaction between commanders and their autonomous assets.

From 2005 to 2009, CERDEC executed the Command Control of Robotic Entities (C2ORE) program to coordinate dynamic battle command tactical-level control of unmanned systems. This control included the synthesis of information from robotic air and ground systems to enable optimal interaction, coordination, and collaboration amongst assets. As the part of the effort, the C2ORE program assessed the impact of integrating these systems into the mission command networks.

From 2010 to 2012, the work continued under the Unmanned Systems C2 for Operations in the Urban Terrain (USCOUT) program. USCOUT focused on adapting C2ORE technology to support complex urban environments, and integrating capability into fielded mission command platforms. In partnership with TARDEC, CP&I conducted an experiment in 2012 at Camp Lejeune, NC, where USCOUT was used to command one air and one ground platform using a mission command system.

Starting in 2013, the Mission Command Technology Enabled Capability Demonstration (MC TECD) program continued to integrate autonomous platforms with mission command. Focused at the company level and below, MC TECD demonstrated command of multiple autonomous platforms using mounted and dismounted mission command systems. MC TECD accessed the network impacts of autonomous platforms at the tactical edge. The program concluded by demonstrating the ability to autonomously task two live Ravens, alongside an autonomous Mobile Detection And Response System (MDARS) platform. This work was the precursor to the current MCAS program.

MISSION COMMAND FOR AUTONOMOUS SYSTEMS

MCAS will be employed within the mission command operations process, with functions performed at multiple echelons extending from the brigade level down to the individual squad. MCAS intends to address some of the major problems with current autonomous system concept of operations (CONOPS). Major problems include the lack of interoperability with mission command systems, autonomous system user interface training, limited opportunities for manned and unmanned collaboration, and a lack of tools and techniques for autonomous system consideration during mission planning. The following section highlights these problems.

Current Concept of Operations

The CONOPS for autonomous systems on the battlefield is challenged, as Figure 3 depicts. These systems can only be tangentially incorporated into the operations process of the mission command warfighting function. This discontinuity is a side-effect of the accelerated battle rhythm and accompanying technology development stemming from the threat of improvised explosive devices and requirements for persistent intelligence, surveillance, and reconnaissance (ISR) [6].

Interoperability between today's unmanned systems and the Army's mission command systems is the single most limiting factor. It requires unmanned system operators to manually interpret and prioritize commander's tasking, monitor sensor data feeds, and communicate potential mission impacts. This shortfall places significant cognitive burden on operators and results in missed opportunities and potentially undetected threats. Additionally, it makes collaboration between assets unfeasible, placing the burden solely on the operators. With such a large demand on the operator, unmanned systems at lower echelons often require dedicated personnel, thereby increases manpower requirements and reducing small unit combat power [7].

The mission planning capability of current systems is usually an afterthought for vendors. This deficiency results in systems being underused and inefficiently used by commanders and operators. A lack of tools and techniques prevent a commander from assessing tradeoffs of incorporating autonomy into mission plans and recognizing the operational consequences of changing missions to include autonomy [6].

The proprietary design of robotic systems has resulted in custom user interfaces from each vendor. This practice requires that operators be trained for each robotic system for which they may be responsible. Their specialized skills are then not easily transferrable between unmanned systems [8].

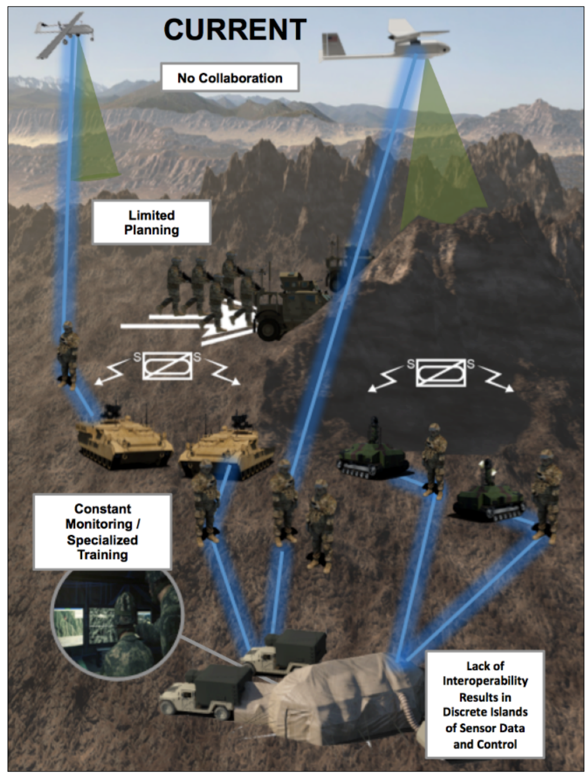

Figure 3: Current operational view for usage of unmanned / autonomous systems.

Future Concept of Operations

The future CONOPS incorporates autonomous systems deeply into all phases of the operations process of the mission command warfighting function. The commander's staff, who are responsible for conducting the operations process, and the commander, who drives the operations process, will now have to consider how autonomous systems augment and enhance these processes.

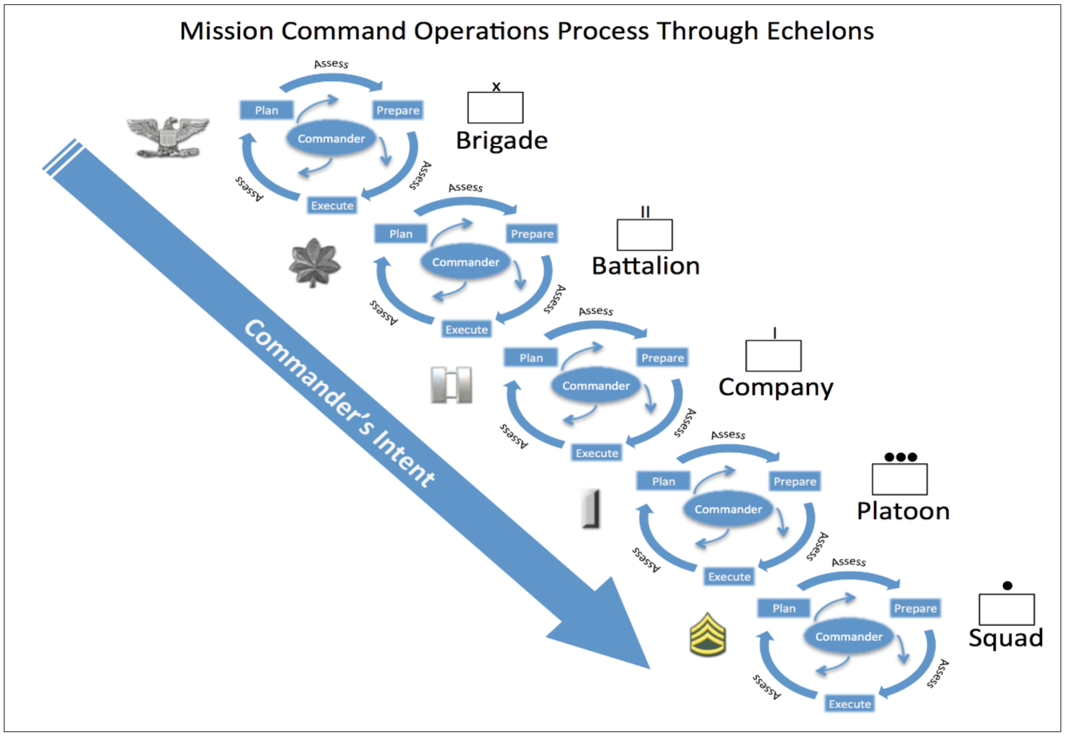

Figure 4: Mission command operations process through echelons.

On one hand, MCAS aims to help the commander and the commander's staff carry out their duties throughout the operations process. On the other, MCAS will enable the autonomous systems to behave as part of the commander's staff and conduct their own planning, preparing, executing, and assessing.

Central to the success of MCAS is a clear understanding of the commander's intent, which is defined as a clear and concise expression of the purpose of the operation and the desired military end state that supports mission command. It provides focus to the staff and helps subordinates and supporting commanders achieve desirable results [5]. Commander's intent provides the flexibility a commander needs to adapt to the changing conditions of battle and is crucial to promoting the exercise of disciplined initiative, while maintaining emphasis on the higher level objectives of an operation. Figure 4 shows how the commander's intent acts as a backbone for the operations process at each echelon. Along with the commander's intent, planning guidance, operational approach, critical information requirements, and essential elements of friendly information also propagates down. MCAS will use this information at each echelon to manage the operations process as it pertains to the autonomous systems.

During planning, MCAS will report the capabilities, availability, and constraints for each autonomous system in the force, allowing commanders to take a holistic approach to mission planning, incorporating manned and unmanned systems as appropriate. MCAS will assess the mission plan to assign and distribute tasks to autonomous systems, identify triggers for task execution, interpret commander's intent to shape behavior during task execution, and recognize critical data collection requirements.

During preparation, MCAS will assess limiting factors such as fuel, battery life, and required maintenance and report the necessary pre-mission preparations to allow for efficient transition to the execution phase. It will also communicate deficiencies with existing Army systems to remedy the situation prior to mission execution. In the event a need cannot be met, MCAS will report on which systems cannot be included in the plan.

During execution, MCAS will instruct autonomous systems to execute assigned tasks and collect platform and payload sensor data. MCAS will assess collected data and determine opportunities for collaboration to improve mission efficiency, gain situational awareness, or foil enemy plans. As the mission evolves, MCAS will use data from the autonomous platforms, sensor payloads, and manned C2 systems to determine how to proceed. This determination will be done through the lens of the mission, factoring in commander's intent and other guidelines. The MCAS system will provide feedback to the mission planners as critical information is collected, enemy forces are detected, tasks are completed, and human intervention is needed. This feedback will allow them to make small modifications or change the course of the mission entirely. The operational view with MCAS incorporated is shown in Figure 5.

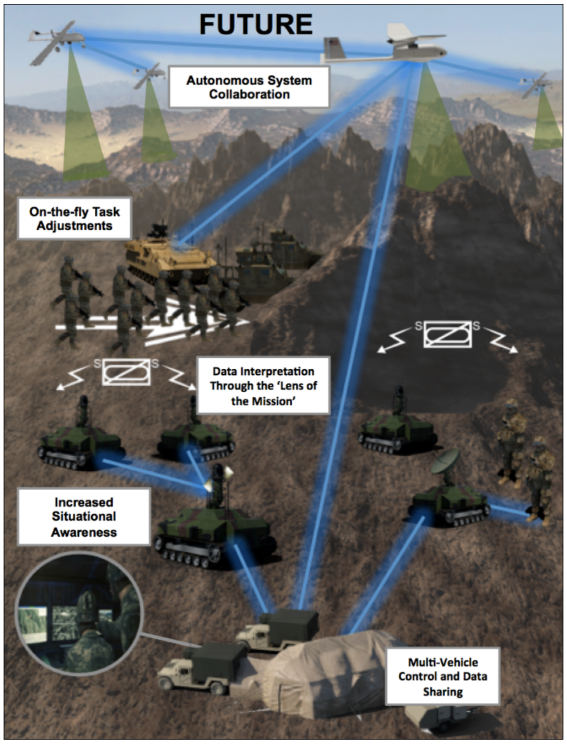

Figure 5: Future concept of operations with MCAS.

Design

To achieve deep integration of autonomous systems with the operations process, the MCAS system defines an architecture that:

- Promotes interoperability with other Army systems
- Enables manual and automatic high-level tasking by any soldier in the formation through familiar user interfaces
- Enables collaboration between autonomous systems
- Provides critical autonomous system data for mission planning activities

The MCAS system architecture is organized into five key views: two soldier views, two developer views, and the core business logic shown in Figure 6.

The first of the two soldier views is composed of existing, external, fielded Army systems that perform various functions in the operations process. The systems are grouped into three categories: Mission Planning Applications, Preparation/ Logistics Applications, and Mission Command Applications. These systems are the main point of contact between end users (soldiers) and MCAS system. Examples of currently fielded systems that fit within these categories are Command Post of the Future, Logistics Modernization Program, and Joint Battle Command-Platform, respectively. Rather than creating new planning, logistics and mission command tools tailored to fit MCAS's needs, the development team is leveraging the Army's significant investments. This approach should promote interoperability with existing systems and reduce both training and sustainment requirements.

The second of the two soldier views is composed of the autonomous systems themselves as well as any supporting data providers. Soldiers responsible for the manual operation, maintenance, and configuration of the autonomous systems have direct access through the second soldier view. Soldiers are able to prepare the autonomous systems for use in the MCAS system through this view. This second soldier view allows soldiers to jump in and manually operate these systems at any time. Additionally, external support data providers are accessible through the second soldier view. As an example, the maneuver network route planner that calculates routes for an unattended ground vehicle (UGV) can be configured with the latest maneuver network data through the second soldier view.

The two developer views allow for the extension of MCAS on the planning and C2 side, as well as on the autonomous system side. As new systems are developed, they can be adapted to work with MCAS, while the MCAS core business logic remains unchanged. These views provide a general-purpose abstraction layer for developers.

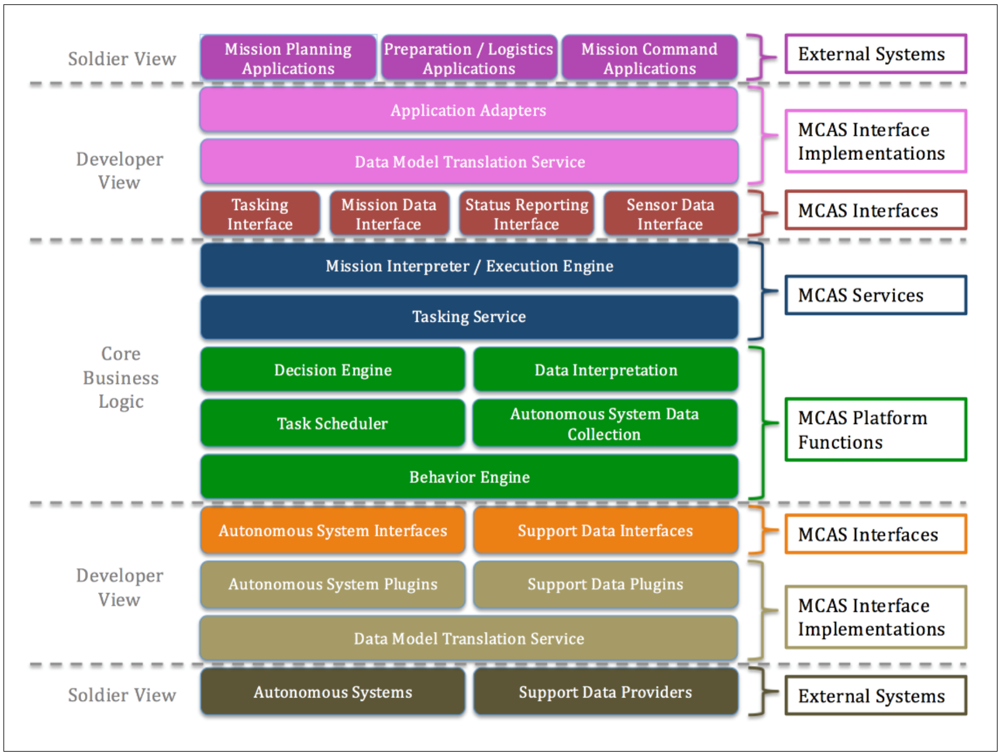

Figure 6: MCAS architecture.

The core business logic components are divided into services and platform functions. Services are applied across many autonomous systems and provide mission oversight, orchestration, and collaboration. Platform functions are applied to each autonomous system and are responsible for executing high-level behaviors and real-time execution decisions.

At each phase of the operations process, the MCAS system enables integration of autonomous systems. Figure 7 shows the flow between phases and specific MCAS activities. During planning, capability and availability data about the autonomous systems is fed into the mission planning process, generating an Operations Order (OPORD). During preparation, the OPORD is decomposed and autonomous system tasks are discovered and interpreted through the lens of the mission. This interpretation is fed back for human-in-the-loop adjustments, after which and any remaining preparations can be made prior to task distribution. During execution, data from platforms, sensor payloads, and manned systems is collected and merged. Upon interpretation, again through the lens of the mission, tasks are updated and milestones are fed back into the planning phase.

Challenges

Realization of the MCAS system capabilities will not come without challenges. Three major challenges are in the following areas: decomposition of OPORD, general-purpose interface definitions for purpose-built autonomous systems, and intelligent agent algorithms to interpret large amounts of data and make near-real-time decisions.

OPORD decomposition presents technical research opportunities in user interface design, data modeling and ontologies, information capture, and natural language processing. A particularly challenging aspect is the capture of tacit information generated and communicated during the creation of the OPORD, yet absent from the final product. OPORDs are created using myriad tools ranging from sand tables to email, PowerPoint, as well as mission planning and mission command applications. The resulting artifact is typically expressed through a five-paragraph textual description of the situation a unit faces, the mission of the unit, and the supporting activities to achieve the commander's intent. Although the OPORD includes annexes and appendixes, much of the thought and analysis that went into developing the OPORD may not be captured in the final product despite being crucial to understanding the plan and in planning for contingencies. Notwithstanding the established OPORD format and common training, the experience, knowledge, personality, leadership, and

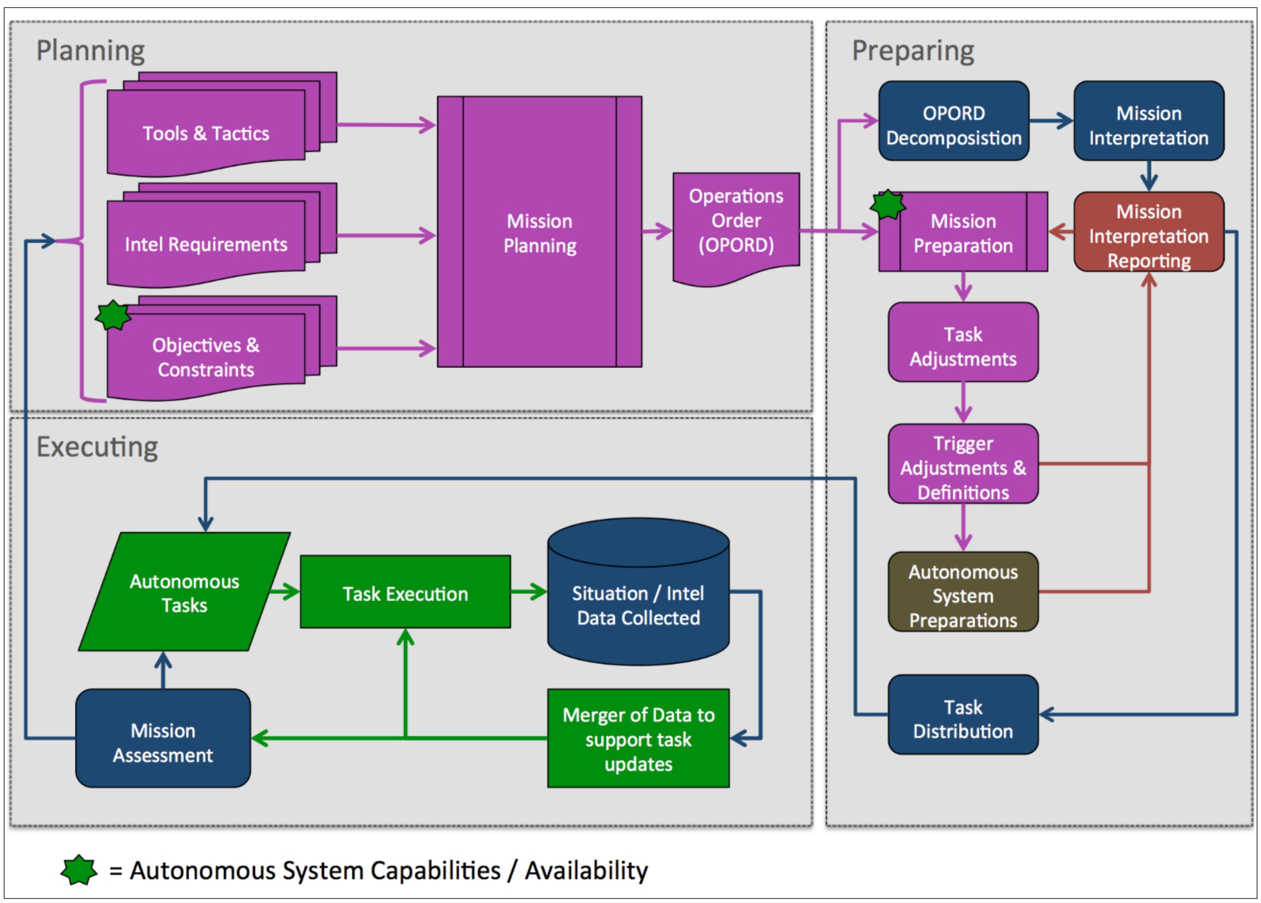

Figure 7: Detailed operations process activities.

communication styles of commanders and their staff vary, and therefore affect human and machine understanding of OPORDS [9, 10].

Another challenge is the definition of general-purpose autonomous system interfaces. These interfaces must allow purpose-built capabilities to be leveraged by the general-purpose modular nature of the MCAS system. For example, imagine one autonomous system with a *zipper mast* that can extend vertically on command, perhaps to raise an antenna, and another that provides a comparable capability but by *telescope mast*. One problem is that not all autonomous systems have an extendable mast, so this capability cannot be incorporated into a general interface. The second problem is that the end user wants to understand what the capability is but may not care about the mechanism behind it. Furthermore, MCAS needs to understand the capability in a general sense so that it can make decisions about which tasks are well suited for that particular system.

The third challenge is the design and implementation of intelligence algorithms capable of considering large quantities of sensor data, changing environmental conditions, friendly and enemy actions, and evolving mission requirements to produce actionable decisions. As the mission progresses, manned and unmanned systems collect massive amounts of information that may have an impact on the mission itself. Information collected must be combined and assessed to identify imminent and potential mission impacts and their effects. Once impacts and effects are identified, potential actions must be identified and assessed to produce an actionable decision. This process presents technical research opportunities in information correlation, causality, and decision-making.

MCAS Prototype

To date, a limited prototype of the MCAS system has been created. The prototype allowed for manual submission of high-level tasks from a handheld mission command system, Nett Warrior (NW) End User Device (EUD). The NW EUD is the fielded mission command system that dismounted soldiers use today and is a software-modified Android device. The data model and transport leverages the Integrated Sensor Architecture (ISA), which the Army's Night Vision and Electronic Sensors Directorate (NVESD) is developing. Two autonomous platforms were integrated: the Mobile Detection And Response System v2 (MDARSv2) UGV developed by Land Sea Air Autonomy, and the RQ-11 Raven UAV developed by AeroVironment. Figure 8 shows the interfaces and components developed for the prototype.

The prototype demonstrated the concept that many soldiers with minimal training could submit high-level tasks to various autonomous systems for execution. The primary capability demonstrated was target reconnaissance. The user was able to tap a target location on a digital map provided by the handheld mission command system and transmit the target along with the intent (e.g., take a picture of the target) to the MCAS enabled autonomous systems. MCAS components instructed the autonomous system to travel to the target location, take a picture of the target, and transmit the image back to the user for viewing. This prototype capability was demonstrated at CERDEC's C4ISR Ground Activity in Ft. Dix, NJ, July 2015.

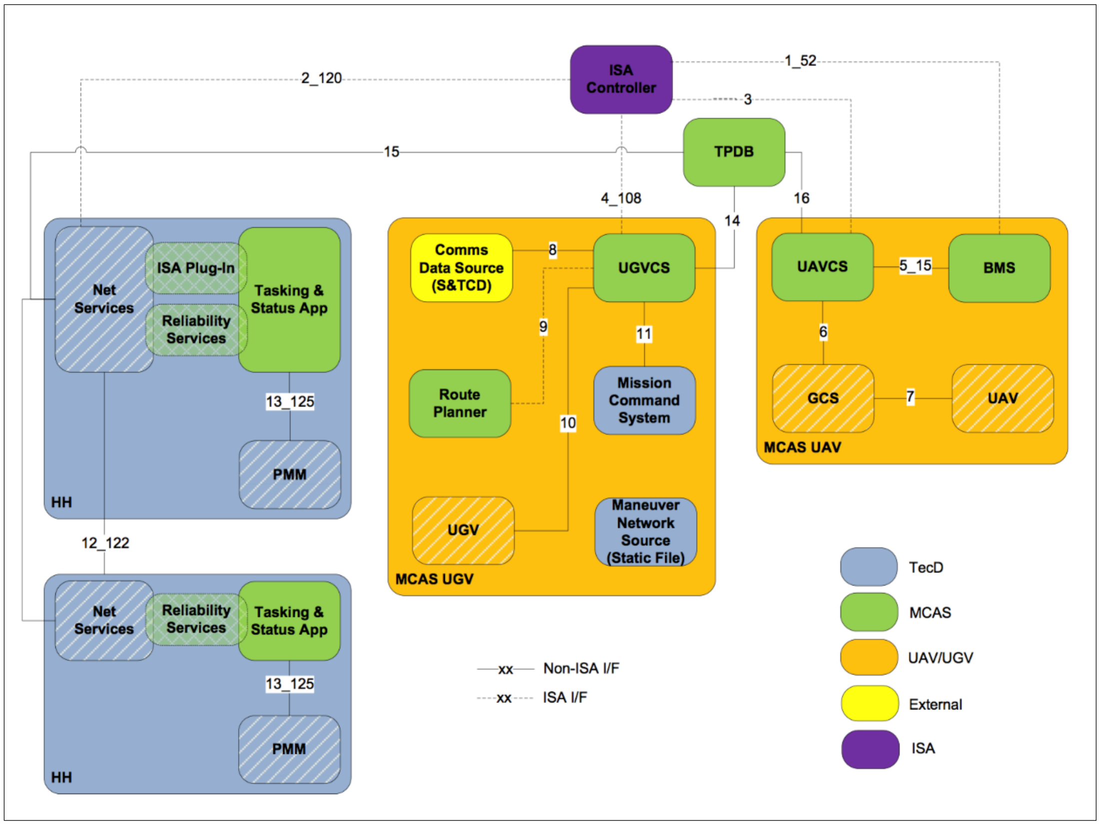

Figure 8: MCAS prototype interface diagram.

FUTURE WORK

MCAS is building on previous experiences at CERDEC in command of autonomous systems. Some future work to further improve the mission command of autonomous systems is described below.

Additional Platforms

Future work will begin to expand MCAS to manage additional platforms. Such work will include the types of vehicles, the payloads on these platforms, and the number of platforms. Additionally, MCAS will explore mission command of micro and nano-sized platforms and assess the impact of integrating these inexpensive and potentially disposable autonomous agents.

Agent-Based Applications

MCAS will invest in capabilities that allow autonomous platforms to operate in a tactical network, to include discovery and coordination of platforms. The research will focus on developing software agents that allow MCAS to operate on a low bandwidth network, while distributing the cognitive workload across various staff (commanders, executive officers, platform operators). This work would push computation further to the edge, and provide capability in the face of near-peer threats to the Army's infrastructure.

OPORD Processing

OPORDs and other documents communicate the mission and commander's intent to subordinate commands. These human-readable documents may include coordinates, graphics, overlays, etc. and may be nuanced or imply concepts that are not clear to a software application. MCAS research aims to develop mechanisms to improve analysis of these documents for specific tasks and subtasks that can be performed by autonomous systems.

Additionally, MCAS will continually analyze and compare its generated products to those generated by the commander (or their staff). It will look for changes/differences and, through machine learning, improve OPORD processing. Over time, MCAS will learn to capture individual commanders' intent with better accuracy, lowering planning workload, and producing personalized mission plans.

Planning User Interface

While the OPORD processing may communicate the bulk of the information, the extraction is unlikely to be 100% accurate. To supplement the automatic processing, meet the commander's expectations, and mitigate risks, MCAS will develop planning tools to allow commanders to edit automatically generated plans, and create new plans. These tools will enable the management of autonomous system and task assignments, coordinated behaviors (including manned-unmanned and unmanned-unmanned; air-air, ground-ground and air-ground), and monitoring tools. These tools will allow MCAS to develop coordinated mission plans that meet the commander's expectations, and mitigate the risks associated with automated processing of free-text documents.

Mission Monitoring

As the Army includes more autonomous systems in missions, with limited numbers of operators and/or commanders, the human-machine interface will need to adapt to the specific mission and the commander's intent. Providing all the information, from every platform, will result in cognitive overload.

MCAS will research a role-based approach to managing the cognitive workload. Software agents will monitor the data streams and present users with only the information they need. The agents will base these decisions on the OPORD processing, planning tools, and asset allocation information to customize the information presented to the commander/operator at the time of mission execution.

For example, a commander may be alerted when enemy movement is detected or when another condition affects the overall mission. At the same time, operators maybe alerted to platform malfunctions, low battery notifications, or a platform operating outside preset conditions.

Coordinated Maneuvers

With the limited number of operators and ubiquity autonomous systems, operators can no longer manage which systems should coordinate to accomplish a task. This creates the need for MCAS to be capable of communicating the commander's intent to groups of systems, not just individual systems. For example, if a commander prioritizes concealment for a specific mission, systems may have to work to together to identify the most concealing locations. In other cases, for example, when speed is a priority, systems may need to notify each other of exposed paths to meet the time constraints.

Security

To provide the appropriate information, some of which may be classified, to a platform on a tactical network requires cross-domain solutions. Typically mission command data resides on SECRET systems that cannot directly communicate with UNCLASS data links/protocols used by autonomous platforms. While still being developed, the distributed nature of MCAS should allow for certain functionality to be executed on SECRET systems while other functionality is carried out on UNCLASS systems.

CONCLUSION

As technology advances provide for greater functionality of autonomous systems, the Army must change the way that it integrates these systems with the existing force structure. Although unmanned systems can augment the warfighter's capabilities and have the potential for increasing combat power and range, current methods for controlling these systems require individual operators and a high cognitive load. By applying concepts drawn from mission command, CERDEC CP&I's MCAS project aims to change the way commanders and their staff interact with their autonomous assets. MCAS developers have demonstrated a core set of capabilities and are actively expanding these capabilities across a variety of unmanned platforms to enhance fundamental approaches to manned-unmanned teaming.

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