DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

DEPARTMENT OF THE ARMY
HEADQUARTERS UNITED STATES ARMY TRAINING AND DOCTRINE COMMAND
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REPLY TO
ATTENTION OF

ATFC-DS

19 MAR 2009

MEMORANDUM FOR SEE DISTRIBUTION

SUBJECT: Robotics Strategy White Paper

1. The enclosed Robotics Strategy White Paper is the result of a collaborative effort between the U.S. Army Training and Doctrine Command (TRADOC) and the Tank-Automotive Research, Development and Engineering Center (TARDEC). This paper builds on a confederated Army robotics "strategy" that is described by senior leader direction, studies, and various systems-based road maps. The purpose of this paper is to propose task areas that can further enable the Army's 1.1 million Soldiers, to drive outcomes that are informed by DOTMLPF-C analysis, and to generate discussion on issues related to the Army's way ahead for robotics. Feedback on this paper is welcome and encouraged; please provide it to the points of contact cited in paragraph 4.

2. Subject Matter Experts from TRADOC and TARDEC, with assistance from over three dozen robotics specialists, collaborated to identify and assess feasibility of robotics systems to conduct or assist with the execution of 32 Soldier tasks. The TRADOC-TARDEC led team assessed these tasks for feasibility based on complexity, estimated cost and time to develop a prototype.

3. The analysis in this paper also provides focus on some key issues that the Army must address or reconcile now and in the future. These issues include, but are not limited to: the degree of autonomy that the human is willing to delegate to increasingly "smart" robotics systems; the impact of robotics systems on training and leadership; and, the effectiveness of current doctrine and policy. It is expected that the analysis contained in this White Paper will serve to inform Army input into the next version of the OSD Unmanned Systems Roadmap, inform and update TRADOC's Warfighter Analysis and Outcomes, and assist in development of the next revision of TRADOC Pamphlet 525-66 (Force Operating Capabilities).

4. TRADOC and TARDEC points of contact for this paper are COL Jim Henderson, Army Capabilities Integration Center, 757-788-2332, james.bruce.henderson@us.army.mil and Dr. Jim Overholt, Director, Joint Center for Robotics, 586-574-8618, jim.overholt@us.army.mil.

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Table of Contents

SUMMARY

Robotics technology offers the potential to realize three critical opportunities for the Army's current force and its future force. First, robotics is being used to reduce risks to Soldiers in the current fight, such as IED detection and neutralization. Robotics systems have saved lives. Second, robotics enabled platforms can reduce the workload on Soldiers today and into the future by performing routine tasks that do not require full-time human intervention and enable sustained high tempo operations by removing humans from some tasks, such as routine surveillance of bases. Third, robotics can enable entirely new capabilities for extended range or stand-off reconnaissance operations using unattended ground sensors for 24 hour operations or advanced sensors for mobile reconnaissance. Advances in robotics technology also offer some promise of relief for the human dimension in operations - Soldiers. Our Army of 1.1 million Soldiers faces an increased demand for their presence in sustained operations now and into the near future.

The Army's use of robotics systems in support of operations in Iraq and Afghanistan has demonstrated the ability of these types of systems to complement and assist Soldiers in a wide range of missions. Robotics systems have already been used to conduct reconnaissance, surveillance, and counter-mine/counter-improvised explosive device (C-IED) operations, and to find, identify and designate targets. However, the Army can potentially leverage robotics systems to perform other Soldier-executed tasks. Current research and development offers some insights as to the prospective opportunity that robotics offers the Army. The Army will determine robotics development and operational use based on Warfighter needs, derived from the needs of the individual Soldier and small unit ("bottom up") and the needs of the Service ("top down"). These opportunities offer the Army a logical sequel to how it has up to now invested in robotics technology.

The Army's ground robotics "investment strategy" has three components: the development and fielding of largely commercial-off-the-shelf (COTS) systems directed by the Rapid Fielding Initiative (RFI) and Joint IED Defeat Organization (JIEDDO) to support the immediate needs of forward deployed Soldiers; robotics systems research, development, and fielding in support of the Future Combat Systems program; and, research and development that is principally guided by Department of Defense (DoD) priorities in four key mission areas as described in the OSD Unmanned Systems Roadmap (2007-2032).

This White Paper provides an operational context for an Army "robotics strategy" by identifying and describing mission-related tasks within three components of the current research and development strategy. Subject Matter Experts (SMEs) from the Army's Training and Doctrine Command (TRADOC) and Tank-Automotive Research, Development, and Engineering Center (TARDEC) have collaborated to assess the feasibility of robotics systems to conduct or assist with the execution of 32 Soldier tasks. With assistance from over three dozen robotics specialists, each with knowledge of industry, academia and DoD robotics research and development, the TRADOC-TARDEC team assessed these tasks for their feasibility based on their complexity, technology maturity and the estimated cost and time to develop a prototype. This analysis serves to assist in establishing additional robotics applied research and advanced technology development thrusts and priorities for the Army, inform Army input into the next

version of the OSD Unmanned Systems Roadmap, and inform and update TRADOC's Warfighter Analysis and Outcomes and the 2010 revision of TRADOC Pamphlet 525-66 (Force Operating Capabilities). This paper provides the basis from which TRADOC and TARDEC can conduct additional integrated cost-benefit analysis of task areas where solutions may be imminent and might have the greatest operational benefit to the force. TRADOC and TARDEC remain open to future ideas regarding additional uses of robotics. Lastly, this paper provides a focus of thought on some key issues that the Army must reconcile within its own culture, such as the degree of autonomy that the human is willing to delegate to increasingly "smart" robotics systems.

INTRODUCTION

The Army's current "robotics strategy" consist of three components: the development and fielding of largely commercial-off-the-shelf (COTS) systems directed by the Rapid Fielding Initiative (RFI) and Joint IED Defeat Organization (JIEDDO) to support the immediate needs of forward deployed Soldiers; robotics systems research, development, and fielding in support of the Future Combat Systems program; and, research and development that is principally guided by Department of Defense (DoD) priorities in four key mission areas as described in the OSD Unmanned Systems Roadmap (2007-2032).

This White Paper operationalizes the Army "strategy" by identifying mission-related tasks that describe the desired usage of the three components of the current strategy. Subject Matter Experts (SMEs) from the Army's Training and Doctrine Command (TRADOC) and Tank-Automotive Research, Development, and Engineering Center (TARDEC) have collaborated to further identify and assess the feasibility of robotics systems to conduct or assist with the execution of 32 Soldier tasks. With assistance from over three dozen robotics specialists, each with knowledge of industry, academia and DoD robotics research and development, the TRADOC-TARDEC team assessed these tasks for their feasibility based on their complexity and the estimated cost and time to develop a prototype. This analysis serves to assist in establishing additional robotics research thrusts and priorities for the Army, inform Army input into the next version of the OSD Unmanned Systems Roadmap, and inform and update TRADOC's Warfighter Analysis and Outcomes and its next revision of TRADOC Pamphlet 525-66 (Force Operating Capabilities). It provides the basis from which TRADOC and TARDEC can conduct additional integrated cost-benefit analysis of task areas where solutions are imminent or might have the greatest operational benefit to the force. The purpose of the paper is to describe outcome-based user needs (both top down and bottom up) and the strategy to achieve them and invite future discussion and thought. Lastly, it provides focus on some key issues that the Army must reconcile, such as the degree of autonomy that the human is willing to delegate to increasingly "smart" robotics systems.

Continuing advances in robotics technology offers some promise of relief to an Army of 1.1 million Soldiers that is faced with an increased tempo of operations, now and in the future. The Army's use of robotics systems in support of operations in Iraq and Afghanistan has demonstrated the ability of these systems to complement and assist Soldiers and small units in a wide range of missions. Robotics systems have saved lives. They will continue to offer the same benefit to the Army as its Soldiers use these systems to conduct reconnaissance, surveillance, and counter-mine/counter-improvised explosive device (C-IED) operations, and to identify and designate targets. However, the Army can potentially leverage robotics systems to perform other Soldier-executed tasks. Current research and development offers some insights as to the prospective opportunity that robotics offers the Army. Robotics can serve as a means by which to reduce the manpower required to perform some tasks, be they dangerous or routine, at home station or in forward deployed locations. These opportunities offer the Army a logical sequel to how it has up to now invested in robotics technology. This White Paper identifies tasks in which robotics systems can most feasibly ease the operational burden on Soldier and the Army, in the Continental United States (CONUS) or forward deployed locations. It serves as a start point for continued analysis of those tasks and robotics systems that might offer increased efficiencies to the Army, or might make its organizations more effective in the accomplishment of their mission-related tasks.

ROBOTICS DEFINED

A robot is a man-made device capable of sensing, comprehending, and interacting with its environment. The main parts of a robot are mechanical systems, computers, and sensors. Current robotics applications, with some exceptions, are geared towards performing repetitive, dangerous, or difficult work that humans cannot perform well or would not want to perform. For example, the automotive industry makes widespread use of robotics systems in its assembly lines, for specialized manufacturing applications, and for hazardous material manipulation.

For the purposes of this White Paper, Army robots (with some exceptions), are sorted into two broad categories: Unmanned Ground Vehicles (UGVs) and Unmanned Aerial Systems (UASs). All of these units are currently tele-operated, meaning there is a human operator that manipulates and controls the robot remotely from a safer location. The military used approximately three thousand UGVs in combat over the last year to support operations in Iraq and Afghanistan. The most common application for UGVs is in support of explosive ordnance disposal. Approximately twenty types of UASs support the current Global War on Terrorism (GWOT) by conducting reconnaissance, precision targeting, and intelligence missions.

The first Office of the Secretary of Defense Unmanned Systems Roadmap (2007–2032), approved in December 2007, provides an overview of current capabilities and guidance for future development of UASs and UGVs. While robotics are extremely useful in the current operating environment, more widespread applications have been limited due to the level of task complexity and the nature of the operational environment, required computing power, and integration of sensors and perception technologies required to perform more dynamic missions.

As robotics technology advances, future land combat forces will gain significant new operational capabilities permitting paradigm shifts in the conduct of ground warfare that are a result of significantly greater survivability, flexibility and sustainability. It is anticipated that robotics platforms will be integrated with other unmanned air, ground and sea assets, unattended ground sensor networks and other wireless technologies to enhance overall operations within a fully integrated and seamless global information grid. In the near and mid-term, it is anticipated that robots will continue to operate under some human control. However, as technology progresses robots will require less human interaction and will be capable of higher levels of autonomy and independent operation. Principal limiting factors on the degree of autonomy of robotic systems used by military forces remain the reliability of the system (mean time between failures) and the nature of the task environment (complexity). Robots operating in a task environment that is complex (large number of associated and inter-related sub-tasks) and containing a high degree of variety (unpredictable and changing conditions) will require highly reliable and extremely sophisticated sensing and decision-making algorithms. Until these technologies are developed and proven, humans will continue to manipulate robots based on a robot's abilities and the conditions in which they operate.

PRIORITIES OF DoD ROBOTICS

The December 2007 OSD Unmanned Systems Roadmap specifies four mission areas that constitute the Department's priorities for how unmanned systems can fill or improve gaps in operational capabilities. These priorities are not meant to exclude research, development, and procurement of robotic solutions to other mission areas. However, they do represent areas in which DoD's most pressing needs exist.

- **Reconnaissance and Surveillance.** Some form of reconnaissance (electronic and visual) is the number one COCOM priority applicable to unmanned systems. Being able to surveil areas of interest while maintaining a degree of covertness is highly desirable. The reconnaissance mission that is currently conducted by unmanned systems needs to increase standardization and interoperability to better support the broad range of DoD users.

- **Target Identification and Designation.** The ability to positively identify and precisely locate military targets in real-time is a current shortfall with DOD unmanned systems. Reducing latency and increasing precision for GPS guided weapons is required. The ability to operate in high threat environments without putting Warfighters at risk makes robotic systems potentially more advantageous when compared to currently manned systems.

- **Counter-Mine Warfare.** Improvised Explosive Devices (IEDs) are the number-one cause of coalition casualties in Operation Iraqi Freedom. Tele-operated robotic systems provide a complementary capability to ground forces and have saved countless lives. Since World War II, sea mines have caused more damage to US warships than all other weapons systems combined. A significant amount of effort is already being expended to improve the military's ability to find, tag, and destroy both land and sea mines. Unmanned systems are a natural fit for this dangerous mission. Robotic systems will continue to play a key role in de-mining operations and the removal of unexploded ordnance across the spectrum of military missions.

- **Chemical, Biological, Radiological, Nuclear, Explosive Reconnaissance.** The ability to find chemical, biological, radiological, nuclear, and explosive agents and to survey the extent of affected areas is a crucial effort in homeland security operations as well as contingency operations outside the United States.

While these areas represent the focus of Army research and development efforts, there is also substantial ongoing developmental efforts related to the Army's Future Combat Systems and areas in which there is Congressional interest.

FUTURE COMBAT SYSTEMS (FCS)

Future Combat Systems manned and unmanned systems constitute the material solutions of the future force; they are representative of the Army's principal modernization strategy that is the embodiment of the modular force, a modular system designed for "full-spectrum" operations. Future Combat Systems unmanned systems will be adaptable to traditional warfare as well as complex, irregular warfare in urban terrains, mixed terrains such as deserts and plains, and restrictive terrains such as mountains and jungles. When fully operational, FCS unmanned systems will provide the Army and its small units with unprecedented capability to see the enemy, engage him on our terms and defeat him on the 21st century battlefield. The FCS family of unmanned ground vehicles consists of the SUGV, the Armed Robotic Vehicle-Assault(Light) (ARV-A(L)), the Transport Multifunctional Utility/Logistics and Equipment (MULE) Vehicle (MULE-T), and the Counter-mine MULE Vehicle (MULE-CM).

Future Combat Systems technology is being accelerated to the Army's modular brigades through Spin Outs. These Spin Outs will allow Soldiers to utilize FCS unmanned systems as they become available. Spin Out 1 equipment includes the Small Unmanned Ground Vehicle (SUGV) and the Class I Block O Unmanned Air Vehicle and will be available to Soldiers in the Army's Infantry Brigade Combat Teams beginning in 2011.

CONGRESSIONALLY DIRECTED ROBOTICS EFFORTS

In support of robotics systems development, Congress set a goal through the National Defense Authorization (NDA) Act (FY01, H.R.4205, Sec. 217) for the Armed Forces to achieve the fielding of unmanned, remotely controlled technology such that, by 2010, one-third of the operational deep strike aircraft of the Armed Forces are unmanned; and by 2015, one-third of the operational ground combat vehicles of the Armed Forces are unmanned. While challenging, many advances have been made and are expected. In Section 220 of the Floyd D. Spence National Defense Authorization Act for Fiscal Year (FY) 2001 (Public Law 106-398), Congress stated two key, overall goals for the DoD with respect to UAS and UGV development:

- By 2010, one third of the aircraft in the operational deep strike force should be unmanned.
- By 2015, one third of the Army's Future Combat Systems (FCS) operational ground combat vehicles should be unmanned.

More recently, the National Defense Authorization Act (FY07, H.R. 109-702, Sec. 941), stated a preference for unmanned systems and a requirement to document and gain approval for development of new manned systems. Additionally, in FY07 H.R. 5122-282. Sec. 941 (d)(2)C required an assessment of progress toward the goals from the 2001 NDA Act.

The current Army budget provides $54 million per year in Program Element (PE) 6.2 (applied research) and PE 6.3 (advanced technology development) for Unmanned Vehicle Technology. This amount does not include the development of “mission payloads” in other technology areas, such as Command, Control, Communications, Computers (C4), Intelligence Surveillance and Reconnaissance (ISR), and others.

Future Combat Systems is the Army’s first major program development that planned for the employment of unmanned ground and aerial systems as part of a system-of-systems approach for a Brigade Combat Team. Future Combat Systems is designed to provide an unmatched operational capability and the program has been the Army’s leading edge for development of unmanned systems. The FCS BCT organizational design consisted of 234 unmanned ground systems when the program began in May 2003 (Program Milestone B). Program adjustments over the last three year have reduced the number of unmanned ground platforms to a total of 192 systems. As a result of these reductions, the approved FCS BCT organizational design includes 192 unmanned systems out of a total of 514 FCS systems - or 37%, thus meeting the Congressional goal of one-third ground combat vehicles being unmanned in the FCS BCT. The FCS BCT also consists of a significant number of unmanned ground and aerial capabilities which include: Unattended Ground Sensors, Non-Line of Sight-Launch System, and Unmanned Aerial Vehicles. Ground combat vehicle fielding begins for the first FCS BCT in 2015.

Today, the main Army investment for robotics technology is aimed at research and development, with additional future programs of record to follow.

EXPECTED ROBOTICS DEVELOPMENTS IN SUPPORT OF MILITARY APPLICATIONS

Robots will not bring an age of “bloodless” push button warfare nor provide “silver-bullet” solutions to every challenge the Army will face in the future, but they can offer US forces operational advantages in the contemporary and future operating environments. Additionally, robotic systems are capable of executing a number of repetitive, mechanically-oriented and possibly automated tasks conducted routinely by Soldiers thereby potentially freeing them for other missions. Robots have proven very efficient and cost effective in tasks that are repetitive and dangerous. They are well suited to perform tasks where Soldier lives are at great risk and they can do much to mitigate that risk with little or no reduction to the successful execution of the task. They can be very effective in performing tasks where the task operating environment is conditioned and controlled and where there is little or no risk of a catastrophic effect on humans due to a robot’s system failure. The current thrust of the Army’s robotics strategy has been in tele-operated systems that rightly support operations in Iraq and Afghanistan, DoD’s four high priority areas, and in research and development for the FCS program. There is also a body of research and development work that is outside of these areas. This innovative research is useful, but not focused by any constructive supplement to the current Army strategy. The TRADOC-TARDEC analysis that follows provides an analytically-based recommendation of those additional tasks that robotics systems could feasibly perform in the next two decades. This analysis is meant to inform and provide focus for a continued, in-depth analysis of the cost-benefit to the Army of the tasks for which robotics might be a feasible solution.

RESULTS AND DISCUSSION

TRADOC and TARDEC subject matter experts divided the tasks that robots could possibly perform into five mission-functional areas: logistics, security, engineering, medical, and maintenance. In some tasks robotics can possibly supplement Soldiers and support their individual execution of the task; in other tasks robotics could possibly reduce the number of Soldiers required to perform the task. In the latter case, robotics could result in significant manpower savings for those tasks where two-to-three shifts per day of Soldiers are required.

The tasks below were nominated and assessed by three dozen TRADOC, TARDEC, and other robotics research and development subject matter experts (SMEs) at a January 2009 Robotics Initiative Workshop. The tasks are linked to several Warfighter Outcomes (WFOs) and are based on Universal Joint Task List (UJTL) and Army Universal Task List (AUTL) tasks. Each broad task description contains the Workshop SMEs' feasibility assessment.

LOGISTICS (L)

There are a number logistics tasks linked to WFOs for which robotics might present a feasible solution. Higher priority Tier-1 WFOs possibly supported by robotics are: anticipatory sustainment and improved distribution; UGV autonomous movement and tactical behavior; improved delivery of supplies in noncontiguous operations; and, improved intermodal platforms technologies and techniques.

The UJTL tasks suggest numerous possible improvements in the logistics area through robotics. Equipment utilization, rate of supply movement, and percentage of cargo ready for operation could be increased during movement of equipment and supplies, while time to offload and cargo rejection could be reduced. Intransit cargo "visibility" and days of supply on hand should be maximized, while cargo damage, percentage of incorrect manifesting, percentage requests unmet, and time to locate specific cargo could be minimized. The amount of fuel moved and number of timely refuel requests met could be increased during robotically-enabled refueling operations, while host nation support and mission interruption for refueling could be reduced. The specific UJTL/AUTL listed tasks listed below, when supported or enabled by robotics, may show improvements in the logistics area.

L1 - Surface cargo transport and delivery of equipment and supplies using logistics convoys. The conduct of logistic convoys falls under AUTL 6.3.3.1, *Move by Surface*, which tasks the Army to "transport cargo, equipment, and personnel by waterways, railroads, highways, or other means, such as organic transportation." While autonomous ground-based robotic logistics convoys may move Soldiers and supplies by logistical convoys to tactical positions, this approach faces many challenges. Chief issues related to using robotics to enable vehicular surface movement include: safety for nearby troop and civilians, battle command and awareness/tracking, integration with manned systems, and timely reaction to unexpected conditions (i.e., weather, obstacles, tactical conditions). Other issues include: load security (i.e., attack against or pilferage of unattended supplies), loading and unloading, sensor vulnerability, and maintenance of the specialized systems in case of damage or breakdown. A final consideration is that robotics-enabled trucks must be capable of providing both on-road and off-road line-haul convoy capabilities to support the Army's worldwide mission, and in the event that their planned routes become impassable. The application of robotics to convoy operations will likely be an iterative process until all applicable robotics technology has sufficiently matured. Robotics could be very beneficial in asymmetrical threat environments, especially in those conditions where the environment is controlled.

Aerial transport and resupply involves requests for, planning, delivery and distribution of supplies and materiel to sustain remote elements. Conventional aerial delivery can be accomplished in one of three modes: airland (where the aircraft touches down to unload), sling loads (using helicopters), or air drop. Army units increasingly find themselves engaged in distributed operations (DO) in OIF and elsewhere. Under the concept of DO, units are widely dispersed across a large theater of operations, but are linked through command and control (C2) systems that permit rapid, flexible application of supporting fires and coordinated employment of dispersed forces. Although units are more widely dispersed in DO, the concept envisions a reduced log structure and small forward footprint through reach-back and distribution-based sustainment.

Robotics technologies and unmanned aerial vehicles could reduce the number of convoys required to support a large number of small units widely separated by unsecured lines of communication (LOCs), reduce Soldier exposure along LOCs, and free up personnel, vehicles, and equipment for those convoys that are still necessary.

Air-based UAV delivery for small, lightweight (less than 200 pounds), high value payloads is quite feasible in the near term. Near-present UAVs, and/or steerable parachutes look attractive, though packaging versus mechanical shock, precision delivery, and flight issues such as weight distribution and release mechanisms may require some further research. A uniform, disposable, shock resistant container or pod would appear appropriate for successful execution of this task. While potentially very beneficial, conduct of aerial resupply for large bulk supplies would require consideration of costs and force structure associated with development and support of heavy UAV delivery assets.

L2 - Cargo packaging and pallet assembly. Use of robotics tools to support palletization falls under the supply functional area which tasks the Army to provide all classes of supply necessary to equip, maintain, and operate military units. Many commercial industrial settings use robotics automation and robotics systems to package and palletize standard items and have led to enterprise improvements in standard packaging and palletizing techniques. For example, automation is used in production facilities to package, box, and palletize items coming off an assembly line where items are identical. Issues with automated packaging and palletization include transportability and flexibility. To be transportable, loads must be secured to pallet, within the allowed pallet geometry, and with load mass properly centered (especially for air loads). However, unlike a commercial factory where loads are often highly uniform, DoD pallets are often constructed to move multiple items to a forward unit. Department of Defense pallets are more non-uniform, and pallet load compatibility must be resolutely monitored (i.e., mixes of packaged Class III and V). Additional attention given toward packaging standardization for ammunition will help improve feasibility and facilitate low cost automated resupply. The use of commercial standard assembly line packaging capabilities will likely require modification and further investment for more near-term utilization.

L3 - Supply warehousing: inventory management, prioritization, retrieval and preparation for movement. The use of robotics technology to support automated warehousing functions falls under the supply functional area. Within the supply functional area, the inventory of items in the warehouse, the "picking" or selection of items from the warehouse shelves, and the movement of heavy items in the warehouse are tasks that could benefit from the application of robotics technology. The relatively clean, rectilinear geometry of warehouse layout and box/pallet dimensions enhances the feasibility of automated warehousing. Highly standardized warehouse layouts designed for robotic storage will improve future feasibility. However, "bin picking" of loose parts to, and especially from, general storage presents a tough machine vision and tactile problem; a common commercial robotics solution is to give up some space during *arranged* placement to simplify robotic retrieval.

L4 - Refueling (Wholesale and Retail). Automated refueling may distance Soldiers from noxious or dangerous fuels. This may be synergistic with future Army concepts (such as an Autonomous Brigade capable of producing synthetic fuel) where new but noxious or highly flammable fuels, such as ammonia or C1-C5 alkanes, may be employed. Even when using robotic systems for refueling operations, safety mechanisms and measures to avoid spills or ignition are paramount. Tactile force and geometrical vision sensor data and standardized "fail safe" robot-friendly fuel transfer ports and couplings will enhance the feasibility of robotics solutions. While this solution is quite feasible, it will take capital investment and time to replace existing fuel infrastructure.

L5 – Crane and lift operations. Cranes are typically characterized by load-under-hook mechanical design, with flexible rigging promoting load centering. However, palletization must present an upright lift point eye over the center of mass or the load will cant and automatic hook throat engagement becomes complicated. Further, to prevent catastrophic disengagement either deep hook lips, automatic latch, or an entirely new but standard robot-friendly coupling (i.e., including tactile/force and vision/geometrical feedback) between crane hook and load rigging eye are required. While robotic crane operations offer potential for improved safety on an inherently risky task by moving human hands from hook-load engagement, and ideally humans from potentially swinging or dropped loads, a fully automated rigging area, or integration with human activities is needed. Further, unexpected conditions such as uneven ground, load irregularities, or precipitation may complicate development of a generalized system. It will take money and time before robot-friendly systems become standardized at all locations, and certification for some delicate handling tasks, such as ammunition transfer, will be difficult.

L6 - Supply yard lift and short movement operations. Forklifts are typically characterized by load-over-forks, with skid capture promoting load safety. However, load-on-pallet shift, and momentum from cantilevered-forked load back onto the forklift can be key stability hazards, particularly during potentially slick, soft or unlevel outdoor work. Newer forklifts have built-in stability control sensors that can minimize some of the potential hazards for both manned and unmanned operation. Force feedback is required, both for fork tactile sensing, and overall load-couple on the forklift. Indoor warehouse operations, where floor lanes or lines are marked for robot guidance and movement, are most feasible for robotics systems. Outdoor work, especially in a changing tactical environment with humans nearby, presents the most challenging conditions for a robotic forklift system. Providing additional system degrees of freedom, whether to save warehouse space by articulation or for self-leveling in outdoor work, may improve functionality and feasibility but at higher development cost.

L7 - Waterborne discharge of equipment – ship to shore. During Joint Logistics Over the Shore (JLOTS) operations, supplies, equipment, and personnel are moved ashore and made available for onward movement. Army responsibilities may include the discharge of equipment, transport and distribution of cargo from the JLOTS sites to inland staging areas, and establishment of marshalling areas. Between on/off-loading, technical variables affecting normal-wave waterborne operations are less demanding than ground transportation. Therefore, JLOTS may be conducive to transport of cargo from ship-to-shore by autonomous vehicle technologies.

Roboticized supply transfer by lighterage systems, ferries and tugs/barges presents the prospect of a wave/wake-induced shifting interface, both boat-to-boat, and boat-to-pier. There also are special sensor obscurant and salt-corrosion issues in addition to problems similar to those noted for outdoor forklifts. New system design will be difficult; retrofit of legacy systems may be so involved as not to be attempted before systems are retired. Given that the Army is a largely land-based force, a US Navy or USMC lead in this area may be best, albeit with Army participation.

L8 - Robotic Re-Arming. The transfer of ammunition from supply vehicle to weapon platform is a common need across a variety of ammunition types, from small arms ammunition boxes to pallets of tank rounds and artillery projectiles and advanced missile systems for attack helicopters. Munitions re-arming continues to be a manually intensive operation. While forward tactical re-arming appears an ideal task for robotic work, it has all the toughest challenges of outdoor work, coupled with ammunition certification and proximity of soldiers in the served vehicle. While challenging, many benefits can be achieved by the application of robotics to re-arming tasks such as enhanced soldier safety, reduction in equipment training requirements, and reduced re-arm time. Application of robotics to re-arming tasks will require development of load sensing capabilities, specialized robotics control techniques, collision avoidance, force feedback and position detection capabilities and systems.

L9 – Soldier Sustainability: Improved Soldier Strength and Endurance and Transport of Equipment and Supplies in Support of Dismounted Maneuver. Soldiers routinely perform extremely taxing and dangerous tasks in difficult terrain. Performance of these tasks under significant equipment loads can leave Soldiers physically drained and unable to operate at a high degree of effectiveness over long-duration missions. Robotics systems that can offer both the ability to increase the endurance and strength of the Soldier and transfer of some equipment load to a robot will combine to increase the Soldier’s speed and stamina. They may also provide a means by which to resupply Soldiers or evacuate casualties under fire. Ideally, systems that carry Soldiers' equipment should maintain appropriate tactical separation from dismounted Soldiers so as not to compromise their location. These systems must be able to follow the supported Soldiers through the full spectrum of mission sets and terrain. The FCS program MULE-T provides one such capability, however the need to operate in very difficult and restricted terrain may require a solution that is smaller and potentially more mobile in buildings, small trails, or very rocky terrain. Robotic systems that provide the Soldier strength and support these kinds of operations must have sufficient un-tethered power, the ability to operate in silence while in the proximity of Soldiers moving to contact, and must be able to autonomously or semi-autonomously navigate for periods of time as designated by the supported Soldier.

SECURITY (S)

There are a number of security related Warfighter Outcomes for which robotics may offer a material solution. High priority security needs include: point detection (and neutralization) of explosives and CBRNE; and, collect and manage biometric data. Lower priority capability needs include: detection and identification of toxic industrial chemicals/materials; stationary (and mobile) hemispherical protection; and sensor/effects packages to deny access to critical points and provide force protection.

The UJTL tasks suggest possible improvements in the security area through robotics. Time to identify friendly forces, and the probability of a false detection or alarm should be minimized. Additionally, the time required for an enemy force to subvert or replicate friendly force cognition or recognition methods would be maximized as would the probability of detection (PD) for a positive identification of individuals. For CBRNE issues, the time to estimate CBRNE situations, develop courses of action, and allocate resources could be minimized. The use of robotics for the following tasks may result in operational improvements in the security area.

S1 - Provide perimeter security of: military installations/airfields, ammunition storage areas, chemical weapons storage areas. The security tasks are divided into four conditions due to the effect of operational differences on technical feasibility. CONUS installations require detection and alarm capabilities but do not necessarily require an automated weapons engagement capability. Therefore, concerns with false alarm rates (FAR) are minimized. Automated armed static Forward Operating Base (FOB) perimeter security is challenging due to need for both high probability of detection and low false alarm rate, though a second outer ring of wire and warning signs may reduce the need for low FAR. Ammunition or chemical storage areas that lie within FOBs will likely see few personnel approach the storage area so a high PD alone may be sufficient. Mobile security using unmanned ground vehicles may be frustrated by changes in terrain and variable threat recognition. However, if the systems are routed in an irregular track around "familiar" but uninhabited terrain such as on a ring around a FOB, then the ability of a robot to discern changes in the terrain based on previously sensed and stored data make this solution more feasible.

S2 - Remotely scan personnel and vehicles entering restricted areas. Employment of automated systems for biometrics scanning at CONUS base Entry Control Points (ECPs), while perhaps more difficult to initially develop due to US multi-ethnicity, will provide an opportunity for long-term use and will be more culturally acceptable than in other operational environments where technologies of this type are not common. Overseas tactical FOB employment, however, may encounter cultural variation in biometric expression, requiring "recalibration" for each country of use. However, there already appears to be ongoing work in this area, though military personnel returning from OIF felt that human security personnel seem to have a special ability to synthesize human factor data (termed a "sixth sense") suggestive of an intruder. Roaming underground robotic security systems for use in CONUS base pipe chases and service tunnels or US border areas must make use of robotic miniaturization. For example, such systems would have provided some relief from sabotage such as seen by USACE in pipes at the Al Fatah crossing in 2004-05 in OIF. This task area provides a good example of the unique capabilities of robots to perform tasks that humans are not suited to execute.

S3 - Detect, identify, assess, report, and provide warning in event of a hazardous spill. While this and the next task may touch on the OSD Unmanned Systems Roadmap CBRNE reconnaissance mission area, any concepts developed in these areas should be checked carefully against existing work (i.e., the FIDO chembot) to avoid duplication of effort. As has been seen with FIDO, the hazardous material sensor is a key element of technology and may in fact "piggyback" on a number of existing robotic chasses. Also, such sensors are often calibrated to a specific targeted chemical, so coordination between CBRNE planners and intelligence analysts for use of the correct sensor is important.

S4 - Remove and clean up hazardous materials from contaminated areas. Lessons learned from US radiological work indicate that robotic systems used in CBRNE areas will likely become contaminated and washdown will likely not be able to remove all trace contamination with certainty. Therefore, inexpensive and disposable systems are required, or they must be robust enough so that little maintenance is required and they may be briefly washed down, bagged and stored until next use. Due to the variability of locations and situations for clean up, it may be difficult to completely automate the decision-making process, so tele-operated systems may be preferred when executing this task.

S5 - Casualty Evacuation. This is a mission-task area that overlaps with FCS robotics research and development. However, if FCS is delayed, or if a cheaper solution is desired, then a relatively cheap UGV based on an automated COTS all-terrain vehicle with a lightly armored (small arms and/or brush contact) pintle-dragged shell might be a feasible solution.

ENGINEERING (E)

There are a number of engineering related Warfighter Outcomes for which robotics may offer a feasible solution. Higher priority engineering needs consist of observing and collecting information worldwide. Lower priority needs include: passive marking and designating; visual and virtual obstacle marking system; specialized urban breaching; and, rapid construction and repair of combat routes and trails.

The UJTL tasks suggest possible improvements in the engineering area through robotics. Support to counter-mine efforts in training and delivery of materiel could be increased. Further, for obstacle or mine employment, delay time and information passage to friendly forces should also be increased. The following robotics supported tasks may show improvements in the engineering area.

E1 - Conduct terrain recon for trafficability and location of barriers/obstacles/mines. The first four engineering tasks are separated into three types of control. Remote control (RC) actions may use typical radio frequency signals for efferent signals, but are limited to line of sight feedback, typically by visual cues to a Soldier-operator. The accuracy of velocity sensors and required power limit feasibility. These same factors limit tele-operated systems which have a potentially longer reach but may be limited in applicability due to field of view, lack of easy depth perception, and fidelity of video feedback to the operator. However, this limitation could be partially overcome by using two separate views on a display that provide the ability to present a zoomed sensor view for precise observation or task work while also displaying a wide field of view that contributes to the operator's general situational awareness. Appropriate, accurate and timely sensor data, communications (i.e., bandwidth), and artificial intelligence algorithm design and speed may limit utility. Generally, the systems in E1-E4 may employ large, existing engineer vehicles (i.e., SEE D7 and M1) but maintaining situational awareness and control are the main challenges.

E2 - Overcome and report obstacles. Issues with this task in most respects mirror those described in E1.

E3 - Conduct breach operations: suppress, obscure, and secure breach lanes. In addition to the comments in E1, the use of robotics to execute this task may introduce the use of weapons systems. Thus, safety and policy issues may affect the feasibility of using robotics.

E4 - Move and emplace materiel, construct obstacles, establish security. An added difficulty for obstacle emplacement is the use of robotics systems to execute earthmoving tasks involved in constructing cribs, ditches, berms, etc.,. Therefore, the same level-ground and stability issues apply as discussed for outdoor forklifts (task L6).

E5 - Mark, record and report obstacles. Feasibility may be enhanced by UAS data. Though many robotic tasks are dependent on global positioning system (GPS) data, GPS will likely be central to obstacle reporting. GPS is susceptible to counter-measures, including spoofing. Images of obstacles developed by robotic systems (i.e., minefield, wire) from a GPS-marked point at a safe distance may be useful for follow-up ground teams that confirm obstacle boundaries or obstacle lanes.

E6 - Conduct firefighting operations. Robotic systems can enhance firefighting operations due to their ability to get closer to the fire than a human. However, all equipment (i.e., communications gear, video, wiring, fuels) must be heat resistant. Further, video visibility may be adversely affected by flames and smoke, and mechanically sensitive equipment must be protected from falling debris.

E7 - Earthmoving for airfields, FOBs, etc. Positive feasibility ratings are for sites located on flat ground; uneven or sloped ground may pose stability issues that make use of robotics difficult. Variables that a robot might need to sense to accomplish this task, especially for a fully autonomous system, include soil mechanical properties, blade orientation, and vehicle drag.

E8 - Detection and removal of explosives, surface and sub-surface, on land or water. Feasibility of robotics solutions relates to the suite of sensors and delicate robotic manipulation of explosives during removal. Further, the probability of detection must be high so that no mines are left behind. However, sensor bias to achieve a suitable probability of detection may result in a concurrent, moderately high false alarm rate. This tradeoff will simply require additional time to execute the task based on unnecessary “false mine” removal.

MEDICAL (ME)

Only a few medically related Warfighter Outcomes might use robotics as a feasible solution. Lower priority needs are seen in the “force health protection initiative” such as the use of robots offering ballistic protection during robotic-enabled evacuation.

The UJTL tasks suggest possible improvements in the medical area through robotics. Task areas of interest include faster casualty recovery and evacuation by fewer personnel, faster and more certain recognition of injuries, and communications supporting remote tele-medicine. The robotic tasks listed below may show improvements in the medical area.

ME1 - Conduct pharmacy operations. While electrical engineers differentiate between digital versus analog operations, automated pharmacy operations may differentiate between quantum deliveries of prepackaged doses versus apothecary dram weight and/or volume aliquot combinations from basic stocks. Subject matter experts focused on the “digital” prepackaged task as a much more feasible task for robotics systems. This is already being done in some CONUS hospitals and may be developed for use at a semi-mobile expeditionary FOB. Some issues to overcome include system size reduction, reloading means, and robustness versus mechanical jams. Additionally, safety certification is a challenge and must be addressed by engagement with the testing community. Of note, “analog” automation from bulk supplies of basic powder or liquid stocks may appear attractive due to lower stock cost and lower in-transit-to-FOB segregation concerns. However, the dispensing task looks much more challenging due to issues associated with contamination/cleanliness or tare and measures calibration.

ME2 - Perform tele-medicine/surgery. Remote tele-operated medicine is quite feasible, but with limitations. Visual examination information is planar, and may lack depth and full five-sense information. As a human assistant will likely be required, a question arises as to the feasibility of doing better than having a trained human assistant, local to the patient, relaying information back to the remotely located doctor. However, vital signs (i.e., skin temperature, pulse, blood pressure) may be available from a simple robotic arm (or bed) enabled contact. DARPA is working on a “trauma pod” which would provide patient scan and diagnostics, but is reportedly only presently available as a component capability, not a full and integrated system.

At first glance, remote tele-operated surgery capability appears to already exist in civilian hospitals (i.e., DaVinci Machine: http://www.intuitivesurgical.com/index.aspx). Specialized surgeons on one coast of the US may remotely operate on a patient using robots in operating rooms on the other coast. However, these large and costly robots are often set up for very specialized procedures. Bandwidth limitations, time lag and transmission disruptions are a very real concern in an expeditionary environment with possible high life threatening risks during an operation.

ME3 - Perform battlefield first aid (tourniquets, splints, shots, IV drips, etc.). The Institute for Nanotechnology (ISN) has ongoing basic research into uniform-based diagnostics and emergency injections. Further, sewn-in tourniquet loops on uniforms are under consideration for fielding, with Soldier-actuation required. However, robotic first aid may dovetail well with recovery (ME4) and evacuation (S5) tasks. Still, local cultural concerns, or prospects of a confused, wounded Soldier may complicate acceptance of close contact by a first aid robot.

ME4 - Recover battlefield casualties (WIA, KIA). Self-assistance of the Soldier cannot be assumed, even for the wounded. Therefore, a practical means to find (S5), assess, stabilize (ME3), then move to a starting position, and then cradle, roll or fireman-carry onto a stretcher or carriage (ME4) before evacuation (S5) must be determined given the complexity of the associated tasks. This may be complicated by the unknown nature of an injury, which may complicate or confound a rote mechanical means of WIA or KIA movement. For instance, a compound fracture or severed limb might not be gripped, or gripping may increase injury. The tele-operated Battlefield Extraction Assist Robot (BEAR) system (http://blogs.zdnet.com/emergingtech/?p=338) is available in the near-term and has a 500 pound, 50 minute casualty-recovery capability. An automated version of BEAR would need additional artificial intelligence to integrate the ME3 and S5 functions.

ME5 - Disposal of medical waste. Whether cleaning up an operating room, or battlefield triage area, this task involves locating medical waste (i.e., tissue, fluids, bandages, etc.) and categorizing and proper packaging of waster for disposal. If automatic, this frees up personnel and limits their exposure to biological vectors. Means of biologic detection, segregation and containment are important issues to resolve.

MAINTENANCE (MA)

Though separated as a distinct mission area, there is a tangency between many maintenance and logistics tasks, and robotics is associated with only a few of the maintenance related Warfighter Outcomes. Lower priority WFOs are in maintainability and tool free maintenance and anticipatory sustainment and improved distribution.

The UJTL tasks suggest nominal improvements in the maintenance area. Maintenance task mission areas include processing of required Class IX parts, in-theater repair of major end items, and use of automated systems to provide battle damage assessment (type damage, location, transportability) to operations and intelligence staff. Further, it may be possible to reduce delays for systems awaiting repair/evacuation and issuance time for Class IX parts. The robotic tasks listed below indicate some possible robotics-enabled improvements in the maintenance area.

MA1 - Maintain and repair facilities. Feasible subtasks include end item painting, lift assist, ammunition maintenance, weapon sighting, and torque assistance. Further, each appears to have advantages in removing Soldiers from noxious or dangerous tasks, or from tasks that humans do not do particularly well (i.e., sighting due to respiration and normal postural tremor). Challenges associated with using robotics systems to perform these tasks include: obscuring sensors (i.e., spray painting), artificial intelligence (AI) algorithm flexibility (for multiple maintained systems), and parts alignment and hazardous materials clean up and disposal.

MA2 - Perform diagnostic checks or Preventive Maintenance Checks and Services (PMCS) on vehicles and equipment. A high quality external vehicle body (or armor) scan appears as a high-tedium area where robotic scans may be intrinsically superior to a human due to lower-tremor, more uniformly sustained speed, and offset distance. Fielding of robust, long calibration, compact sensors will be a key challenge. Also, developers must weigh the choice to put inexpensive sensors on the vehicle and use of the robot for interrogation, against mounting of a single more expensive sensor on a robot arm. Access to various vehicle locations for process variable reading will be a part of these decisions.

MA3 - Perform vehicle recovery/wrecker functions. Unintended vehicle movement, lift of load, and potential for sudden release of stored potential energy in wire rope make tele-operated or fully autonomous wrecker development attractive from a safety perspective. As expected from comments on robotic cranes (L5), a key challenge lies in development of a standard, robust latched linkage. Navigation and anti-tamper concerns echo traffic and pilferage issues with leader-follower convoys (L1).

MA4 - Deliver and control repair parts. Parts delivery control reinforces the logistical concerns with parts delivery (L2 and L3). Subject matter experts assessed that automated maintenance part tracking and delivery will be enhanced by a (sub) UID requirement for all separable Class IX sub-parts.

MA5 - Perform tele-maintenance (i.e., remote mechanic). The ability to have a remote maintenance expert's robotic tele-operated assistance in real time may suffer from available bandwidth, communication latency and two-dimensional screen spatial awareness issues. A fully automated robotic solution may have fewer communication issues, but requires greater sensor integration and has more AI development challenges. Further, unexpected "twisted metal" damage, as seen from field or combat use, may be outside AI recognition and make task performance difficult.

MA6 - Perform advanced manufacturing (i.e., robotic welding, machining, etc..). Although turning and welding automation is highly feasible in CONUS depot maintenance, expeditionary applications seem limited due to set-up expense and low lot size when compared to human-only work. However, lithographic part manufacturing is potentially feasible if current costly systems are upgraded for use with more applicable, durable metals, rather than presently used plastics.

Contained in the attached Annex to this paper are the relative rankings of tasks most feasibly supported by robotics solutions, potentially supported by robotics, and not feasibly supported in the near-term. The TRADOC-TARDEC team and other supporting robotics subject matter experts categorized tasks based on the ability to develop a robotics prototype at certain cost, schedule, and technology-to-task breakpoints. Tasks deemed *feasible* are those for which a prototype could be developed in less than two years, where estimated cost would be less than $500,000, and where the complexity of the tasks performed by the robot was low. Tasks identified as *potentially feasible* are those where a prototype could be delivered between two and five years, for less than $10 million, and where task complexity was deemed "moderate." Tasks deemed *infeasible* in the near-term are those where it would take over five years to develop a prototype, cost exceeds $10 million, or the task complexity is so high that technology is not expected to reasonably accomplish the task or its subtasks. There were five tasks deemed *feasible*, 20 identified as *potentially feasible*, and seven tasks identified as *infeasible*. Refer to the annex for further details.

DOTMLPF CONSIDERATIONS

The additional tasks proposed in this paper as well as current and future research, development, and fielding of systems that address Warfighter needs should be analyzed in terms of the beneficial impact that these tasks and solutions may have on the force. The Doctrine/Policy, Organization, Training, Material, Leadership, Personnel, Facilities (DOTMLPF) model provides a suitable methodology for this analysis. Lessons learned from current operations in Iraq and Afghanistan indicate that the fielding of any robotics system has a significant impact on the force. They have done much to save the lives of Soldiers and have proven to be a true complement to Soldiers engaged in the execution of dangerous tasks. Robotics systems require initial fielding and sustainment training. They must be supported throughout their life cycle. Personnel changes may be required depending on the degree of impact that a robotics solution has in supporting Soldiers, or redirecting their workload from humans to robots. Any new robotics development should undergo a detailed DOTMLPF assessment because of the potential impact that a robotics system may have on the force. This assessment allows the Army to fully understand the benefits and costs of fielding a specific solution, and enables an informed decision based on the holistic value of any proposed material solution. The following discussion provides some key considerations regarding the impact of fielding robotics systems that could conceivably address the tasks cited in this paper.

Doctrine and Policy

There is no capstone Army doctrine for the use of robotics systems in the contemporary operating environment, nor is there a need for one. Robotics systems, like many other technologies, support specific Army needs and requirements that are developed by branch proponents. Each of these proponents develop a set of "how to fight" manuals that describe how their forces will operate in a wide range of operational environments. The tactics, techniques, and procedures (TTPs) described in these manuals offer a description of how that part of the operating force will use robotics to execute mission tasks. These TTPs must then be encapsulated into training manuals or pamphlets that units and Soldiers will use when planning and executing training.

There are some key conceptual issues that proponents must address as they articulate how robotic systems will support their forces. Resolution of these issues may determine the sophistication of the robotics solution and the eventual cost-benefit of the system. First, the degree of autonomy that a proponent expects from a robot is based on the current and emerging state of technology and the conditions in which their forces operate. As proponent tasks can vary greatly, the expectation of Soldier-in-the-loop control of robotic systems will range between manual remote control of a robot to an expectation of a robot’s fully automated execution of a task. The degree of autonomy will be based on robotic system reliability (mean time between failures) and the nature of the task environment. Robots operating in a task environment that is complex (large number of associated and inter-related sub-tasks) and containing a high degree of variety (unpredictable and frequently changing conditions) will require highly reliable and extremely sophisticated sensing and decision-making technologies. A human controller might enable varying degrees of autonomy to a robot based on its inherent reliability and changes in the task environment, each of which could change over time and use of the system. Until these technologies are developed and proven, humans will continue to manipulate robots based on a robot’s abilities and the conditions in which they operate.

The ultimate objective, however, remains the pursuit of increased autonomy that improves the ability of unmanned systems to operate independently of the human, either as an individual system or system of mutually collaborating systems that are capable of executing highly complex tasks in a dynamic environment. These collaborating systems are not simply other robotics systems, but could be command, control, and communication networks and non-robotic hosted sensors that could provide robotic systems with the situational awareness and targeting data required for increasing degrees of autonomy. Further analysis of fielded or emerging robotic systems should evaluate those systems for efficiencies based on their ability to interoperate with other systems of the same or different modalities, among systems operated by different Services, and with systems of non-DoD organizations, allies, and coalition partners. The efficiencies gained by interoperability will be achieved through the use of common components, hosted systems (i.e., sensors, weapons, etc.), and software, or by building the systems according to common standards. To achieve this degree of interoperability requires an increased, integrated effort between combat developers who represent the user and scientists in research and development organizations. This collaboration early in the development of robotics systems ensures that they are shaped to enable human users.

Interoperability is also facilitated through adherence to standard message formats and data protocols. Currently, two such standards exist – NATO Standardization Agreement (STANAG) 4586 and the Joint Architecture for Unmanned Systems. The long term goal within DoD is the evolution to a unified standard where practical. Current and future systems should be analyzed against their ability to adhere to these standards and their ability to accommodate a transition to a unified standard.

There are a number of policy issues that the Army will have to address as the research and development community develops robotics systems as solutions to Soldier needs. For example, current Army policy prohibits unattended casualty evacuation (CASEVAC). Evacuated casualties must be accompanied by trained medical personnel – combat life savers, medics, or physicians. This policy should be amended to allow for substitution of portable critical care systems (i.e., Lightweight Trauma Module, MedEx-1000, MOVES) instead of, or with a human medical attendant, for casualty extraction or short-range CASEVAC missions.

There are doctrinal and policy issues associated with armed robots that might perform a combat or installation security task. These issues are shaped by expected mission tasks, the environment in which the robot will operate, reliability of the robot, and potential cultural or political sensitivities that might limit the use of armed robots. Additionally, armed robots must have safeguards that will not allow an unauthorized person to gain control of the robotic system. Surety of control and protection of the weapon system must be underlying tenets of any developed and fielded armed robot.

Organization

Any evaluation of the cost-benefit of a current or emerging robotics system must be accompanied by analysis of the impact that system may have on Army organizations. A modification to organizational structure can be the result of efficiencies gained through the introduction of robotics systems into the force, or can be a necessary byproduct of the system without any apparent increase in efficiency. Holistic analysis of organizational impact includes not only the organization to which a system is fielded, but also the impact on training and sustainment organizations.

Program Management tenets require that Program Managers (PMs) address these issues in their Total Life Cycle Systems Management (TLCSM) processes and plan for training and maintenance in their support plans, including the requirement for a reduced logistics footprint. Organizations with organic maintenance capabilities may be required to operate differently when supporting robotic systems. Robotic systems must meet key design criteria for reliability and maintainability or compensate with increased maintenance needs. Without strong TLCSM planning, maintenance organizations will likely grow and have additional mobility requirements including recovery of robotic platforms. Unit, direct, and general support and depot level maintenance for wheeled or tracked vehicles can maintain standard components on large unmanned ground vehicles (UGVs). Possible new training and maintenance responsibilities are addressed in the next section. Maintenance skill sets will likely evolve based on PM requirements.

While doctrine is evolving, specific mission directives are needed to cover organizational needs. For example, the Joint Robotics Repair Facility (JRRF), with their deployed and embedded training and repair capabilities, currently performs important specialized robotic maintenance in forward operational theaters. The JRRF, operated by the Robotic Systems Joint Project Office (RSJPO) under the Program Executive Officer - Ground Combat Systems, sustains operating units. The JRRF provides user training, robot maintenance, spares provisioning, and repair and is an important factor in robotics readiness, especially in Explosive

Ordnance Disposal (EOD) support against improvised explosive devices. The JRRF is required to support current operations and a similar capability will be needed for future operations. However, the JRRF operates on supplemental wartime funding with no operational budget or manpower. Without formally establishing the organization against a documented operational needs statement, the skills and knowledge of this organization could disappear when current operations terminate. Depots could assume the JRRF mission for large scale UGVs as they are fielded through programs of record. They will need deployable teams with reach-back capability for technical support and must be equipped with deployable repair equipment to “fix forward” in theater.

The development of operational and systems architectures will assist with further analysis of the cost-benefit of developing and fielding robotics systems, especially with respect to organizations using or supporting these systems.

Training

There will be new training requirements for robotics systems. The development of a robotics system that enables Soldiers will require the establishment of a commensurate set of live, virtual, and constructive training means. These training means should support individual, leader, and small unit collective training, and possibly staff training, that can adequately prepare Soldiers and units to effectively employ these systems.

Training on the application of robotics systems must begin well prior to their use in an operational environment. Some Soldiers may train on robotics systems as part of their initial entry training in the Army. Most Soldiers will conduct individual and unit sustainment training on robotics systems at their home station. Soldiers in the Army Reserve and National Guard should expect to conduct pre-deployment training on robotics systems at their Reserve Centers and armories, during annual training, and at Power Projection Platforms just prior to deployment. Units conducting training at Combat Training Centers should expect to train on systems that they have been training with at home station and that they will use in their operational missions. Leaders and staffs should expect to conduct virtually-enabled robotics systems sustainment training at home station, and training seminars as part of the Battle Command Training Program and other seminars that will prepare them to conduct training at Combat Training Centers.

The main objective of a robotics system training strategy is to ensure that Soldiers and leaders have sufficient training on the use of these systems well prior to their employment in a forward operational theater, or in the conduct of Homeland Defense or support to civil authorities in the continental United States. This requires the provision of a sufficient number of robotics systems to TRADOC schools, First U.S. Army Power Projection Platforms, Combat Training Centers, and the home stations of units preparing for possible deployment in accordance with Army Force Generation planning. Early collaboration between combat and training developers and the research and development community is required to achieve this objective. Training developers should focus their efforts on those systems that are most technologically promising, have or will undergo developmental experimentation, and are likely to soon be fielded to the force. TRADOC Centers of Excellence and schools that are designated leads for air and ground unmanned systems should work with robotics systems research and development centers to develop training transition strategies as systems are identified for eventual transition into established programs or newly designated programs of record. These collaborative strategies must be synchronized to ensure that system training is integrated and not duplicative. The need for synchronization requires a measure of integration between air and ground unmanned systems combat and technology developers that must be fostered and established as routine practice.

Commercial-off-the-shelf (COTS) systems that are developed in support of urgent needs requests also require much collaboration and synchronization between combat developers and Program Managers charged with fielding systems to the Army. Program Managers deploying COTS robotics systems are responsible for developing a training strategy for these systems in accordance with Total Life Cycle Management. Program Managers must ensure operational and maintenance training is developed, documented and available for Soldiers and any affected or designated maintenance organizations. A new equipment training team or self-paced training may be initially sufficient for most training requirements. Satisfying these requirements starts with the Program Manager. Program Managers deploying COTS robots and support maintenance capabilities must ensure operating and maintenance training is developed, documented, and available for users and maintenance organizations. A recent coordinated review indicated that while no new Military Occupational Specialties (MOSs) are needed for robotics in the near term, assignment of small unit responsibility for operator and maintenance training is needed to support infantry or Explosive Ordnance Disposal (EOD) users and robotic systems tracked or wheeled vehicle maintenance.

Future requirements may emerge for a new MOS if the cumulative effect of many fielded robots demands it. Program Managers should strive to establish common design criteria that will minimize unique training demands. However, training requirements for mechanical, electronic, and software maintenance will evolve as new robotic systems are deployed. Requirements might be simplified because of modularity and remotely connected technicians, or they could be complicated due to a high volume of unique requirements. This issue, and several others discussed above, should be addressed by Army designated combat development and material development leads in robotics systems, and their Joint community counterparts, to stress the need for standardization in training methods and means.

Materiel

Details on robots and robotics acquisition strategy, fielding process, life cycle support, and information system support can vary. Fielding robotic systems requires an analysis of platform and force structure tradeoffs that might impact system design and life-cycle costs as well as Army deployment, manning and OPTEMPO (peacetime and wartime) costs. For example, design and life cycle costs could be influenced by selection of an energy source for the system in order to achieve requisite scaling of mission duration and system size, weight, and power. Combat developers and Program Managers must fully consider these elements of material programs using Total Life Cycle Systems Management standard processes so that when fully executed they will provide adequate material support.

Standard processes may need to be modified to adjust for organizational and force trade-offs, systems deployability, and personnel requirements and training needs. Key Performance Parameters (KPPs) for reliability and maintainability must consider force structure footprint constraints and organizational composition as required by the TLCSM process. For smaller procurements, PMs must address lifecycle support issues under Modified Acquisition Plan procedures. Additionally, Program Managers should strive to reduce systems logistics needs by limiting requirements for contractor support personnel through intelligent design and depot repair teams with the goal of making these systems "maintenance free."

Program Managers must share material support decisions with combat developers, users and key combat service support organizations. Material support concepts using commercial support, Performance Based Logistics (PBL) support, Army organic capabilities, or a mixture of each, are all viable robotics support concepts. The proper deployment of robots to perform Soldier functions is well supported in standard acquisition doctrine and policy. New robotic systems procured to support emerging requirements or improve existing capabilities across the Army must be procured in accordance with DOD Directive 5000.1 as it requires TLCSM for all procurements.

The Army may realize a shift in doctrinal tactics, techniques and procedures (TTP) where maintenance organizations are required to "roam" the battlespace to recover and repair robots rather than having the crew or unit bring the system to a centralized maintenance site. Impact on inventory policy and bench stock for this dynamic operating environment will require supply business rule changes as well as an improved Automated Information System (AIS) to capture, track, and stock spares in a dispersed battlespace. Operational experience will indicate whether supply policy guidance on controlled exchange of spares due to combat loss or reconfiguration needs special consideration for robotic systems.

The organizational lines from the Program Manager to the Soldier using a robot must be examined to ensure doctrine or TTPs are in place to ensure operational efficiency. Integration of robotics systems into any warfighting effort can potentially strain traditional practices and procedures. An example of this tension is property book accounting. Robots deployed with infantry units or Explosive Ordnance Disposal teams sustain significant battle damage. Soldiers and units that evacuate their robot for repair do not know if it will be repaired or replaced with a robot from a common pool of spares. For pool exchanges, the unit's property book is often a far distance from the exchange pool location. Property book accounting, while recognized as necessary, is cumbersome in these forward deployed operational environments. Procedures should be examined to see if more efficient property accounting, like Property Book Unit Supply Enhanced (PBUSE), is capable of improving processes for these often battle-damaged items.

Leadership

The full impact of robotics systems that support small units and Soldiers is still undetermined. Without question, however, unit leaders at levels battalion and below must understand how robotics systems can most effectively support their operations. They must integrate these systems into operational planning much like any other enabling system. They must plan for their support and their replacement in the event that they are destroyed or break down. Leaders must be capable of integrating robotics systems into the full suite of live, virtual, and constructive training means available to small units and must integrate them into unit training strategies and plans.

Leaders will need to understand how and when robotics systems best support their operations in different environments, cultures, and missions. They must be as adept in their understanding of when not to use a robotics system, or how to most effectively manage the use of a robotics system to best suit their operational conditions and needs. In the future, leaders will need to understand how robotics systems can seamlessly cooperate and operate as a system-of-systems that are mutually supporting and reliant on one another for data and information. Leaders achieve understanding of how to effectively use, integrate, and support robotics systems through training and education.

The Army must also continue to explore how fully autonomous robotics systems will affect the conduct of operations and how they might impact small unit leadership. Autonomous systems act as an enabler to small units and are therefore an extension of manned systems or Soldiers. They must be responsive to the directed and pre-established intent of a leader no less than are Soldiers. Autonomous systems should be programmed to request further intent or direction from leaders as conditions change to such an extent that the system has reached its limit of safe autonomous activity, or when the robotic system is no longer operating to a pre-determined level of reliability. “Leader-in-the-loop” control of robotics systems is an undeniable requirement, and the degree of control will be tempered by the ability of the system to operate effectively and reliably based on pre-determined thresholds.

Personnel

The impact of fielding robotics systems on military and DOD civilian or contractor personnel is program specific. The knowledge, skills, abilities, and competencies necessary to operate, repair, and maintain robots and robotic components of large systems are generally similar to the personnel skill sets required to operate and repair electronics, computers and networks, avionics, and wheeled and tracked vehicles. Operators and maintenance personnel will need training on new equipment, but the needs are expected to be evolutionary. Any increase in required small unit manning must be based on a clearly identified increase in operational effectiveness that fully justifies the increased manning. Changes in Military Occupational Specialties (MOS) or significantly increased training requirements of existing MOSs must also be supported by reciprocal increases in small unit effectiveness. For example, maintenance of robotic systems could increase the need for multifunctional mechanics.

Combat developers and material developers should continuously conduct system design reviews during development of robotics systems to assess required hardware and software skill sets. They should identify specific design development mitigation areas to reduce task complexity. Lastly, combat and material developers will need to identify significant manmachine interface issues as well as required Soldier user and mechanic diagnosis and troubleshooting skills that will assist in the Soldier-operator selection and training processes.

Facilities

Currently there are no special or unique facilities requirements for security, maintenance or storage of robotics systems. Combat developers and Program Managers will need to ensure that normal infrastructure is available to ensure secure storage of pilferable items and spares and the availability of buildings for maintenance, if required. These requirements are program specific and will be based on the needs of the specific system as they can vary greatly based on size and complexity of the system. Program Managers will need to determine whether covered storage is required to maintain desired readiness levels. Maintenance workload may increase if robotic systems are stored outside. Inadequate storage could result in decreased initial readiness.

CONCLUSIONS

This paper builds on a confederated Army robotics "strategy" that is described by senior leader direction, studies, and various systems based "road maps." It provides a "next step" to this strategy by identifying mission-related tasks that are additive to those that define the three components of the current strategy.

Subject Matter Experts from TRADOC and TARDEC with assistance from over three dozen robotics specialists collaborated to further identify and assess the feasibility of robotics systems to conduct or assist with the execution of 32 Soldier tasks. This TRADOC-TARDEC lead team assessed these tasks for their feasibility based on their complexity and the estimated cost and time to develop a prototype. The feasibility analysis contained in the attached annex is a start point for follow-on analysis and evaluation by designated TRADOC robotics systems leads and their material development community counterparts. Further DOTMLPF-based analysis and modeling will determine effectiveness of proposed systems and the impact they might have on the Army. This impact analysis should serve as the basis by which to determine the return on investment to the Army of proposed robotics solutions to Soldier capability needs, and areas where further analysis or research is required.

The brief DOTMLPF analysis in this paper provides focus on some key issues that the Army must reconcile or might have to address now and in the future. This includes issues such as the degree of autonomy that the human is willing to delegate to increasingly "smart" robotics systems, thoughts on the impact of robotics systems on training and leadership, and the effectiveness of current doctrine and policy, among other considerations. It is expected that the analysis contained in this White Paper will serve to inform Army input into the next version of the OSD Unmanned Systems Roadmap, inform and update TRADOC's Warfighter Analysis and Outcomes, and assist in development of the next revision of TRADOC Pamphlet 525-66 (Force Operating Capabilities).

Many of the robotics systems in use by Soldiers and small units in Iraq and Afghanistan have proven their worth – they have saved dozens, perhaps hundreds of lives. They will continue to offer the same benefit to the Army now and in the future in myriad ways. The Army can potentially leverage robotics systems to perform a host of tasks, and current research and development offers some insights as to the ability to reduce the manpower required to perform some of these tasks. These opportunities offer the Army a logical sequel to how it has up to now invested in robotics technology and how it might focus its future investment. Doing so could provide some promise of relief to an Army of 1.1 million Soldiers that is faced with an increased tempo of operations, now and in the future, in CONUS and overseas.

APPENDIX - Detailed Task-Robotics System Feasibility Analysis

The task-system analysis contained in the following tables is based on work conducted at a 15 January 2009 workshop at TARDEC's Robotics Initiatives Working Group (AMSRD-TAR-R/263) by 40 select robotics subject matter experts representing organizations within the Research, Development, and Engineering Command (RDECOM), TRADOC schools and centers, industry and academia. These SMEs were assigned, according to individual specialty, to working groups representing tasks in 5 areas: logistics, security, engineering, medical, and maintenance. The TARDEC Robotics Group and TRADOC action officers determined the feasibility assessment areas depicted in the tables: estimated schedule and cost to develop a prototype, and complexity of associated tasks and subtasks that the system would have to perform. The SME groups were briefed on the criteria for high-medium-and-low ratings within these areas and using the following metrics:

Schedule	**Cost**	**Task Complexity**
Low (0-2 years)	Low (<$500K)	Low
Mid (3-5 years)	Mid ($1M-$10M)	Mid
High (>5years)	High (>$10M)	High

Logistics:	Description	Schedule	Cost	Complexity
L1-A:	Surface cargo transport and delivery of equipment and supplies using logistics convoys	Mid years	Low cost	High complexity
L1-B:	Aerial cargo transport and delivery of equipment and supplies using pods	Low years	Low cost	Low complexity
L2:	Cargo packaging and pallet assembly	Mid years	Low cost	Low complexity
L3-A:	Packaged warehousing: Inventory management, prioritization, retrieval and preparation for movement	Mid years	Low cost	Low complexity
L3-B:	Loose binning warehousing: Inventory management, prioritization, retrieval and preparation for movement	High years	Mid cost	Mid complexity
L4:	Refueling (wholesale and retail)	Mid years	High cost	Low complexity
L5:	Crane and lift operations	Mid years	High cost	Low complexity
L6-A:	Indoor yard lift and short movement operations	Low years	Low cost	Low complexity
L6-B:	Outdoor yard lift and short movement operations	Mid years	High cost	Mid complexity
L7-A:	New design for waterborne discharge of equipment ship to shore	Mid years	Mid cost	Mid complexity
L7-B:	Retrofit for waterborne discharge of equipment ship to shore	High years	High cost	High complexity
L8:	Robotic re-arming	High years	High cost	Mid complexity
L9:	Soldier Sustainability: Improved Soldier Strength and Endurance and Transport of Equipment and Supplies in Support of Dismounted Maneuver	Mid years	High cost	High complexity

Security:	**Description**	**Schedule**	**Cost**	**Complexity**
S1-A	Provide unarmed perimeter security of: military installations/airfields, ammunition storage areas, chemical weapons storage areas: CONUS, unarmed, static	Low years	Low cost	Low complexity
S1-B	Provide armed perimeter security of: military installations/airfields, ammunition storage areas, chemical weapons storage areas: FOB exterior, armed, static	Mid years	Mid cost	Low complexity
S1-C	Provide perimeter security of: military installations/airfields, ammunition storage areas, chemical weapons storage areas: FOB interior, armed, mobile	Low years	Low cost	Low complexity
S1-D	Provide perimeter security of: military installations/airfields, ammunition storage areas, chemical weapons storage areas: FOB exterior, armed, mobile	Mid years	Mid cost	Mid complexity
S2-A	Remotely scan personnel and vehicles entering restricted areas: fixed at Entry Control Point	Low years	Low cost	Low complexity
S2-B	Remotely scan personnel and vehicles entering restricted areas: mobile	Mid years	Low cost	Low complexity
S3	Detect, identifies, assess, report, and provide warning, in event of a hazardous spill	Mid years	Mid cost	Low complexity
S4	Remove and clean up hazardous materials from contaminated areas	Low years	Mid cost	Low complexity
S5	Casualty Evacuation	Mid years	Mid cost	Low complexity

Engineering:	**Description**	**Schedule**	**Cost**	**Complexity**
E1-A	Conduct terrain recon for trafficability and location of barriers/obstacles/mines: Remote control and tele-operation	Low years	Mid cost	Low complexity
E1-B	Conduct terrain recon for trafficability and location of barriers/obstacles/mines: Fully autonomous	High years	High cost	Mid complexity
E2-A	Overcome and report obstacles: Remote control and tele-operation	Low years	Mid cost	Low complexity
E2-B	Overcome and report obstacles: Fully autonomous	High years	High cost	Mid complexity
E3-A	Conduct breach operations: suppress, obscure, and secure breach lanes: remote control and tele-operation	Low years	Mid cost	Low complexity
E3-B	Conduct breach operations: suppress, obscure, and secure breach lanes: Fully autonomous	High years	High cost	Mid complexity
E4-A	Move and emplace material, construct obstacles, establish security: Remote control and tele-operation	Mid years	Mid cost	Low complexity
E4-B	Move and emplace material, construct obstacles, establish security: Fully autonomous	High years	High cost	Mid complexity
E5	Mark, record and report obstacles	Mid years	Mid cost	Low complexity
E6-A	Conduct firefighting operations: Remote control and tele-operation	Low years	Mid cost	Low complexity
E6-B	Conduct firefighting operations: Fully autonomous	High years	Mid cost	Mid complexity
E7-A	Earthmoving for airfields, FOBs etc: RC Remote control and tele-operation	Low years	Mid cost	Low complexity

E7-B	Earthmoving for airfields, FOBs etc: Fully autonomous	Mid years	Mid cost	Low complexity
E8-A	Detection and removal of explosives, surface and sub surface on land or water: Remote control and tele-operation	Mid years	Mid years	Mid complexity
E8-B	Detection and removal of explosives, surface and sub surface on land or water: Fully autonomous	High years	Mid cost	Mid complexity

Medical:	**Description**	**Schedule**	**Cost**	**Complexity**
ME1-A	Conduct pharmacy operations: at CONUS	Low years	Low cost	Low complexity
ME1-B	Conduct pharmacy operations: at FOB	Mid years	Mid cost	Low complexity
ME2-A	Perform tele-medicine: vital signs	Low years	Low cost	Low complexity
ME2-B	Perform tele-medicine/surgery: tele-operated surgery	High years	High cost	Mid complexity
ME3	Perform battlefield first aid	High years	High cost	Low complexity
ME4	Recover Battlefield casualties	Low years	Mid cost	Low complexity
ME-5	Disposal of medical waste	Mid years	Mid cost	Low complexity

Maintenance:	**Description**	**Schedule**	**Cost**	**Complexity**
MA1	Maintain and repair facilities:	Mid years	Mid cost	Mid complexity
MA2	Perform diagnostic checks/PMCS on vehicles and equipment	Mid years	Mid cost	Low complexity
MA3-A	Perform vehicle recovery/wrecker functions: tele-operated	Low years	Mid cost	Low complexity
MA3-B	Perform vehicle recovery/wrecker functions: fully autonomous	High years	High cost	Low complexity
MA5-A	Perform maintenance: tele-operation	Mid years	High cost	Mid complexity
MA5-B	Perform maintenance: fully autonomous	High years	Mid cost	Mid complexity
MA6-A	Perform advanced manufacturing: turning and welding	Mid years	Mid cost	Mid complexity
MA6-B	Perform advanced manufacturing: metal lithography	High years	High cost	Mid complexity

LIST OF ACRONYMS

AI	Artificial Intelligence
AIS	Automated Information System
ARV	Armed Robotic Vehicle
ARV-A (L)	ARV- Assault (Light)
AUTL	Army Universal Task List
CASEVAC	Casualty Evacuation
CBRNE	Chemical, Biological, Radiological, Nuclear and High Yield Explosives
CM	Counter-mine
COTS	Commercial Off-the-Shelf
CONUS	Continental United States
COCOM	Combatant Commander
C-IED	Counter-Improvised Explosive Devices
DARPA	Defense Advanced Research Projects Agency
DoD	Department of Defense (also DOD)
DO	Distributed Operations
DOTMLPF	Doctrine, Organization, Training, Materiel, Leadership, Personnel, and Facilities
EOD	Explosive Ordnance Disposal
FOB	Forward Operating Base
FCS	Future Combat Systems
FAR	False Alarm Rate
FY	Fiscal Year
GPS	Global Positioning System

GWOT	Global War On Terror
IED	Improvised Explosive Device
ISN	Institute for Nanotechnology
JIEDDO	Joint IED Defeat Organization
JRRF	Joint Robotics Repair Facility
JUTL	Joint Universal Task List
KPP	Key Performance Parameter
LOC	Lines of Communication
MOS	Military Occupational Specialty
MULE	Multi-function Utility/Logistics and Equipment Vehicle
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
OSD	Office of the Secretary of Defense
PBL	Performance Based Logistics
PBUSE	Property Book Unit Supply Enhanced
PD	Probability of Detection
RF	Radio Frequency
RFI	Rapid Fielding Initiative
RS-JPO	Robotic Systems Joint Program Office
SEE	Small Emplacement Excavator
SME	Subject Matter Expert
SUGV	Small Unmanned Ground Vehicle
TARDEC	Tank-Automotive Research, Development and Engineering Center
TLCSM	Total Life Cycle Systems Management
TRADOC	Training and Doctrine Command

TTP	Tactics, Techniques, and Procedures
UAS	Unmanned Aircraft System
UAV	Unmanned Aircraft Vehicle
UGV	Unmanned Ground Vehicle
UJTL	Universal Joint Task List
WFO	Warfighter Outcome