Rapid Assessment Process (RAP) Report # 03 - 10

Unmanned Effects (UFX): Taking the Human Out of the Loop

Project Alpha

Joint Futures Laboratory

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September 2003

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"The best way to predict the future is to invent it."
-- Alan Kay, a Pioneer in the Development of the Personal Computer

Executive Summary

The purpose of Project Alpha is to discover, explore, and accelerate good ideas across the Department of Defense (DOD). The good ideas are selected and vetted for their potential to assist in the USJFCOM-charted mission to experiment with transformation of the future joint force. Unmanned Effects is one of those candidate ideas. The purpose of this Rapid Assessment Process (RAP) report is to document the advances in robotics and urge early adoption of robotic concepts.

This report discusses the feasibility of employing **autonomous** robotic forces (called Tactical Autonomous Combatants or TACs in this paper) for a variety of military applications. In the following pages you will read about three imperatives for transforming to a future joint force that is significantly robotic. You will also read about technological advances that can change the fundamental way wars are fought. We believe it is not so much a question of **if** this

transformation will happen, but one of **when**, **by whom** and **how efficiently**. Project Alpha team members believe that the introduction of unmanned entities into the battlespace promises to have a greater impact on future conflict than any other technological innovation to date. Our research has convinced us that unmanned entities will provide significant new capabilities

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Three Imperatives for Robotics

1. National Security
2. Save Human Lives
3. Economics

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to the forces, and that the capabilities will be available sooner, rather than later – if decisions are made to pursue the robotic course.

Based on our discussions with the technologists, we believe that if we can articulate a future vision and provide clear goals and adequate resources, the scientific community can create it. The disagreements among the scientific community about the feasibility of future robotic forces are slight, and they deal primarily with the question of when the technological advancements will occur, not if they will occur.

This report discusses our vision for the role of unmanned entities in future joint forces. We discuss the technical feasibilities and the value of employing autonomous unmanned entities. Short vignettes (such as one on the next page) are spread throughout the report to show how unmanned entities might be used in future military operations. They offer only a hint of the possible. Much more exploration will be required to determine how to best use the unmanned entities in various domains and scenarios and what capabilities will be required.

Vignette 1

Applicability of Robotics to Operation Iraqi Freedom

Imagine a future in which robots significantly reduce human exposure to danger in both major combat operations and stability operations. In fact, we believe significant capability could be built today to reduce the exposure of our forces to mines as well as direct attack. Following are some things we think could be done with existing or near-term technologies to provide capabilities to support our forces presently operating in Iraq.

- Autonomous guard TACs could provide security in numerous scenarios. Using existing technology, small vehicles could patrol perimeters and report on intruders. The TACs would carry acoustic, thermal, and optical sensors.

- Guard TACs could provide convoy security. The guards would autonomously drive on the flanks in open areas or ahead and behind convoys to ensure that assailants could be driven off or avoided. While we don't think target recognition algorithms are accurate enough to use today, the guards could fire if fired upon and could investigate suspicious activity. Sensor technology would likely provide the TACs with the capability of detecting human activity where none is expected.

  TACs providing lead security would inspect suspicious items along the road, looking for possible mines and booby traps. Existing technology should make them highly reliable in sniffing out a range of explosives from rigged artillery shells to homemade bombs and other improvised explosive devices (IED).

Guardbots may be able to autonomously identify threats like this IED (an artillery shell disguised to look like a cinder block).

- Small guard TACs, in the size range of the 40-pound Pacbots used in Afghanistan, could serve as initial sentries at guard posts. These Pacbots could be fitted with explosives sniffers, to identify potential threats before the threats come in close contact with friendly forces. These same sniffers could be used to inspect vehicles parked near US forces and facilities.

- Swarms of low-cost UAVs could be flown ahead and around convoys providing the convoy commander with video coverage of the surrounding area. These lightweight, inexpensive UAVs would be under the nominal control of the convoy commander, but because they would utilize swarming algorithms would not require constant attention as do the current family of UAVs.

- Swarms of inexpensive UAVs could provide over watch around airfields and helicopter landing pads. These swarms would report on discrepancies in their environment and report to ground guard TACs or humans to investigate.

Unmanned Effects (UFX): Taking the Human
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A Vision for Future Robotic Forces

Our vision assumes that between 2015 and 2025, the joint force could be largely robotic at the tactical level. We term these future land, air, space, sea, undersea and cyber robots, *Tactical Autonomous Combatants* or *TACs*. The TACs are networked and integrated. They coordinate with each other and with humans.

The TACs will take on physical forms that will optimize their uses for the roles and missions they will perform. Thus, some will look like vehicles with tracks, wheels or other means of locomotion. Of course there will be unmanned aerial vehicles (UAVs) that look like airplanes, and will be autonomous, unlike todays remote-controlled Predator or Global Hawk. In an attempt to camouflage or to deceive the adversary, some may look like insects, animals, or other inconspicuous objects. Some will have no physical form, existing only in software – intelligent agents or cyberbots. Some will be quite large (like tanks, aircraft or submarines); some may be very small – even microscopic. There will be unmanned underwater vehicles and surface vehicles. Probably none of the TACs that we envision will look like humans – so don't envision anything like the *Terminator* or the '*droids*' in *Star Wars*.

The TACs will fulfill a variety of roles to include sensors (reconnaissance and surveillance), weapons (unmanned tanks and howitzers), logistics support (supply vehicles), transport, search and rescue, mine clearing, sentries and medical care. Microbots and nanobots[1] will fill roles that, presently, have largely not yet even been envisioned. Cyberbots (viruses and worms) will attack adversary information systems. Intelligent agents and decision support systems will process information and support decision makers. TACs will fill roles ranging from mundane tasks like cleaning ship bilges, chipping paint, painting, and warehouse sentries (functions requiring very little 'intelligence') to sophisticated sensors and combatants. But, TACs will probably not fill roles that require human-level cognition.

Unmanned entities will be networked and will work together. For example, a UAV will provide targeting information to a group of unmanned ground vehicles (UGVs) that will coordinate with each other how to best engage targets. The unmanned entities will use "on-board" artificial intelligence to self-synchronize.

Even though we use the term "autonomous", we do not envision total autonomy. The term "supervised autonomy" is more accurate. Humans will "supervise" the unmanned entities when objectives change or when decisions outside the bounds of the TAC's autonomy are required. TACs might replace humans but shouldn't be thought of as human replacements. TACs will be expendable while humans are not. This characteristic presents new ways to think about roles and missions. Like the introduction to the military of every other new technology, TACs will open up an entirely new way of conducting combat. We call the machines "tactical autonomous combatants" because they will be used largely at the tactical level, will possess some level of autonomy and will free up people by performing much of the functionality currently provided by humans. We call them combatants to signify that they will be used for numerous roles, including

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[1] "$1 Billion Places US on Nano-road," Electronic Engineering times, pp. 62, March, 2003.

combat. Today's servicemen and women are considered combatants whether they are mechanics, pilots or infantryman. Some TACs will deliver logistics, some will conduct suppression of enemy air defenses (SEAD), others might locate underwater mines while still others will have only ISR responsibilities. Because they are networked, all TACs become ISR sensors, providing information to each other and to the humans making operational and strategic level decisions. They will exhibit robotic ESP – that is, they will be able to read each other's "minds" because they will be linked. The network of TACs will simultaneously share all information with other TACs and with humans. Unlike humans, who often have unique perspectives, the TACs will truly have common shared situational awareness. They will view the common information from the same context or framework.

Vignette 2

By 2015 the battlespace will be filled with autonomous machines that will be networked with each other and humans. TACs, by definition, must have sensors. They must be able to sense and make sense of their environment as well as transmit and receive what they sense and what is sensed by other TACs.

Now: Dedicated sensors are deployed to sample particular types of information in particular environments. If we need radar images, we deploy machines, perhaps manned, that can supply radar imagery. Later, if thermal sensors will provide greater advantage we deploy them.

The Future: All TACs will have sensors that will supply information to the net. Based on mission requirements and adversary disposition, different types of sensors will be distributed to the TAC force to help provide total information about the enemy. Imagine small air TACs, which are able to self-organize to provide total coverage of an urban environment. These TACs – PERCHBOTs – would coordinate with each other to ensure total coverage of an area of interest. If some of the perchbots were to be destroyed or malfunction, the others would reorganize to provide coverage designated as essential by the commander, or by other TACs on the ground. In the end, a friendly commander may have better information about the enemy than the enemy commander.

Perchbot – Allied Aerospace's iSTAR UAV can fly both horizontally and vertically.

The idea of using robots is not new[2]. In fact, the military has constantly looked for ways to use machines for dull, dirty and dangerous missions. Until today the machines have been controlled remotely. Project Alpha thinks that the machines can be given the ability to control themselves, thereby removing humans from having to make many decisions. This report follows a previous Project Alpha study that advocated the adoption of swarming as a means of controlling several unmanned vehicles by a single person. That study advanced the position that swarms of essentially simple machines could produce an emergent behavior that would give the battle space commander significant capability while reducing the human footprint. This capability allows one person to control dozens of unmanned vehicles, instead of using a half dozen people to control a single UAV, for example. Unmanned effects continue the trend by not just reducing the number

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[2] Dembeck, C. "Homeland Security Drawing Industry Interest." Journal of Electronic Defense. 26 (April 1, 2003), p. 38.

of required humans, but by removing them from some tactical level decision-making, freeing them for higher-level missions.

Robotic Progression

The development and employment of TACs – taking the human out of the loop for missions and decisions - follows a continuum of development toward more autonomous operation. Current technology relies on constant human supervision – a **human in the loop** – to control machines that are largely tele-operated. In some cases, as in the case of Global Hawk, numerous operators (up to 24) and technicians are required to operate a single platform.

To reduce the human footprint, theorists have examined swarming[3] – as in emulating the way bees and ants behave – as a method of controlling machines. Swarming would permit a single operator to control dozens of vehicles simultaneously. The operator – **human on the loop –** controls the swarm, not the individual machines.

Global Hawk (Human in the Loop)

Individually, an ant has little capability. However, collectively, large numbers of ants are able to perform missions and functions that individual ants cannot do alone as they go about their day-to-day activities of hunting for food, tending the queen ant and protecting the nest from intruders. These simple insects exhibit a higher level of collective behavior - an emergent behavior - that accomplishes complex tasks for the good of the hive or colony. Many believe that machines can also produce an emergent behavior that will exceed the ability of the individual machines and would allow a single person on the loop to control numerous, perhaps dozens of machines. Swarming experts tell us that while we might not always be able to predict the exact actions of swarm members we can effectively predict the behavior of the swarm and control the swarm's actions.

The term, **human on the loop**, is derived from the practical application of this control methodology. Humans would be required to program given behaviors and monitor results, but would not actually steer the machines as they accomplish the mission.
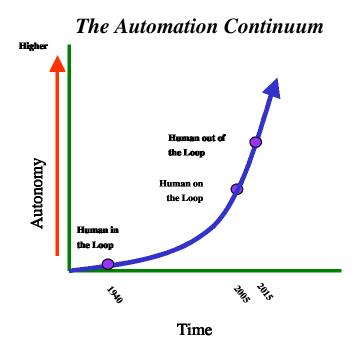
In practical terms this means that a single operator could program a swarm of UAVs to patrol a large grid square, say 25 by 25 kilometers. Their computer instructions might tell the UAVs to fly no closer than two kilometers to their nearest neighbors and that the area must be completely covered every hour. Using one of many available control mechanisms, the machines would then be sent to the area and allowed to perform their missions without human interference. If a UAV were to be shot down or otherwise lost, the remaining vehicles would self-organize and continue to perform the mission.

Human out of the loop - The next logical step on the automation path is to remove the requirement for humans to control machines – getting them out of the loop except for supervisory

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[3] And other methods of autonomous control.

functions. Removing humans from making decisions about how to task the machines will speed the pace of conflict. If machines can control their own movements, humans can concentrate on higher-level decisions – those requiring synthesis, nuance and subtleties.

With the current state of robotic capabilities, the human in or on the loop appears entirely appropriate. But, considering the future, and the explosive developments in technology, we can envision a world in which humans need not be in the decision loop. In future conflict we can anticipate many roles and missions for TACs - without humans in the loop.

The Automation Continuum

Higher

Autonomy

Human out of
the Loop

Human on
the Loop

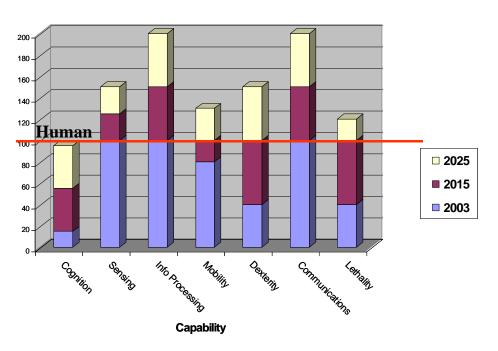Human in
the Loop

1940   2005   2015

Time

Imperatives for Greater Use of Robotics

Moving toward machines that conduct missions autonomously is a natural progression in terms of both technology and warfighting. Throughout history, technology has worked at removing man from conflict. Each new advance, whether the archer's longbow or the Apache Longbow, has permitted man to have greater accuracy at greater distance, in effect deriving the desired effect while keeping friendly forces further from danger.

We have found three imperatives for the adoption of TACs within the military:

1. **National Security**: TACs should be integrated into the force when they are at least as capable as humans and can help improve national security. Even if the machines save lives, it does little good to use TACs if their inclusion into the force weakens or fails to improve our security posture. TACs are already more capable in some respects than humans, and, in the future, will likely be more advanced in all areas. The chart below shows our projections on machine capabilities, expressed relative to human capabilities over the next 20 years. These projections were made following interviews with leaders in the fields of sensing, mobility, machine cognition, automatic target recognition and power, and they were vetted at an Unmanned Effects Workshop (August, 2003) that involved many of the leading scientists in the country working robotic issues. Machines

are already equal to or superior to humans in sensing, information processing and communications. By 2015 machines could exceed human capability in all areas except cognition. However, the lack of cognition does not impede our ability to use TACs. We believe that human-level cognition is <u>not</u> required for most envisioned tasks.

Machines vs Humans over Time

Note: The red line above, at 100 percent, represents human levels for all of capabilities listed on the horizontal axis. Machines will equal or exceed human in all areas except cognition by 2015.

Besides having many capabilities greater than humans, machines aren't afraid, don't get cold, hungry or thirsty, nor worry about the "Dear John" letter in their pocket. TACs will be more survivable, more mobile, and will react faster than humans. In fact, putting humans in the middle of TAC OODA[4] loops will probably slow the pace of combat.

History has shown that everything else being equal, the force with the best technology (and the ability to properly use it) usually emerges victorious. Other countries are seriously pursuing robotics. The US can lead in the area or follow.

Speaking to current transformation efforts, Secretary of Defense Donald Rumsfeld stated that he expects technology to allow the United States to reduce military manpower levels without reducing our fighting capabilities. Robotics offers the potential to be the key mechanism in this regard, without sacrificing national security.

2. **Removing humans from danger**: This is the most intuitive of the imperatives. The implications of removing humans from danger allow us to think of combat and conflict in an entirely different way. Our adversaries know that head-on conflict with our traditional

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[4] Observe, Orient, Decide and Act – from the works of John R. Boyd.

forces is suicidal. They understand how Americans value human life and will attempt to erode public support by constantly sniping at our forces causing a seeming endless stream of casualties. TACs will not only reduce the number of humans put in harm's way but can also significantly add to the security of those who must face danger. Additionally, the public will be little concerned about losing machines in conflict.

The use of TACS also gives us ways to use military power that have heretofore been unthinkable. Imagine the implications of pre-stationing TACs on allied territory to help in the defense against potential aggressors. Any doubts a potential aggressor might have about American resolve to protect their allies would be erased. From thousands of miles away, the machines could be sent to the defense without endangering the lives of American fighting men and women. Attackers would pay in human lives while the US would pay with metal and silicon. At best the TACs would serve as a deterrent, and at worst, they would weaken or delay the invaders until full defenses could be mounted[5].

Vignette 3[5]

Using acoustic and shockwave sensors mounted on a single vehicle, the source of a gun report can be detected within one-meter accuracy. When fused with sensors from other locations, that accuracy can be significantly increased. And, when married with a vehicle and weapon system, we could develop a TAC capable of providing security over humans in a joint urban battlefield environment. A TAC using this technology and a kinetic energy or non-lethal means could disable further attacks.

Now: A sniper shoots a soldier – perhaps wounding him. His comrades take cover, assess the situation, and attempt to provide cover for a rescue mission to take their fallen comrade out of the line of fire. They communicate over radios to coordinate a counter attack on the sniper. Many minutes later they find that the sniper has melted into the cityscape—able to mount another attack later.

The Future: A TAC would not attempt to take cover, but, at the speed of light would have determined the origin of the gun shot and returned fire – killing or disabling the assailant before he could drop his weapon and run. Terrorists would learn that they must pay in blood for each attack.

Humans could use TACs in an anti-access environment for forcible entry as a precursor to arrival. Air, land and sea TACs would cooperate and coordinate probes and attacks on enemy defensive positions. Mine TACs would be able to set up blocking positions and reorganize as required by the changing situation. At worst all the TACs would be destroyed, but our forces would have gleaned significant intelligence about the disposition of forces and the general defense. At best, the TACs would weaken the enemy enough to reduce the cost of lives when follow-on forces arrive. Regardless of the

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[5] McKenna, T. "*Tools of the Unknown Hunter: Look to Passive Targeting to Supply Element of Surprise*." Journal of Electronic Defense, 26 (April 2003), p. 44.

outcome, the commander would have increased situational awareness and be able to make a decision about follow-on action without risking a single life[6].

3. **Economics:** Significant evidence exists to suggest that TACs would be more economical than humans. While Project Alpha does not advocate replacing all humans, we recognize that many humans, such as those required to drive tanks or airplanes would be unnecessary if the vehicles could be automated. We used current budget numbers to arrive at rudimentary costs of each service member, from recruitment to grave, including retirements. Depending on the person's rank, the costs ranged between $3.2 million and $4.3 million. These figures include such things as salary, retirement, housing, relocation, and education. The figures do not include associated costs such as salaries for support staff or infrastructure.

As an example, we believe an unmanned tank would cost less than a manned tank without sacrificing capabilities. An unmanned tank could be smaller, because it would not require compartments for humans. Without humans, it would not require heavy armor. Less armor, and thus less weight, could result in smaller, more economical drivetrains, which could further reduce the size of the tank. Subtracting the cost of maintaining a human crew further reduces the fielding costs. (And it follows that if they are smaller and lighter, we can move more capability farther and faster than current forces.)

PacBots, were used in Afghanistan to remotely search caves – removing soldiers from danger.

According to Dr. Red Whittacker with Carnegie Mellon University's Robotics Institute, robotic farm equipment will be cheaper than the manned versions. He has been working with a farm implement manufacturer to perfect autonomous agricultural machines. He said that the producer is looking to sell an unmanned version of an implement for $30,000 less than the manned version.[7]

As another example, the Air Force is currently paying $150,000 for an unmanned sentry capable of patrolling a military installation and reporting intrusions. A human sentry, whether contracted or military would cost significantly more over a period of several years. After the initial outlay, the unmanned vehicle will require fuel and maintenance. A human requires an annual salary (with benefits) and a vehicle. While humans will remain on the loop for emergencies, our look into the future reveals a trend for less human involvement and greater machine autonomy for lower-end missions.

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[6] DARPA's Dr. Alexander Kott, Program Manger for SideKick, claims that technology available in 3 – 5 years will be sufficient to perform this task.
[7] Based on personal interview, May 2003.

Potential Impact

The study title "*Unmanned Effects (UFX): Taking the Human out of the Loop*" is descriptive and evocative. The name evokes the image of autonomous machines performing many roles previously accomplished only by humans. Effects, tactical to strategic, can be made by using machines in places that might be too dangerous for humans or for missions better suited for machines. We think the special capabilities provided by machines will give us another way to achieve the desired effects, but at reduced operating costs and more importantly, costs to human life. If embraced and coordinated, the use of robotics will change the way wars are fought. If not embraced, the changes will occur, but at a slower pace and with less jointness. Just as the tank changed the conduct of combat in the early 20th century, so too, will TACs change the way war is conducted in the 21st Century.

We have reached a technological frontier where the military is no longer dependent upon serendipitous technological discoveries that at some point are integrated into current equipment. Instead, scientific advancements are happening at such a rapid pace that we must determine requirements, and then put the resources into programs to generate those capabilities. We no longer have to wonder whether machine X or weapon Y can be built. We do need to answer the questions: "Do we want X or Y?" "When can the capabilities be made available?" and "How should we speed their delivery to the military?" And, if we obtain the desired capability, we must consider what these technologies mean to future conflict – in other words, how best to use them.

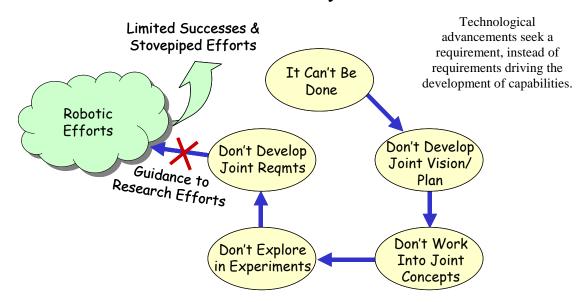*Firescout capabilities are being investigated by the USMC*

The sooner the military agrees on the imperatives for TACs, the sooner the technical community will be able to develop the required capabilities. Technology is advancing too rapidly to permit unguided and uncoordinated efforts from DOD. Some of those working on transforming the military say they fear that the old models of integrating mature systems into the military will ensure that our efforts produce mediocre results. For example, a concept developer for the Army's Future Combat System complained that the Army's dependence on proven and mature technologies ensures that whatever is fielded will be years behind state-of-the-art developments in robotics. Advancements in autonomous behaviors are moving too rapidly to attempt predicting what system should be fielded in 2012 or later. He agreed that the Missile Defense Agency's approach would help ensure that what is eventually fielded is not yesterday's technology.

The Missile Defense Agency (MDA) uses a spiral-block approach that identifies the required technology to fulfill requirements but waits until the last possible moment to identify the materiel solution. MG John Holly, program manager for MDA's ground-based missile defense, recently told attendees at a Space and Missile Defense Conference that his agency is unable to even predict what technologies will be available in four to six years[8].

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[8] US Army Space and Missile Defense Command Conference, August 2003 and Testimony of Dr. Marvin Sambur, Assistant Secretary of the Air Force for Acquisition, before the Tactical Air and Land Forces Subcommittee of the House Armed Services Committee, April 2, 2003.

The Technological Dichotomy

We found a world divided between the scientists and engineers and those watching the programs develop – those on the periphery. The technologists all espoused a belief that by 2015 technology would allow machines to collaborate and cooperate in the battlespace to execute commander's intent. Others, not directly involved with solving technological problems, frequently espoused disbelief that technology would advance so quickly. After talking with the two groups, the Project Alpha team came to the conclusion that both sides are correct. The technologists envision a future as it could be and the others see a world as it has been. The diagram below lays out the paradigm of past program failures.

Avoid the "Can't Do Cycle"

The cycle begins with "It can't be done." Based on science's failure to meet projections and promises, those on the periphery take a cautious stance. They say that science is always late and can't meet the objectives. The failures keep us from developing a vision or plan to produce the new capability. In this case, we fail to develop a joint vision for the use of TACs.

The failure to develop a joint vision and plan for the future results in a failure to conceptualize a future with such capabilities, and a failure to develop joint concepts involving robotics. Thus, there is no reason to conduct joint experiments and no evidence about what works or does not work. As a result, we don't understand or develop joint requirements. This leads to further disjointed efforts that result in programs that fail for lack of vision, money or time, or result in programs that produce capabilities that are off track. Those who say "it can't be done" then point to these failures as proof of their argument – and the cycle begins anew.

Cultural Impediments

We found the trend lines for technological developments are pointed in the right direction, but that better direction (vision) would make the lines steeper. One of the greatest impediments is cultural. For example, three automatic target recognition (ATR) experts contacted opined that by 2015, TACs would be fully capable of discerning enemy from friendly, but also said they believed, because of the "CNN factor", that machines would never be given authority to make lethal decisions. What would happen if a machine were to make a deadly error? Military legal experts say that no law prohibits machines from using lethal force.

Many espouse fear over letting machines make decisions, lest errors be made. What few can describe, however, is how accurate TACs must be. Is human level accuracy good enough, or must TACs be better than humans? We must develop metrics for measuring TAC decision-making skills, e.g. accuracy in discerning friend from foe and conducting autonomous operations, and hold TACs to standards comparable to those for humans. If we agree that TACs should not be allowed to make decisions until they are at least as capable as humans, we need to better understand human capabilities. In ATR, for example, the benchmarks for human capabilities in recognizing targets are poor. Researchers understand how well their machines do at recognizing targets, but they are uncertain how the systems measure-up against humans. Certainly we need to avoid demanding perfection from machines when we do not hold humans to that standard.

Stakeholders and Relevant Activities

The idea of using TACs will touch all services and most OSD level offices. During our research we contacted the following organizations and agencies, all of which are involved in robotics-related activities:

- USJFCOM Concepts Development Path Leads
- OSD Office of Force Transformation
- Assistant Secretary of Defense – NII
- U.S. Joint Robotics Office (Unmanned ground vehicles only)
- Defense Advanced Research Projects Agency (DARPA) (Numerous programs)
- US Army Training and Doctrine Command
- OSD UAV Planning Task Force
- Air Force Research Laboratories
- Naval Research Laboratory
- Office of Naval Research
- Army Research Laboratory
- Institute for Defense Analysis
- National Defense University
- US Army Space and Missile Defense Battle Lab
- US Army Research Institute
- US Army Research Institute for the Behavioral and Social Sciences
- National Institute of Standards and Technology
- Oak Ridge National Lab
- Argonne National Lab
- Johns Hopkins University Applied Physics Lab
- Draper Labs
- Massachusetts Institute of Technology

- Carnegie Mellon University
- Center for Technology and National Security Policy
- Center for Adaptive Strategies and Threats
- Penn State Applied Research Lab
- Jet Propulsion Laboratory/California Institute of Technology
- Communications Electronics Command
- Sandia National Lab
- Canadian Forces Experimentation Centre

Project Alpha found dozens of UAV programs across OSD and the four services. (See the box for a sample of the UAV programs.) We are certain that we did not identify all of the military programs dealing with robotics. The Air Force is working UAV issues to include automatic target recognition as well as robotic sentries. The Marine Corps has its own ground robotic systems that in some aspects mirror Army efforts, and is looking to find its own solution for UAV-mounted sensors. The Navy is working autonomous littoral vehicles and unmanned undersea vehicles to identify and clear mines as well as ship launched UAVs. The Army is largely involved in ground vehicles and is also conducting research on UAVs.

The following will provide a flavor for the amount of effort being undertaken to develop unmanned systems.

➢ DARPA listed in its revised 2002 budget 64 programs dealing with artificial intelligence and robotics. These programs would spend $3.2 billion between 2002 and 2005.
➢ A recent JFCOM memo listed such activities as:
  - AMRDEC Unmanned Autonomous Collaborative Operations STO
  - TARDEC's Crew Integration and Automation Testbed ATD
  - Robotic Follower ATD
  - Proposed STOs on Armed Robotic Vehicle Robotic Technologies for Increment II and Human Robotic Interface
  - ARL's Semi-Autonomous Robotics for FCS STO
- Navy's Joint Unmanned System C2 ACTD.

UAV Programs

•*OSD*
  AT&L led UAV Planning Task Force (PTF)
  9 working groups
  "Directive" UAV Roadmap (Sep)
  TCS program review / Tiger Team
  ACTDs - 13 UAV / related efforts
  JTEs - 1 UAV project / 2 related efforts
•*USJFCOM*
  Joint Operational Test Bed System
  Joint ISR
  JI&I
•*Air Force (Reachback philosophy)*
  Predator MAE UAV (ISR & armed)
  TCS for C4I dissemination only (Tentative)

Global Hawk HAE UAV

Predator B

•*Army (Common GCS cornerstone; TCS compliant w/in Army only)*
  Hunter TUAV (contingency; training)
  Shadow TUAV [Bde asset] (TCS when ready)

ER/MP

Future Combat System w/OAV

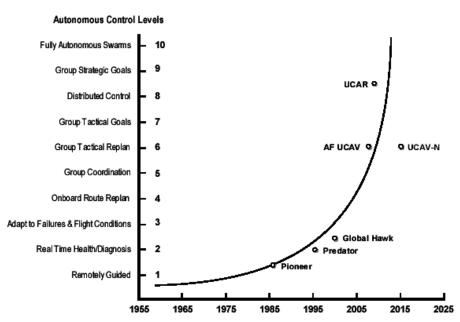•*Coast Guard ("Deepwater" program)*
  69 Cutter-based TUAVs; 7 shore-based HAEs
•*Naval UAV Strategy*
  -*Marine Corps (TCS core)*

Tier 1 - Dragon Eye

Tier 2 - Dragon Warrior

  Tier 3 - Pioneer Improvement Program [PIP];
  USMC Shadow; Predator B
  - *Navy (TCS core)*
  Global Hawk experimentation (BAMS)
  Pioneer (in layup)
  Firescout VTUAV (cnx) (TCS)
  PIP (TCS)

➤ A Joint Operational Test Bed System program, headed by USJFCOM, is examining how to control multiple UAVs from a single terminal. Leaders of the congressionally mandated project expect to be able to control up to four UAVs of various types from a single terminal. This program is expected to expend tens of millions of dollars. Meanwhile, a DARPA program, Multi-Initiative Control of Automa-teams (MICA) is developing methodologies to control all UAVs autonomously.

Frank Roberts, Director of USJFCOM's Joint Operational Test Bed, said that greater coordination in the UAV world is required – that even with a UAV Roadmap developed by OSD's UAV Planning Task Force[9], the services are pursing their own interests.   A year ago his office proposed Project Robot Venture that would have put USJFCOM at the center of UAV decision-making. That proposal was disapproved, but as recently as March 2003, OSD approached USJFCOM to take the lead in joint planning for UAVs. At the time of this report, that suggestion had not been acted upon.

Autonomous Control Levels

Level label	#
Fully Autonomous Swarms	10
Group Strategic Goals	9
Distributed Control	8
Group Tactical Goals	7
Group Tactical Replan	6
Group Coordination	5
Onboard Route Replan	4
Adapt to Failures & Flight Conditions	3
Real Time Health/Diagnosis	2
Remotely Guided	1

UCAR

AF UCAV   UCAV-N

Global Hawk
Predator
Pioneer

1955 1965 1975 1985 1995 2005 2015 2025

The above chart is from the UAV Roadmap prepared by the UAV Planning Task Force. The curve shows availability of total autonomy by 2015 although no fully autonomous systems are shown as being deployed.

➤ The Army Research Lab (ARL) is working on systems to allow operators to control two to four ground vehicles (for inclusion in FCS), while DARPA is simultaneously working on systems that would control and coordinate dozens of ground TACs under a program called Sidekick. ARL's efforts are directed at FCS[10], but our research indicates that totally autonomous systems would be feasible by the time FCS is fielded.

OSD provides loose guidance over some of the efforts. However, many involved in the programs say that the services generally do as they want. For example, OSD AT&L has a UAV Planning Task Force whose charter is to be the "focal point responsible for assisting the Services in their acquisition planning, prioritization, and execution of Unmanned Aerial Vehicles." Joint Forces

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[9] Department of Defense. <u>Unmanned Aerial Vehicle Road map</u> 2002 - 2027.
[10] <u>Joint Robotics Program Master Plan FY 2002</u>.

Command has been directed by Congress to establish a Joint Operational Test Bed to examine control of multiple UAVs. For the past two years DARPA has worked on a program that would also control UAVs. The Air Force has programs that parallel these OSD efforts. The Joint Robotics Program (also under AT&L) has the mission: "to develop and field a family of affordable and effective mobile **ground** robotic systems; develop and transition technologies necessary to meet evolving user requirements; and serve as a catalyst for insertion of (ground) robotic systems and technologies into the force structure." Like the UAV Planning Task Force, this congressionally mandated organization produces a roadmap for unmanned ground vehicles.

Although the Joint Robotics Program Master Plan does not address how a system of systems would be employed, it aggressively pursues the idea of a common joint architecture for unmanned systems (JAUS) communications. All ground vehicles must be JAUS compliant.

While the Joint Robotics Program Office has long had autonomous behaviors as one of its goals; it was only this summer that the Army Research Lab began work on constructing a roadmap for autonomy that would develop autonomous vehicles for Future Combat Systems. Future Combat Systems concept developers see autonomous behaviors incorporated in 2018. Two of the family of ground vehicles would be given the capability of autonomous maneuver and target execution. The vehicles could operate totally autonomously or would be required to consult humans in the loop before moving or executing targets.

The Navy has kept its hands on the littoral and underwater unmanned vehicle programs as well as UAVs[11]. Much of the undersea efforts are aimed at such things as autonomous search and survey, anti-submarine warfare, mine detection, undersea reconnaissance and meteorology, and oceanography[12]. Surface vehicles are being looked at for fleet and port protection.

Risks or Vulnerabilities

The adoption of robotic concepts now and the postponement of that action both carry risk. The risk of adopting robotic concepts now is that science will not provide the desired technological breakthroughs. However, the failure to begin planning now for autonomous forces presents an even greater risk. For example, if we begin now planning for the integration of autonomous forces by 2015, and science fails to provide the technological underpinnings, we will be able to fall back on the legacy systems, which still provide significant capability. However, if we fail to pursue the development of TAC forces, we place ourselves at risk of being outpaced by our military competitors. The US also risks falling behind other potential adversaries in the development of TACs. If we believe that TACs will make our forces more capable, then falling behind in this technology places our combatants and national security at risk.

Some in the military would also point out that billions of dollars would be wasted if we are unable to build the vision espoused here, but yet finance the research and development at a pell-mell pace. If concepts are developed around capabilities that are not produced, the military will have squandered valuable time planning an unrealized future. And, the opportunity cost can be significant. Resources thrown at robotics will not be available to develop other systems that might have been more feasible.

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[11] U.S. Navy Unmanned Aerial Vehicle Road map, 2003, Report to Congressional Appropriations Committee.
[12] US Navy Unmanned Undersea Vehicle (UUV) Master Plan, April 20, 2000.

A unanimous theme voiced by engineers and scientists, many of international renown in the field of robotics, is that they can build whatever the military requires. For example, they complain that no one has envisioned or given them the task of building an automated infantry TAC that can close with and kill the enemy. Instead, the military is farming out small pieces of the puzzle: platforms, sensors, processors, etc. The scientists and engineers say that they would be more effective and efficient if given the big picture, the requirements and the funds.

As an example of what can be done, contractors developing autonomous ground vehicles for the Army Research Lab say they have made tremendous progress in the last three years because they were given clear direction, adequate funds and time, and left alone to complete the project. Three years ago, they said, a ground vehicle would have had a difficult time recognizing a chair in the middle of the desert floor. Today, their control algorithms have guided vehicles across 600 kilometers of diverse cross-country terrain. In these tests, the machines operated autonomously for 95 percent of the distance.

Assessment

Project Alpha believes that technological advancements will support the use of TACs. In our assessment we looked at what experts agree are the most difficult problems to solve:

- Mobility
- Automatic target recognition
- Data fusion
- Power for human-sized machines and smaller
- Cognition

Autonomous Maneuver

An autonomous vehicle maneuvers through trees in recent tests at Indian Town Gap.

 "*Unmanned Ground Systems are beginning to realize the promise of providing our servicemen and women with leap-ahead warfighting capabilities they need at reduced risk levels to our personnel.*"- Joint Robotics Program Master Plan[13].

Ground vehicles present the greatest challenges in the area of autonomous maneuver. The ground TACs must examine everything in their paths and make decisions about traversability. For example, ground TAC's must decide if a hole is shallow enough to drive through or must be avoided. They must make decisions that involve discerning differences between bushes and trees, small rocks and boulders.

Solving the air and sea TAC maneuver problem is somewhat easier than the ground problem – since air and sea TACs must avoid all obstacles. The UAV Planning Task Force's UAV Roadmap predicts the ability to build autonomous UAVs by 2015 (see the figure below).

Dr. James Albus, of the National Institute of Standards and Technology, said that the ground TAC autonomous maneuver problem would be solved sooner rather than later. Albus led NIST

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[13] Joint Robotics Program Master Plan FY2002, , pp. 10.

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efforts during a recent evaluation of the Army Research Lab's Demo III vehicles. He predicts that, based on current rates of progress, new sensors in the production pipeline will enable vehicles to be 100 percent autonomous for cross-country mobility by 2010 and by 2015 will be as good as humans in urban and cross country settings[14]. In recent tests conducted at night, manned vehicles found it difficult keeping pace with unmanned autonomous vehicles.

Automatic Target Recognition: Machine perception also presents problems for those working automatic target recognition. How do we teach machines to discern the difference between a 5-ton truck and a school bus full of children? A typical three-year old child can correctly identify a cell phone as a telephone, even though she has only seen wall and desktop phones. Computers have difficulty making such inferential leaps. Computers can correctly identify a particular item if the object is stored in its database. A human might recognize a gun barrel of an anti-aircraft gun sticking through camouflage, but the clutter from foliage might confuse machines. Still, experts are having great successes and see advancement in the labs that will help overcome most if not all ATR problems.

Mr. Joe Diemunsch[15], working the ATR issue for the Air Force Research Lab said current airborne platforms have a high probability of seeing all targets and correctly identifying the targets up to 90 percent of the time. However, adverse weather, distance, and other factors can take the accuracy rate down to 50 percent. He predicted that new sensors under development and production would significantly increase capabilities. His lab's goal, he said, is to achieve 95 percent accuracy by 2010. By 2015, he predicts, ATR technology will be able to differentiate between a pickup truck with a mounted machine gun and one being used by a farmer. Improved sensors and data fusion, information from various sensors and numerous platforms including blue force tracking, will help TACs make decisions about target friendliness.

DARPA's Dr. Robert Hummel[16], developer of the agency's Jigsaw Project, said target recognition algorithms should produce accuracy rates of 98 – 99%. The Jigsaw program produced algorithms that identified targets using snippets of information gleaned from radar sensors. Using 25 target types that were programmed into the computer database, the machine turned in results of 90 – 95% accuracy. The best a human was able to do with the same data was 80 – 85% achieved by only one analyst. All other analysts turned in scores of 20 – 50% correct.

Hummel has no doubts about machine capabilities in 2015. He claims we should be able to get a resolution of 1 inch at distances of 5 kilometers by using high resolution LADAR (laser radar). This resolution will provide machines the ability to distinguish between armed and unarmed people, between a truck full of soldiers with rifles and a truck full of farm workers, Hummel said. This level of resolution, made possible by faster processors, should permit accuracy rates of 98 – 99% against conventional targets.

With this kind of information, it would be easy to imagine a TAC pulling the trigger. However, Hummel has doubts. He wonders whether cultural obstacles, and military/political mindsets will keep lethal decisions in the hands of humans.

Those working ATR talk of trade-offs between detection and errors. Accuracy and detection are inversely related. In general, if sensor sensitivity is set to locate each potential target, the parameters might allow it to make some misidentifications. As parameters become more

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[14] Unmanned Effects Workshop, USJFCOM sponsored. August 2003.
[15] Telephonic interview. August 2003.
[16] Telephonic Interview. August 2003.

discerning target identification accuracy improves, but some potential targets might not be reported. If we tell a machine to identify targets only if it reaches 99 percent confidence, many potential targets may be ignored, because the machine doesn't have enough data to give it a high confidence value. Still, a system that can autonomously identify, with a high degree of certainty, half, or even a third, of all ground targets and direct fire to those targets would present a significant capability. American doctrine says that a force is rendered combat ineffective if it is attrited by 35 percent or more. Being able to autonomously eliminate 35 percent of an enemy's capability presents a significant technological advantage.

Full ATR is not necessarily required, according to DARPA's Dr. Alexander Kott, Program Manager for a seedling project, SideKick, which is examining the feasibility of building control algorithms for autonomous machines. Dr. Kott said he could imagine situations in which machines, feasible today, could be directed to targets without humans actually guiding or aiming the weapons. He said that we can direct machines to targets using GPS coordinates or allow machines to use sensors to return fire.   While these are forms of target recognition, they don't require machines to think about their world and make decisions about the situation.

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Vignette 4

Imagine: We will be able to find uses for machines that have been unimaginable up to now. In urban environments our service members are constantly placed in danger by the threat of car or truck bombs and suicide bombers who attempt to cross checkpoints.

 Now: Vehicles and cars approach a checkpoint. One guard keeps a weapon trained on those wishing access while another guard searches the vehicle.

 In the Future: TACs armed with sensors able to detect explosives will be the first to inspect vehicles and personnel. These guardbots will be the first line of defense for humans, ensuring that suicide bombers or armed assailants are not allowed across the checkpoint. After passing the guardbot inspection, humans will apply an even more discerning eye on the personnel and cargo. The guardbots, using face recognition algorithms, may even be used to identify wanted personnel.

Mobile Detection Assessment Response System - Exterior (MDARS-E) Autonomously conducts surveillance activities checking for intruders, conducts lock interrogations, and assesses the status of facility barriers, such as the doors of storage bunkers.

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Data Fusion: Fusing data from various sensor types and platforms across the battlespace is thought to be one of the primary methods TACs will use for gaining enough information to distinguish between friend and foe or determining the best route between points A and B. In a network-centric environment, all TACs will share information. Radar signatures, LADAR images, thermal sightings and optical pictures will all be combined into one fused picture to give TACs enough information to make decisions about what they sense in their environments. A TAC requiring additional information about specific targets will request additional information from the net. And this information would not just be used for targeting. Autonomous logistics

vehicles would use such information for route planning, and tracking both friendly and enemy forces.

Dr. Amulya Garga[17], a data fusion expert from Pennsylvania State's Advanced Research Lab, thinks that data/information fusion can provide TACs the information they will require by 2015. However, he cautioned that he has seen little effort to make this a reality. Garga, who works on data fusion efforts for DOD, said that, while not trivial, the problem of producing a common vision of the world generated from different platforms is one that is largely understood. One of the hurdles for data fusion is that all the information available on the net must be of a format that all machines and humans can understand. The TACs must be able to interoperate.

Power*:* Providing power for small TACs poses one of the most difficult hurdles, but not one that should stop the drive toward automation. Scientists have a difficult time predicting the adequacy of future power sources because they don't know how much power the TACs will require. The general trend is for improvements in efficiency and greater battery and fuel cell power densities, but putting a time frame on when required improvements are going to occur is difficult. Nevertheless, scientists working the issues have some ideas about pending near term power improvements. In the end, failure to significantly improve batteries and fuel cells will mean that the vision of small robots might be delayed. The unavailability of power for small machines will not prevent us from fielding larger machines. Smaller machines will be integrated when they become technologically feasible.

Dr. James Miller[18], program manager for Argonne National Lab's Electro-Chemical Technology Division, said he expects battery power densities to increase 30 – 50 percent in the next five years. He also believes that fuel cells will solve many of the problems of future TACs. In general, batteries are generally good for surges, like when a radio transmitter is keyed. Fuel cells are better suited to steady state operations, such as when a radio is in the receive mode.

Dr. Tim Armstrong[19], Manager of Oak Ridge National Lab's Fuel Cells and Functional Materials Division said that hybrid sources composed of batteries and fuel cells look to be a promising solution. In a hybrid system, the batteries would be recharged with excess capacity produced by fuel cells when the machine's requirements become less demanding. Batteries would be used for surge requirements. DARPA announced in April 2003 that it had flown a micro-UAV, powered with a fuel cell, for 15 minutes. The UAV weighed a mere 15 ounces[20]. That same UAV, powered by lithium batteries, flew one hour and 47 minutes in October of 2002.

Cognition: Few scientists working on artificial intelligence or robotics believe computers will achieve human level cognition by 2025, if ever. However, Project Alpha believes TACs will not require human level cognition. Focused artificial intelligence (AI) applications will give machines the intelligence needed. Most TAC problems will be solved by using separate modules to control various functions – a module for ATR, mobility, communications, etc, all tied together by a module designed to integrate the sub-functions.
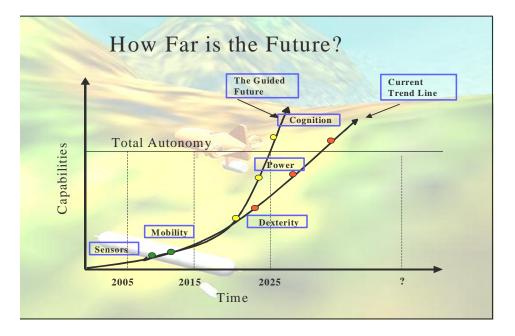
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[17] USJFCOM Workshop: *Unmanned Effects: Taking the Human Out of the Loop*. August 2003.
[18] Telephone interview. August 2003 .
[19] Interview. June 2003.
[20] DARPA News Release. "Micro Air Vehicle Powered Entirely by Fuel Cell Makes Debut Flight." April 28, 2003.

Ray Kurzweil[21], a recognized international expert in artificial intelligence and a leading futurist, recently told the audience at a J9 Unmanned Effects Workshop that machines would achieve human-level cognition capabilities by 2029. Dr. Rodney Brooks, Director of MIT's Computer Science and Artificial Intelligence Laboratory and one of the world's foremost robotic experts, told the same audience that he is not so sanguine about robot cognition. He said that any inroads will be made in focused AI and general cognition will not be available to solve problems for autonomous machines. An example of focused AI would be the control algorithms used by IBM's Deep Blue to beat Garry Kasparov in chess. Focused AI uses a set of algorithms to solve a limited set of problems. Within the DOD, we have found only DARPA conducting research on general AI.

The chart above shows two notional curves. The one on the right represents a time line for the development of autonomous systems without any additional coordination and synchronization action by DOD. The curve on the left depicts how the future capabilities can be achieved sooner with better coordination, synchronization and integration of efforts.

Conclusions

Many people remain skeptical about integrating robotics into the military. Many bridle at the thought of giving machines significant levels of autonomy. Regardless, if one has a cultural aversion to the use of robots or thinks that technology will not solve the problems, the services are already moving forward in building robotic capabilities. Those working in the programs agree that efforts could be and should be better coordinated and synchronized.

Some robotics experts think that most of our problems will be solved with computational brute force. Others think that some unknown breakthrough will need to occur. While we can wait for the serendipitous discoveries, we can better control our future if we direct it – if we decide what we want and then make it happen.

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[21] USJFCOM Workshop: Unmanned Effects: Taking the Human Out of the Loop. August 2003.

Recommendations

DOD needs to develop a guiding vision now and begin experimentation to determine the capabilities best suited for robotics. The vision needs to include capabilities that are not only possible today from a technological standpoint, but also capabilities that will enhance future joint warfighting. New combat capabilities will evolve into new operational concepts. DOD needs to direct the robotics efforts of the scientific community to improve national security and get humans out of harm's way sooner, rather than later. The military needs to begin work now to find the right balance between man and machine and ascertain the best uses for tactical autonomous combatants.

In 2001, Congress mandated that "by 2015, one-third of the operational ground combat vehicles" and by 2010, "one-third of the aircraft in the operational deep strike force aircraft fleet" will be unmanned. Project Alpha believes the military can do better than one-third and that the vehicles can be autonomous. (The congressional wording does not exclude remote-controlled vehicles.)

In an effort to speed the development of a coherent policy covering TACs, Project Alpha recommends that USJFCOM and OSD partner to develop the vision and conduct experiments with the capabilities espoused in that vision. Toward that end, Project Alpha recommends:

1. That OSD AT&L and USJFCOM partner to provide leadership across all robotic domains- air, land, sea and undersea. Robotic efforts being pursued by DOD are the result of service-centric (stove-piped) ideas of what is best pursued. In some cases, robotic research is geared toward solving a particular problem, instead of a range of problems. A unifying DOD robotics vision must come first to ensure that the resources are spent appropriately. Following a vision, a strategy and accompanying goals, tasks and subtasks would aid in shaping the future. Therefore, this report advocates that OSD AT&L establish a joint military robotics task force, along the lines of the UAV Planning Task Force or the Joint Robotics Program Office. Project Alpha believes TACs need to be designed and built as part of an overarching system to support joint warfighting.

➢ A joint military robotics task force would have several functions, but most importantly, would write a roadmap establishing a vision. Additionally, the taskforce would:

- Reduce opportunities for duplicated efforts
- Provide a joint vision for the use of TACs
- Synchronize efforts with industry and research organizations
- Ensure that joint concepts and TAC capabilities are linked
- Develop roles and missions for TACs
- Ensure interoperability and compatibility of all systems
- Ensure DARPA research is promulgated and that it supports the vision
- Ensure that service efforts adhere to the architecture defined in the roadmap

➢ The task force would also supervise a study aimed at developing benchmarks for robotic behaviors. If comparing machines to humans is the best method of measuring robotic accuracy and capability, we need to develop standard measures based on human models.

Failure to develop these measures will relegate us to requiring robotic perfection. Machines, like humans, will never be perfect – we need to determine when we can turn over decision making to machines, freeing humans for higher level thinking.

➢ In support of the OSD, USJFCOM would explore the inclusion of TACs into future concepts and conduct experiments to examine the effectiveness of proposed robotic forces. The results of the experiments will be provided to the task force to refine the vision and help guide robotic research and development efforts.

➢ To understand required TAC capabilities and how they support such concepts as Effects Based Operations, Joint Forcible Entry, and Joint Urban Operations, to name a few, USJFCOM J9 should conduct workshops and seminars that explore incorporation of robotic capabilities into future concepts. Project Alpha and this report have explored some uses of robots. However that is not enough. Military experts within USJFCOM and the services working with leading scientists should expand the work already done and determine which TAC capabilities would best support the future concepts. The results of the workshops would identify capabilities to be used in experiments, wargames and simulations conducted by USJFCOM J9. The workshops and seminars should be conducted at J9 and facilitated by Project Alpha with assistance from an organization which has previously taken on similar efforts (like Oak Ridge National Lab for the Army's Objective Force).

2. That the USJFCOM Commander recommend that the Defense Science Board study the issue of robotics, their feasibility, and roles for joint forces in 2018. The board should also make recommendations on spending priorities. In 1999, the Board identified unmanned effects as one of six areas that deserve special attention by DARPA.

During the research for this report, Project Alpha found two efforts among dozens of promising endeavors, that if continued, would significantly add to the vision, sooner rather than later.

3. The Army should be encouraged to spend an additional $4.5 million on the Army Research Lab's autonomous maneuver efforts. That money would buy an additional three vehicles to be used in testing autonomous maneuver technologies. Currently, progress in autonomous maneuver is hampered when one of only the three vehicles currently being tested is down for repairs or being used for testing. This small amount of money would help assure that progress continues apace in this extremely important area.

4. DARPA should be encouraged to continue aggressive research in areas exemplified by efforts such as SideKick and MICA. Such programs should be encouraged to research methodologies and technologies to permit collaboration and cooperation between heterogeneous TACs - land, sea and air. The programs should explore control of machines with varied levels of autonomy ranging from reactive swarming techniques to anticipatory behaviors requiring proactive, anticipatory, look-ahead adversarial reasoning, from local behaviors to centrally guided command. Special attention should be given to innovative, unconventional, non-human-like tactics that emerge with unmanned vehicles and automated control.

Glossary

Acronym	Expansion
ACTD	Advanced Concept Technology Demonstration
AFRL	Air Force Research Laboratory
AI	Artificial Intelligence
AMRDEC	Aviation & Missile Research & Development Engineering Center
ARL	Army Research Laboratory
AT&L	Acquisition, Technology and Logistics
ATD	Advanced Technology Demonstration
ATR	Automatic Target Recognition
BAMS	Broad Area Maritime Surveillance and Armed ISR
Bde	Brigade
C2	Command and Control
CNN	Cable News Network
Cnx	Cancelled
DARPA	Defense Advanced Research Projects Agency
DOD	Department of Defense
ESP	Extra Sensory Perception
ER/MP	Extended Range/Multipurpose
FCS	Future Combat Systems
GCS	Ground Control Station
GPS	Global Positioning System
HAE	High Altitude (Long) Endurance
IED	Improvised Explosive Device
ISR	Intelligence, Surveillance and Reconnaissance
JAUS	Joint Architecture for Unmanned Systems
JCD&E	Joint Concept Development and Experimentation
JI&I	Joint Integration and Interoperability
JT&E	Joint Test and Evaluation
LADAR	Laser radar
MDA	Missile Defense Agency
MAE	Medium Altitude (Long) Endurance
MDARS-E	Mobile Detection Assessment Response System – Exterior
MICA	Multi-Initiative Control of Automa-teams
MIT	Massachusetts Institute of Technology
NII	Networks and Information Integration
NIST	National Institute of Standards and Technology
OAV	Organic Air Vehicle
ONR	Office of Naval Research
OODA	Observe, Orient, Decide and Act
OSD	Office of Secretary of Defense
PIP	Pioneer Improvement Program
RAP	Rapid Assessment Process
SEAD	Suppression of Enemy Air Defenses
STO	Science and Technology Objectives
TAC	Tactical Autonomous Combatant

Acronym	Expansion
TARDEC	(U.S. Army) Tank & Automotive R&D and Engineering Center
TCS	Tactical Control System
TUAV	Tactical Unmanned Aerial Vehicle
UAV	Unmanned Aerial Vehicle
UFX	Unmanned Effects
UGV	Unmanned Ground Vehicle
USJFCOM	United States Joint Forces Command
USMC	United States Marine Corps
UUV	Unmanned Underwater Vehicle
VTUAV	Vertical Takeoff Unmanned Aerial Vehicle