

HUMAN CENTERED TEAMING OF AUTONOMOUS BATTLEFIELD ROBOTICS

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ABSTRACT

This paper surveys the state of autonomous systems and outlines a novel command and control (C2) paradigm that seeks to accommodate the environmental challenges facing warfighters and their robotic counterparts in the future. New interface techniques will be necessary to reinforce the paradigm that supports the C2 of multiple human-machine teams completing diverse missions as part of the Third Offset Strategy. Realizing this future will require a new approach to teaming and interfaces that fully enable the potential of independent and cooperative decision-making abilities of fully autonomous machines while maximizing the effectiveness of human operators on the battlefield.

INTRODUCTION

As the Department of Defense (DOD) determines how to meet new environmental challenges on the battlefield in future conflicts, an unprecedented opportunity exists for unmanned systems to give the warfighter a critical edge over near peer competitors in urban and rural environments. The ability for these unmanned systems to provide valuable data to the warfighter will continue to increase exponentially as humans work alongside their robotic teammates to complete missions. The warfighter's advantage will grow as relevant and timely data is shared across disparate entities in theater, but as the number of robotic teammates increases, so does the volume of data they can share with their human teammates. The result will be overwhelmed humans struggling to manage, decipher, and act on the voluminous amounts of available data. The success of Manned Unmanned Teaming (MUM-T) on the battlefield rests entirely

on human-centered command and control (C2) and mission planning/replanning paradigms that afford warfighters the right interfaces displaying the right data at the right time. Anything less will fall prey to the finite processing capabilities of humans as errors are introduced and solidify as commonplace.

WHY HUMAN CENTERED?

The motivation for the development and interest in human-centered user interfaces and concepts of operations (CONOPSs) for unmanned systems not only is critical to manned-unmanned teams achieving operational effectiveness, but also is key to controlling lifecycle costs for the unmanned systems of the future. Specifically, manpower is one of the largest cost drivers in the DOD budget. Maximizing the potential of human operators in future missions can only be done with a sensible approach to user interfaces, as it is not enough to simply capture more salient data through advanced

sensors/capabilities of machines if the information collected is not actionable because humans cannot process it quickly, efficiently, or correctly.

A fallacious belief has propagated within the unmanned systems industry that research interest is better invested in “solutions” apart from a dedicated Human Systems Integration (HSI) plan, and that the inclusion of human factors practitioners during system design and acquisition is optional. This same mindset in other industries has resulted in preventable disasters on the scale of nuclear power plant meltdowns to high casualty aviation mishaps.

In truth, unmanned systems deserve careful attention from human factors practitioners that can not only ensure CONOPS are human centered, interfaces are usable, but ensure workload estimates and dynamic function allocations for operators and maintainers of unmanned systems are appropriate. Successful MUM-T depends on this.

A careful analysis of the capabilities and limitations of humans in context is essential to generating realistic function allocations that ensure an appropriate workload exists in the humans’ relationship to robotic systems. Simply relying on a dated Fitts list [1] (a list of statements that try to quantify the relative capabilities of humans and machines) to guide the development of function allocations is insufficient for future battlefields where fully autonomous robots will be acting as functional team members alongside humans.

There are two main reasons this is insufficient as a guide for the future. First, the abilities of humans and machines in this context are not commensurate; rather they are complimentary based on the context of what is occurring on the battlefield at a given time. Second, the Fitts list statements are not quantitative in nature when it is possible to quantify the capabilities and limitations of humans and machines in context. A detailed job analysis as part of a broader task analysis undertaken by competent human factors

practitioners as part of an HSI plan is the appropriate way to allocate functions between robots and humans to realize a future for MUM-T on the battlefield.

Theodore von Kármán, the father of supersonic flight is quoted as saying, “scientific results cannot be used efficiently by soldiers who have no understanding of them, and scientists cannot produce results useful for warfare without an understanding of the operations [2].” These words embody the importance of the work of human factors practitioners who are able to study and understand military operations, and provide analysis-driven solutions to problems (such as function allocation for MUM-T).

Competent human factors practitioners know that it is not their role to simply ask users what they want and give it to them. It is irresponsible to push the task of design off onto users who may not know what they need/want, and in general have difficulty envisioning something new and radically different. The future of autonomy on the battlefield will be new and radically different. The role of users in informing human factors decisions about MUM-T is more appropriately applied as advisors about what they are currently doing operationally, and what they are trying to accomplish. Users are experts at this, and while they may have good design ideas, should not be relied on to define future system requirements.

THE FUTURE OF AUTONOMY

It is often demonstrated throughout history that previously victorious militaries are always fighting the last war. This subsequently serves as the catalyst for reforms and new ways of thinking that prove successful thereby establishing new military doctrines that prove to be revolutionary. For instance, Frederick the Great’s innovative tactics propelled him to success at the head of the Prussian army and it was upon these revered reforms that Napoleon Bonaparte based much of his success in Europe.

These same tactics can rightly inform strategies employed by the United States on the battlefield as large scale operations are increasingly supplanted by small, highly mobile, and sustainable ground operations that will heavily involve autonomous unmanned systems in contested urban environments. Just as it can be unwise to plan to fight the last war, it is equally unwise to design and build the last war's weapon to operate in these environments. When considering U.S. Army acquisitions such as the Next Generation Combat Vehicle (NGCV), careful emphasis must be placed on ensuring that the last war's tank is not being built or else the reward of outpacing future threats via disruptive technologies on a new and novel ground platform will not be realized.

As future unmanned systems are developed that are said to exist at higher levels of autonomy, appropriate consideration of what this means for MUM-T is essential. Assuming that the NGCV model relies on manned and unmanned vehicles working together, the dynamics of this team should not be modeled on the relationships of humans and their robotic counterparts of the past on the battlefield.

Many unmanned systems can be characterized by the level of control humans exhibit over them. This supervisory control was and remains appropriate for semi-autonomous machines or robots carrying out preprogrammed behaviors and routines, but is not suitable for the future where fully autonomous systems will be commonplace. The NGCV is an opportunity to showcase such capability on the battlefield, but a fully autonomous system will necessarily require a different approach to the design of the interfaces for soldiers that will rely on robotic teammates. In this way, it can rightly be asserted that MUM-T is the future of autonomy.

Defining Autonomy

When designating unmanned systems, the term "autonomous" has historically been used loosely to refer to everything from remotely controlled

robotic platforms to machines that require little to no human intervention during operation. For the purposes of discussing future MUM-T on the battlefield, it is necessary to clarify terms. Most systems that are referred to as "autonomous" are really semi-autonomous. They are not making their own decisions in real time, but rather engaged in preprogrammed actions and reliant on human supervisory control for specific tasking.

For instance, an Unmanned Ground Vehicle (UGV) may be automatically following preprogrammed waypoints along a route (while relying on sense and avoid technologies on board), however a human sensor operator may be managing the Information, Surveillance, and Reconnaissance (ISR) package remotely and determining what is important.

This stands in contrast to fully autonomous thinking machines that interpret their own surroundings, make their own decisions, and are intelligent enough to know what ISR information their human counterparts need and when to share it. This sort of relationship with highly intelligent and capable machines is the future of MUM-T and future programs should prepare now (in the acquisition phase) for future operational paradigms where intelligent robotics are not subservient in terms of control to humans, but rather are teammates in the truest sense of the term. Such a future will require a different approach to human-machine interfaces and the function allocations that characterize them.

In particular, communication between machines and humans will have to be rethought to operate successfully under this paradigm. Consider Explosive Ordnance Disposal (EOD) robotics that are almost entirely remotely operated. If such machines were fully autonomous in their abilities to carry out EOD missions, the relationship of human operators to these machines would change. There would be a need for communication, but not controls in the traditional sense. Hence, the design focus for the future would need to be on communication interfaces that support human

operators' understanding of the mission being carried out autonomously. Under such conditions, the human may not even need to communicate in real time with robots, but rather assume a job is being completed in the same manner that they would if a human was assigned the task.

Demonstrations of Full Autonomy

A temptation may exist to view such fully autonomous robots as a feature in the distant future and therefore continue to plan for traditional supervisory control mechanisms as primary. Doing so is designing and building the last war's weapon. Further, the technologies necessary enabling fully autonomous machines to complete useful missions on behalf of and alongside humans exist and have been well demonstrated.

Perhaps the most prominent demonstration of fully autonomous robots engaged in DOD-relevant missions is the International Aerial Robotics Competition (IARC). For nearly three decades, the mission of the IARC has been to advance the state of the art in aerial robotic behavior through the completion of missions that are impossible at the time they are proposed. While there is an emphasis on the aerial platforms in the competition, the technologies demonstrated are relevant for all unmanned platforms.

Across seven missions spanning twenty-seven years, the IARC has demonstrated fully autonomous aerial robots complete highly advanced behaviors including the manipulation and movement of physical objects, outdoor and indoor mapping of structures, interaction with other ground robots and sub-vehicles, mapping dynamic and hostile environments, locating humans on the ground and identifying them as alive or dead, ISR tracking/sharing, and sense and avoid in contested GPS-denied environments. None of these behaviors were preprogrammed routines, but rather involved fully autonomous intelligent machines making their own decisions in real time. The technical significance of these

behaviors to DOD missions for robotics on the battlefield cannot be understated.

Prophetically, Hungarian physicist and father of the hydrogen bomb Dr. Edward Teller stated in 1981 that, "the unmanned vehicle today is a technology akin to the importance of radars and computers in 1935 [3]." In reference to this quotation, Robert Michelson, originator of the term "aerial robotics" and the founder of the IARC, stated, "That being the case, then I believe the unmanned vehicles of Teller's day will be seen as the progenitors of an astonishing new class of mobile "thinking" machines able to assemble disparate data from an array of sensors and intelligently draw conclusions upon which to act with the adeptness and fallibility of a human [3]." Michelson further stated, "Fully autonomous aerial robots exist today and have been around for years, but the future of sentient robotic technologies is still mostly ahead of us. The day will come when behaviors of robotic vehicles will be indistinguishable from those of manned vehicles. Speech synthesis will allow these robots to communicate with us in a manner that can and will fool us into thinking that we are interacting with another human being [4]."

An emphasis on these communication techniques is a primary focus of IARC's eighth mission, and will prove to be essential to the success of MUM-T on the battlefield in the future (particularly at the platoon level). The eighth mission requires humans and teams of robots to interact in a GPS and Simultaneous Localization and Mapping (SLAM) denied environment while fending off attacks from hostile robot sentries. The mission is designed to be only accomplishable through fused sensory enhancement of a human operator through interaction with a team of fully autonomous robots. Communication by speech and gesture (just as human soldiers would do) is required.

This mission has been described as seeking to, "allow an individual to communicate with his 'team' much as one would communicate between members of a tactical unit. Complex

speech/gesture patterns will be needed to allow autonomous aerial robotic team members to perform intelligently. Commands like, ‘Unit 2: find the target to your right, Unit 3: hold position, Unit 1: follow me, Unit 4: wrong target; disengage and find the target approximately three meters to your left.’ [5].” The injection of communication to this degree in real time should be considered of prime interest to those designing the next generation of battlefield robotics.

Consider a fire team engaged in a complicated shoot-on-the-move maneuver where commands such as “cover” and “moving” are originating repeatedly from different sources during live fire. The ability of battlefield robots to distinguish these commands and whom they are intended for just as humans currently do is essential. The age of single vehicle single operator proprietary ground control stations (GCS) needs to end to realize this MUM-T future.

The sustainable design of interfaces and command and control paradigms that can remain relevant across many years and generations of users is a real need facing the unmanned systems industry [6], and that means less joysticks, shielded displays, and ruggedized laptops, and more natural communication. The former elements, while necessary for now, should be seen as temporary.

Implications of Full Autonomy

Highly intelligent machines that do not require human supervisory control to complete complicated missions also should cause the unmanned systems industry to consider if the term “drone” is proper. Certainly, the media makes heavy use of the term to define in a broad sense anything robotic that can be classified as belonging anywhere within the levels of autonomy, but this is perhaps misguided when considering fully autonomous machines. The term “drone” implies a lack of intelligence in contrast to a thinking machine or unmanned system that is capable of making its own decisions. In this way,

MUM-T of the future should consider the inclusion of terms such as “team members”, “counterparts”, or “intelligent assets” to supplant the term “drone” as these terms more accurately describe what is occurring and set intelligent machines apart from robot toys available commercially off the shelf.

Unmanned Aerial Systems (UAS) have rightly been defined as, “the fusion of aeronautics with IT, and Aerial Robotics is the infusion of cognition into Unmanned Aerial Vehicles [4].” This definition correctly identifies the capacity for intelligence as a key delineator. As it is applicable across platform domains, one can easily expand this definition to include all unmanned systems. In truth, on the battlefields of the future, successful MUM-T and mission completion will involve the synthesis of a variety of unmanned platforms working together to provide ISR, targeting, and kinetic effects in appropriate measure.

Dismounted soldiers know that one of the first elements to degrade in a firefight is communication. If robots are to truly be capable of working as functional team members that can serve alongside humans, they must be able to understand human communication as well as communicate themselves. It is critical that infantry teams have knowledge of where their team members are and where they are going. This is as important to supporting one another as it is to mitigating fratricide. Trust in automation becomes a potential limiting factor in this environment, and humans may have an uncomfortable transition. Such behavior of course sets the basis for the removal of humans from direct contact with the enemy altogether.

The considerations for unmanned systems in such scenarios vary by platform. For instance, UGVs may need to distinguish the difference between cover and concealment, understand a human commander’s order to shift fire, and be able to interpret hand signals or human speech (which may be limited to radios). Unmanned Aerial Vehicles (UAVs) may be concerned with

noise discipline, dynamic routing (distinguishing what routes a human can traverse if they need to follow the robot), what imagery is useful to deliver to which humans and when, and operating beyond line of sight (BLOS).

Each of these considerations have profound communications implications for humans on the battlefield and in some instances require specialized human-machine interfaces. Alongside such implications are the necessary realities of manpower, personnel, and training. Often when new systems are advertised as the future solution for warfighters, little thought is attributed to what the warfighter is already expected to be doing. Who will carry this new system (and the burdensome batteries it requires for operation)? Who will fix this system when it breaks? Who will maintain this system so that it does not break? Who will have to be trained to operate the system? Who fills out the paperwork when the system is lost?

These sorts of concerns are all too real when considering the injection of robotics at the platoon level. Competent human factors practitioners as part of an overall HSI strategy can appropriately study the impacts of proposed solutions early in the design process to quantify and mitigate problems of this nature before they arise and ensure that sensible function allocations are in place that promote sustainable workload patterns for MUM-T.

Another implication of full autonomy is that opposing forces will also eventually make use of it. Enemies are already taking steps in that direction and it could have devastating results for blue ground forces if not countered. For decades, the U.S. military's air dominance has gone mostly uncontested and this has resulted in a comfort for ground forces that they need not think about threats from above. Yet, enemies are already weaponizing inexpensive commercial drones and carrying out successful attacks [7]. The need for counter UXV technologies is great however; there

is a psychological element that should not be ignored.

John Boyd, fighter pilot extraordinaire and military strategist whose contributions to modern warfare are deeply evident, stated, "People should come first. Then ideas. And then hardware [8]." While counter UXV technologies are essential, more hardware can prove to be part of the problem. The U.S. military's unmanned systems are too expensive when compared to a commercially available weaponized drone. Counter UXV systems could also easily suffer from ballooning cost, and when matched against fully autonomous systems, may not be useful. One cannot attack the data link if one does not exist, and fully autonomous machines may be entirely operable without one.

In such a future, John Boyd's key contribution to strategy, the Observe, Orient, Decide, Act (OODA) Loop, should be considered. This decision cycle quantified the way in which people observe, orient, decide, and act and has been rightly applied to understand how humans attain an edge over adversaries in contexts from the battlefield to the boardroom. The stimulation of chaos and confusion is the basis for the disruption of an adversary's OODA Loop.

Clearly, machines are capable of extrapolating the consequences of decisions and adapting this mental model to rapidly shifting conditions in order to suppress the decision-making abilities of adversaries more quickly and effectively than humans can. Such an ability is the overmatch the U.S. military desires in any situation – against human adversaries. An important research horizon is the study and design of machines that can disrupt the OODA Loops of other machines on the battlefield. In a real sense, this is counter-counter-UXV as intelligent robots exhibit behavior capable of deceiving other intelligent robots into over or under reacting to a situation.

Similar missions have been undertaken by the IARC in the past where fully autonomous machines compete head to head in an effort to

disrupt the intentions of the other, forcing them to reorient their approach to a problem. Pursuing the acquisition of battlefield robotics that can perform at this level meets the objectives of the U.S. Army's Robotic and Autonomous Systems Strategy (RAS) and Army Operating Concept (AOC), and gives the warfighter a critical edge as part of the Third Offset Strategy.

A NEW C2 PARADIGM

When considering the acquisition and integration of semi-autonomous and fully autonomous machines into military MUM-T, it is instructive to consider the phases necessary to responsibly make a transition from current practice. The AOC often includes broad desired capabilities that cannot be acquired simultaneously or in the near term. In this way, MUM-T should be understood as a transition that will have an immediate term, a midterm, and a future term.

The following MUM-T paradigm should be considered a midterm solution that seeks to accommodate the environmental challenges facing warfighters and their robotic counterparts in the future. New interface techniques such as this will be necessary to reinforce the paradigm that support the C2 of multiple human-machine teams completing diverse missions as part of the DOD's Third Offset Strategy.

While speaking about Third Offset potential and the capabilities of unmanned systems, Deputy Defense Secretary Bob Work is quoted as saying, "These include autonomous learning systems for handling big data and determining patterns, human-machine collaboration for more timely relevant decision making, and assisted human operations through technology assistance...Other capabilities are advanced human-machine combat teaming such as with manned and unmanned systems working together...[9]"

Realizing the future Secretary Work describes will require a new approach to teaming and interfaces that fully enable the potential of independent and cooperative decision-making

abilities of fully autonomous machines while maximizing the effectiveness of human operators on the battlefield. While a complete analysis as part of an HSI plan should govern the development of specifics of any new concept, the following paradigm could serve as a worthy basis for such an analysis.

Considerations for a New Paradigm

Current C2 interfaces for unmanned systems do not support the complex operational needs of MUM-T on future battlefields. There is arguably too many functions and too much training required to allow all soldiers in the loop the ability to utilize the benefits disparate robots across multiple platforms can bring. Given the current state of autonomous systems and the sensor packages available to them, the amount of data robots can capture and share with humans far outpaces what current GCS interfaces can responsibly display, or what the finite cognitive processing abilities of humans can process. Unmanned platforms in this way have far outpaced the user interfaces designed to support them.

One of the largest cost drivers in the DOD budget is manpower (combined with training), and this is major bottleneck for the management of unmanned systems. There is a lot of research and development targeting "universal" and "common" GCSs that support the C2 of multiple heterogeneous unmanned platforms. Such GCS concepts are needed, but should be seen (in their current form) as temporary because the advent of fully autonomous systems can make them obsolete, and because the manpower and training cost of supporting them is probably not sustainable in the long run. "Pilots" and "operators" should be seen as temporary.

Military doctrine must come to terms with the notion of what it means to be responsible for/work alongside an unmanned system. One approach is to strive to expect every human to be a trained operator. This is as expensive as it is impractical.

Another approach is to limit the use of unmanned systems to a select trained few.

The future of C2 for unmanned systems is entirely unsustainable unless simplicity and commonality is found amongst disparate platforms. For instance, it makes little sense for the EO/IR sensor package interface on a high altitude large scale UAS to not mirror one on a simpler ground based platform. The complexity might be less, but the interface should be similar and easily recognizable to users.

An example of this kind of universal interface commonality can be found in consumer automobiles. “A user that is familiar with the four-door sedan that they own and drive on a daily basis generally has no trouble knowing where to sit or how to start a rental car of another brand having only two doors. While finer details of the dashboard may be different, the common and necessary elements for success are familiar and universal. Interoperable GCS designs that support such commonality are ripe for integration into many DOD programs of record and doing so would enhance system effectiveness, efficiency, and affordability [6].”

A proper outlook for the C2 of unmanned systems on the battlefield is one where interface

familiarity is universal, learnability is high, and services are accessible to all. Therefore, the success of MUM-T in the future will rest on these pillars. The natural consequence will be that the use of robotics on the battlefield will not be limited to a select few operators, and their use will be so simple that little training is required for humans to benefit.

A Scenario for a New Paradigm

Solutions in the midterm for dismounted soldiers in particular will be hindered by high training requirements. The notion that everyone needs to be a “pilot” or “sensor operator” is impractical from this perspective, yet all soldiers would benefit from the situational awareness and enhanced lethality that employing a team of robots could bring to a fight.

Consider a scenario where a team of dismounted soldiers must reach a hostile hilltop compound in a contested area to secure vital intelligence as depicted in Figure 1. In such a scenario, the team’s mission will be made easier and safer by the assistance of unmanned assets of various platforms distributed throughout the Area of Operations (AO) that can be summoned at key moments deemed most valuable to the team

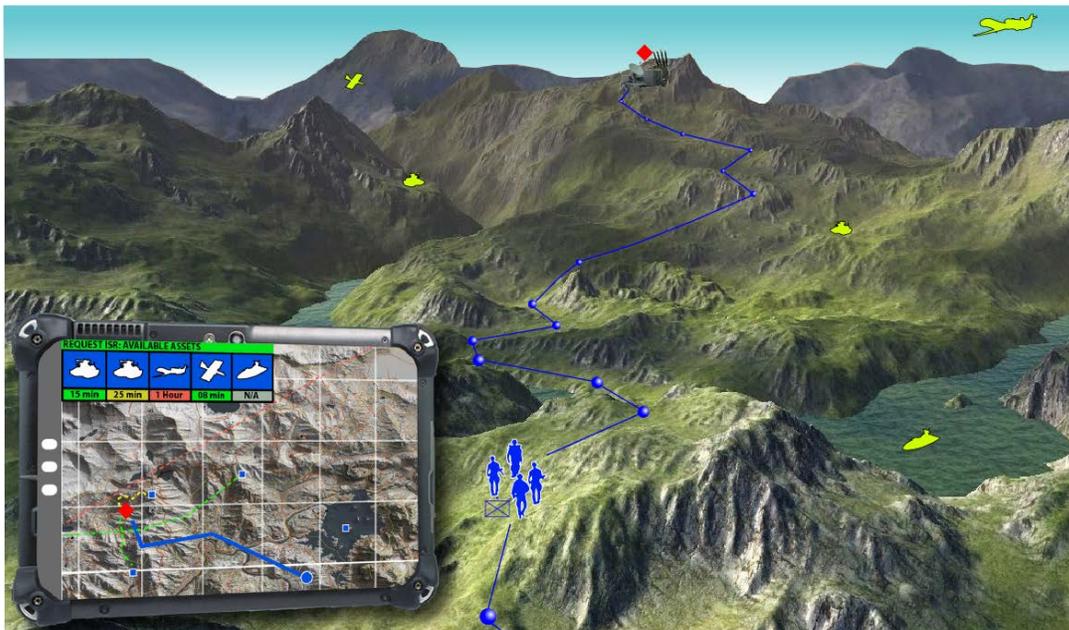


Figure 1: A depiction of how blue forces could utilize an interface (notionally depicted) for the management of distributed unmanned assets for an ISR mission without having to be knowledgeable about the nuances of each system’s operation.

leader.

The following scenario is only feasible if humans are not burdened by the extensive learning curves necessary to operate proprietary C2 interfaces unique to each unmanned platform. Rather, a common interface that extends the capabilities of soldiers will provide UXVs as a service (ISR, strike, transportation, etc.) on a Nett Warrior-like mobile device that is notionally depicted in Figure 2.

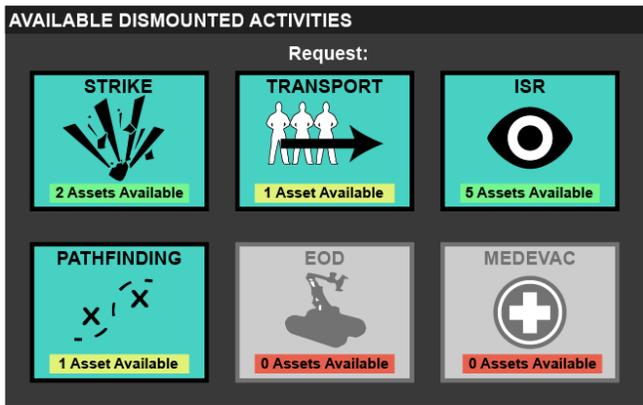


Figure 2: A notional wireframe of an interface that would enable soldiers to select UXV services relevant to their mission by their availability in the AO.

Consider that when a person purchases a train or airplane ticket, they become a user of a system but are by no means required to know how to drive the train or fly the airplane, yet they are users who benefit from the service provided by these platforms. This paradigm promotes the same notion for autonomous battlefield robots.

As the team proceeds along a pre-planned route, they enjoy overwatch from unmanned aerial ISR assets with strike capability, and unmanned ground assets with transport capability. The team leader can make changes to the team’s route based on information shared from these platforms.

By these means, assume that the team becomes aware of hostile ground forces waiting in ambush along their route to the hostile compound. A human team member can make use of an interface to call for an aerial strike on the hostile ground

forces’ position. The availability of strike-ready assets in the AO is easily selectable and the human team member is able to prioritize which asset to use based on the time it would take the particular asset to arrive in a position to deliver the desired kinetic effect. In such an interface, only applicable strike platforms would be shown to the team member to minimize the number of choices.

As the team progresses closer to the hostile compound, the team leader requires a clearer picture of the planned entry point into a target structure on site. The team has access to several dated aerial photographs of the target structure, but has no information about possible entry points into the building. Once again, making use of a UXV as a service interface, human team members can summon an unmanned ISR asset in the AO to assist with this problem.

The human team member has several options available. They can get a low quality image from a small fast aerial asset nearby almost immediately, or they can wait an hour or more for a larger high altitude aerial asset to provide extremely high quality imagery of the target structure as shown in Figure 3. In addition, a number of UGVs nearby can discretely augment the available aerial imagery as necessary, but may be hindered by rough terrain.



Figure 3: A notional wireframe depicting available ISR assets and their routes across platforms that are available to the human requester. Note the time to arrive on station is key to which asset may prove to be most appropriate.

Because the picture the team leader wants is from a unique perspective, it will make sense for the multiple unmanned assets to work together to fuse the right picture together from multiple angles. The human team member opts to summon the fast small aerial platform and a nearby UGV to provide imagery together. Once available, sensors across these disparate platforms are fused together to provide a unique image of various entry points to the human team via a secure link to a Nett Warrior-like mobile device.

After a successful breach of the enemy compound, the securing of the targeted intelligence, the human team reaches a predetermined extraction point (dynamically rerouting their waypoints as necessary with the help of UXVs) where they summon a UGV that transports them safely back to a staging area.

In each of these instances, the human team's situational awareness, lethality, and survivability is enhanced by the use of UXVs as a service in context. No specialized interfaces were required for the use of multiple platform capabilities. Anyone on the human team could make service requests of unmanned assets in the AO. Humans were not required to sift through live data feeds, but rather were presented with sensor-fused imagery that the unmanned systems were intelligent enough to provide in context upon request.

This scenario is just one of many possible battlefield activities where unmanned systems can team with humans, and none of the humans had to be expert operators or pilots of the specific platforms. Such a condition is preferable to reduce human workload and reliance on human cognition for tasks in which humans are increasingly going to be limited at handling mentally. Robots however can excel at activities such as directing advanced Electronic or Cyber Warfare techniques against complicated targets.

Interfaces of this sort should have high appeal to the next generation of military users who will be more accustomed to the use of service-based

applications on mobile devices. In many ways, scenarios such as this supported by a common interface would be typical of a C2 paradigm similar to that of civilians summoning a ride share via a smartphone.

The new C2 paradigm described meets many of the challenges set forth in the RAS. In particular the goals of "increase situational awareness", "lighten the soldiers' physical and cognitive workloads", "facilitate movement and maneuver", and "protect the force" [10]. Fully autonomous fleets of UXVs on station awaiting requests for services such as ISR, transport (medevac), or kinetic effects support meeting these challenges for dismounted soldiers in the hypothetical scenario given.

A Future where MUM-T Works

Many of the technologies necessary to begin to build a future where MUM-T operates as described in the notional scenario exist or are being developed. The state of full autonomy for robotic agents has been established and will only continue to grow in capability and prevalence. The advent of capabilities like Nett Warrior for dismounted soldiers provides a viable platform for the insertion of new C2 technologies that increase the lethality and survivability of the warfighter.

In the near term, multiple disparate unmanned systems on the battlefield will increasingly be able to fuse different sensor feeds together effectively for human operators. While such a capability is thought to be a force multiplier that enhances situational awareness, studies have shown that such automation has actually led to a degradation of human awareness in some instances. In particular, a sense of scale, orientation, and speed can be lost when the human's only experience in an environment is through a small display [11].

Recently, a variety of other ways to share imagery from unmanned systems with warfighters have been popularized. These include augmented reality, head mounted display integration, and haptics. Above all, if these techniques are to be

successful, they must account for the amount of data being shared and the manner in which it is presented to users in the context of the state of the unmanned system. Given the amount of data that will be possible to share, GCS interface designers should note that most often situational awareness fails when cognitive overload causes a human operator to lose their perception of the environment (otherwise known as Level I SA) [12].

An appropriate strategy for documenting and mitigating these sorts of issues that can severely inhibit or completely disrupt successful MUM-T should be led by competent HSI and Human Factors practitioners. A principled approach that considers situational awareness and workload of human operators interacting with unmanned systems can be undertaken as part of a Mission Task Analysis (MTA). A Mission Level Analysis can identify broad mission specific requirements that map to human performance requirements. This can then be coupled with a Function Level Analysis that appropriately defines the distribution of activity between humans, hardware, and software. A successful Function Level Analysis can produce machine-related requirements that can be translated into human performance requirements. A Task Level Analysis can identify specific task behaviors, performance metrics, workload estimates, information requirements, and a list of potential errors. It can be useful to pair relevant Knowledge, Skills, and Abilities (KSAs) of the human operators at this stage.

The Task Level Analysis is particularly important to GCSs as it should drive the specific interface design. Tasks should be characterized by whether they are system inputs or outputs. System inputs generally pair to display requirements, while outputs generally pair to control requirements. Coupling this to a relevant design reference scenario is how a designer can determine what belongs on a GCS display, and when to display it.

The value of such an approach goes well beyond interface design, as these techniques can help model human workload and performance to generate analysis-driven crewing concepts. These sorts of analyses should be commonplace in the future, as quantifying these sorts of values is exactly how an emphasis on the human and their needs is maintained for MUM-T. Without such analyses, CONOPS may assume too much about the cognitive capacity of the warfighter, and future MUM-T solutions will be found to not be solutions at all.

CONCLUSION

New ways of thinking will be necessary to successfully implement MUM-T on the battlefields of the future. As John Boyd would advocate, this future should be governed by an attitude that puts the human first as opposed to simply injecting advanced hardware into existing paradigms. Thoughtful guidance from competent human factors practitioners as part of an HSI strategy should guide a human-centered design process that properly allocates tasks to maintain safe workload levels. In this context, designers should plan for highly capable fully autonomous machines that are able to disrupt the OODA Loops of other machines to counter adversarial robotics.

When considering near term solutions, single operator, single platform, and proprietary GCS interfaces are not a sustainable path forward to properly implement MUM-T in a meaningful way on the battlefield as fully autonomous robotics become more commonplace. In the meantime, considerable human factors analysis is needed to solve hardware/software interface problems facing warfighters involved in the C2 of UXVs from other vehicles. In particular, human operators in manned ground vehicles face challenges such as display visibility, operations in vibratory environments, gloved operation, and vehicle integration/control issues.

Programs in acquisition should consider how to plan for a future where not everyone is expected to

be a skilled pilot, but rather can be a user/beneficiary of UXV services. Whether it is delivering warheads or soldiers to locations around a battlefield, unmanned systems should be designed to play a critical role in maximizing damage to the enemy without increasing human workload. Any solution that adversely affects the warfighter's capacity for attention, increases their workload, or otherwise inhibits effective performance should be redesigned or scrapped.

The battlefields of the future will be radically different places when intelligent robotics become ubiquitous. Planning for this future now will ensure that military doctrine and tactics do not stagnate and place the warfighter at risk. At present, the focus of MUM-T should be on human-centered solutions that enable, not frustrate the effectiveness of human teams.

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