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Unmanned Ground Systems Roadmap

Robotic Systems Joint Project Office

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Robotic Systems Joint Project Office

Unmanned Ground Systems Roadmap

July 2011

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The 2011 Robotic Systems Joint Project Office (RS JPO) Road Map is a biennial publication and this second edition follows the inaugural 2009 edition. The 2011 edition incorporates the roadmap addendum published in July 2010.

The RS JPO is a dual service organization reporting to the Program Executive Office for Ground Combat Systems (PEO GCS) and the Marine Corps Systems Command (MARCORSYSCOM) as the executive agencies for the acquisition of unmanned ground systems. As with the first Road-map edition, this document will serve as a practical reference to assist in Warfighter requirements definition, identify relevant technology maturation and to focus Science and Technology (S&T) investment on Warfighter needs.

Many changes in the Department of Defense (DoD) strategy for robotic acquisition as well as the structure of the RS JPO have occurred within the last 18 months. Perhaps the most significant is the development of the Joint Initial Capabilities Document (ICD) for Unmanned Systems which defines the need for broad unmanned capabilities across air, ground and maritime domains. The ICD enables exploration of greater capabilities generation than those found in current Programs of Record (POR). This will also help to expand the more "niche applications" currently fielded based on Operational Need Statements (ONS) and Joint Urgent Operational Need Statements (JUONS). In February 2011, the Army Training and Doctrine Command (TRADOC) submitted the ICD into Joint Requirements Oversight Counsel (JROC) phase two staffing. To enhance the Voice of the Customer and define more specific Warfighter needs, TRADOC's Army Capabilities Integration Center (ARCIC) designated the Maneuver Center of Excellence (MCoE) at Ft. Benning, GA as its "lead agent" to synchronize and coordinate robotic needs across all Army Centers of Excellence (CDEs).

In addition to the staffing advancement of the ICD, in January 2011 the program charter for all Army unmanned ground vehicles (UGVs) within Program Executive Office Integration (PEO-I) (formerly Future Combat Systems) was transferred to the RS JPO. Under this reassignment, the Small Unmanned Ground Vehicle (SUGV) XM1216, Autonomous Navigation System (ANS) and Common Mobility Platform (CMP) were transferred for procurement, fielding and life cycle management to the RS JPO. This addition to the RS JPO portfolio now creates programmatic activities in both Huntsville, Alabama and Warren, Michigan.

Recent significant events for the RS JPO include the Milestone C Decision approval for the M160 Anti-Personnel Mine Clearing System (APMCS) on 12 May 2011. This action will permit full implementation of system supportability requirements, configuration management, and additional system purchases based on resourced requirements. The Marine Corps' Route Reconnaissance and Clearance (R2C) robotic program, the first Marine Corps POR managed by the RS JPO since its move to Warren, Michigan in 2008, is approaching its Milestone Documentation Decision (MDD) and Request for Proposal (RFP) phase. Additionally, the SUGV XM1216 was delivered to the First Unit Equipped (FUE) in March 2011 and is expected to be deployed to combat later this year.

The RS JPO Project Manager's overarching priorities and commitments remain world-wide support to the Warfighter, support to our team members with developmental opportunities, finalizing the transition of former PEO-I personnel and programs, and continuous process improvement.

Chapter 1: RS JPO Goals and Vision: 2011–2020

1.0 Roadmap Background

The RS JPO initiated the development of an Unmanned Ground Systems Roadmap in August 2008 soon after the Project Office moved from Huntsville, AL to Warren, MI. The intent of the first version of the Roadmap was to establish a baseline for the goals and mission of the RS JPO. The 2011 edition will build off this baseline with an added emphasis on strategies as well as a continued focus on the following:

- Providing insight to the Warfighter and acquisition community on Unmanned Ground Systems (UGSs) managed by the RS JPO
- Forecasting technology growth areas based on developments within the S&T communities
- Identifying needed capabilities or areas of improvement based on previously fielded systems
- Keeping the S&T community informed regarding technology being researched or used to improve the current UGV fleet in a hope to reduce redundancy in S&T projects.

The main goal of the 2011 Unmanned Ground Systems Roadmap (2011-2020) is to convey the RS JPO's short- and long-term strategies. The short-term period covers one to five years, with long-term covering beyond five years. The RS JPO is focusing heavily on the improvement and modernization of the current robot fleet, as well as assisting in the development and release of emerging requirement documents such as the Squad Multi-Purpose Equipment Transport (S-MET). These efforts support the achievement of RS JPO's overarching goal of ensuring the Warfighter's needs are addressed both now and into the future. Along with these goals, this 2011 Roadmap is intended to inform the various stakeholder communities consisting of S&T Labs, other Program Managers (PMs), and the TRADOC CoE regarding:

- Advancements in technologies for UGS
- Changes within the organization of the RS JPO
- RS JPO interoperability efforts
- Updates on the RS JPO Commercial-off-the-shelf (COTS) and POR robotic programs

1.1 Major Events since Release of the 2009 UGS Roadmap

Since the release of the 2009 RS JPO Roadmap, several important events have taken place that resulted in a growth of manpower and responsibility within the RS JPO. The following is a partial list of events:

- On 24 November 2009, the Assistant Secretary of the Army for Acquisition, Logistics and Technology (ASA[ALT]) issued the "U.S. Army Policy for the Acquisition of Unmanned Ground Systems and Integration of Mission Capability Packages," directing the RS JPO to be the focal point for all future U.S. Army UGS acquisition efforts
- An ICD to leverage existing robotic strategies and JUONS/ONS to define the capabilities and operational performance criteria required is currently in JROC staffing. This ICD provided a basis from which Capability Development Documents (CDDs) and Capability Production Documents (CPDs) for unmanned capabilities can be supported and from which PORs can be facilitated when necessary
- The RS JPO formed a Government/Industry Working Integrated Product Team (WIPT) to focus on Interoperability and address the concerns stated in the ICD
- The Office of the Secretary of Defense (OSD) developed and published the OSD Integrated Roadmap which focuses on the Services' S&T development efforts and Unmanned Systems (UMS) program projections out to 25 years

Additional information on these developments can be found in the July 2010 Addendum to the 2009 RS JPO Roadmap.

1.2 RS JPO Mission

The RS JPOs mission is to "Lead the development, systems engineering, integration, acquisition, testing, fielding, sustainment and improvement of unmanned systems for the Joint Warfighter to ensure safe, effective and supportable capabilities are provided while meeting cost, schedule and performance."

The strategy for accomplishing our mission is a multi-tiered plan involving both near- and long-term strategies. Essential to this plan are robotic modernization and interoperability. Modernization allows for the upgrade and implementation of technology that increases system functionality and reliability. Planning for interoperability ensures that our current systems as well as future systems are able to communicate with other manned and unmanned systems and function without interference on the battlefield. Critical to modernization and interoperability is the understanding of the Warfighter's needs, wants and desires. The ability to support and maintain our fielded systems with internal resources affords us the opportunity to gain insight into operational gaps. The ability to develop, collect, and align technology to fill operational gaps enables the RS JPO to meet its mission. With RS JPO systems deployed to Operation Enduring Freedom (OEF) and Operation New Dawn (OND), a wealth of information has been collected on potential areas for improvement and enhancement. These areas include power sources, battery life, communications, situational awareness, and more versatile tools.

1.3 RS JPO Partnerships

The RS JPO works closely with many different organizations that support the robotic mission. These working relationships have lead to partnerships being established to determine or refine robotic requirements as well as improve fielded robots and fulfill emerging urgent robotic requirements. Organizations such as TRADOC, Research, Development and Engineering Command (RDECOM), Joint Ground Robotics Integration Team (JGRIT), Naval Explosive Ordnance Disposal (EOD) Technology Division (NAVEODTECHDIV), Rapid Equipping Force (REF), and Joint Improvised Explosive Device Defeat Organization (JIEDDO) are prime examples of partnering organizations that the RS JPO has established working agreements with to ensure the smooth transitioning of technology and products.

1.3.1 RDECOM, Academia, Industry

Given the RS JPO's close working relations with academia, industry partners and the RDECOM Labs, the RS JPO has been able to rapidly engage in modernizing current capabilities with advanced technology. Having the ability to reach out to the S&T communities with operational issues has allowed the RS JPO to quickly bring forth innovative technologies to the Warfighter. A recent example of this synergy is the development and integration of the Universal Antenna Mount (UAM) for the RG 31 Mk5E Route Clearance vehicle and the Joint Explosive Ordnance Disposal Rapid Response Vehicle (JERRV). The need for a capability to control robotic systems from the safety of armored vehicles was identified in JUONS 00333. The RS JPO worked with PM Assured Mobility Systems, CERDEC, and TARDEC to determine the best mounting location, type of mount, cable routing, and operator tie in points giving a full plug-and-play capability to the robotic operator. The upfront partnering of UAM contributing organizations allowed for the UAM to begin fielding in fewer than 12 months. In addition to collaborating for development work, the RS JPO also partners with RDECOM labs through the Small Business Initiative Research (SBIR) and Cooperative Research and Development Agreement (CRADA) processes to enhance and improve currently fielded robotic technology. Using the SBIR or CRADA process, labs will typically request the RS JPO to review and endorse robotic initiatives being pursued with industry to ensure they are aligned with the Warfighters current needs. The RS JPO assists by providing robotic test assets, assisting in the research, and participating in the final technology reviews.

1.3.2 Rapid Equipping Force (REF) and Joint Improvised Explosive Device Defeat Organization (JIEDDO)

Along with partnering with development organizations, the RS JPO routinely partners with the REF and JIEDDO who function as rapid acquisition organizations specializing in providing materiel solutions to niche problems. Given that the majority of the fielded robotic systems have been fielded under a rapid acquisitions structure, the established working relationship between JIEDDO and REF has been well defined. The RS JPO is currently working with both organizations on several initiatives aimed at filling operational gaps being experienced by the Warfighter in OEF. Efforts such as a light weight reconnaissance robot and a culvert exploring robot are currently underway, and are leveraging the talents and experience from each organizations core competency.

1.3.3 RS JPO/Army Capabilities Integration Center (ARCIC) Partnership

The RS JPO works with ARCIC and ASA(ALT) as a partner in cradle-to-grave material solution development to ensure the timely release of products to the Warfighter. Our close ties with TRADOC's CoEs have allowed the RS JPO to be closely involved with the development of emerging requirement documents. As a result, lessons learned from the RS JPO's feedback from the field are integrated into requirements documents as they are being developed. Our participation in the Joint Ground Robotics Integration Team (JGRIT) allowed us to ensure that key interoperability requirements and future growth needs were cemented into the Unmanned Systems ICD. Having these requirements within the ICD will provide us the "hooks" to mature technology such as modular payloads, modular radios and a common controller. The Project Manager's (PMs) insight into technology maturation and potential materiel solutions for required capabilities drive a cost as an independent variable (CAIV) trade study process to articulate to the Warfighter what capability can be delivered at what cost.

1.3.4 The Joint Ground Robotics Integration Team

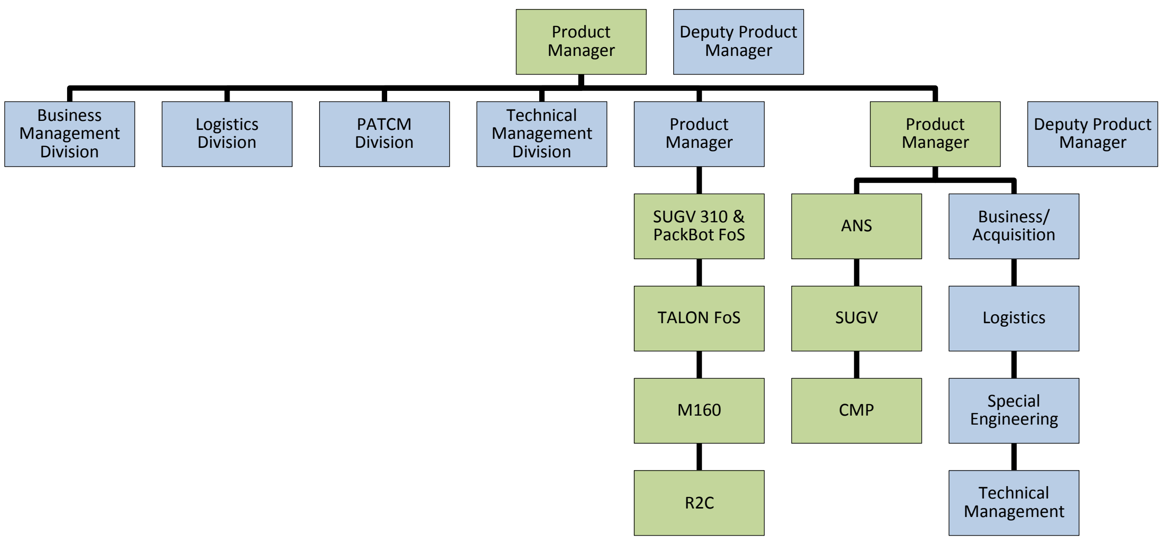
An important event that significantly affected Unmanned Systems was the designation of the MCoE as the TRADOC lead for ground robotics (21 July 2009). As a result, the JGRIT was established to synchronize ground robotic development and integration efforts across the DoD. The JGRIT consists of members from TRADOC's CoEs, Army labs, Marine Corps Warfighter Lab (MCWL), and other DoD components. These core members assembled and authored the Unmanned Systems ICD (November 2009). The overarching Unmanned System ICD provides a unifying strategy for the development and employment of interoperable unmanned systems across all domains and every Warfighting function. This ICD defines a required set of capabilities, to be further defined within subsequent CDD or CPDs. The goal of the JGRIT is to field technologically advanced unmanned systems. The RS JPO plays a vital role in the development and integration of such technologies.

Given the common goal of smoothing the technology transition, TRADOC, the CoEs, MCWL, RS JPO, labs, and partners are now better aligned to accomplish the goal of developing and integrating advancing technologies onto UGSs. Upcoming experiments, such as the Army Expeditionary Warfighting Experiment, are focused on emerging technologies and concepts. These experiments are primarily network-enabled and provide a venue for aggressive experimentation. The output of these experiments feed requirement documents and the development of tactics, techniques and procedures (TTPs). By linking these experiments to critical programs and the modernization plan, the RS JPO, TRADOC, and the U.S. Marine Corps Combat Development Command (MCCDC) will have the ability to enhance program objectives and quickly get equipment to the hands of the Warfighters. Other experiments may be conducted in a similar manner, or through modeling and simulation (M&S), in order to support current and future developments, as well as provide insights and influence changes to various development documents.

1.4 RS JPO Organizational Structure

The RS JPO Project Manager (PM) and Deputy Project Manager (DPM) are currently supported by two Product Managers (PdMs) and four Divisions, as reflected in Figure 1, RS JPO Structure. The PdMs are responsible for managing the current fleet as well as emerging programs. The PdMs are supported by Assistant Project Managers (APMs) and Product Integrators (PIs) who manage the day-to-day activities associated with the various robotic platforms. The functional divisions within the RS JPO provide support to the PdMs and APMs in the areas of Business Management, Logistics, Technology, and Product Assurance, Test and Configuration Management (PATCM). Outreach support is provided by RS JPO Liaison Officers, which have been strategically placed at the CoEs and various other key organizations.

Figure 1. RS JPO Structure



Recently, as a result of the transition plan signed by PEO GCS and PEO-I and approved by the Army Acquisition Executive, the RS JPO organization has grown to include the former UGS portion of the PEO-I portfolio. The APMs for the ANS, SUGV and CMP are currently located in Huntsville, Alabama and have been fully integrated into the RS JPO organizational structure as of 5 January 2011.

1.4.1 APM and PI Roles and Responsibilities

The RS JPO recently restructured internal APM assignments. The APMs moved from mission specific roles to a product based alignment. The new APM roles were initiated as of 1 October 2010. There are currently seven APMs and one PI on staff supporting two PdMs, as shown in Figure 1.

The APMs/PIs are accountable for meeting project/system cost, schedule and performance objectives. With the support of cross-functional integrated product teams (IPTs), APMs are responsible for project scope, risk management, budget, achievement of requirements, resource support, and resolving and mitigating issues that could threaten the effective achievement of project objectives. As managers of the RS JPO's programs, APMs/PIs are the principle interface with the user community and acquisition stakeholders. The APMs/PIs management and execution strategy are provided in greater details in Appendix-A, RS JPO Systems/Programs Portfolio. The following paragraphs provide a basic system description of the APM/PI programs.

1.4.1.1 APM – M160 APMCS

The M160 APMCS is a component system in the Area Clearance Family of Systems (FoS) that was developed to support the U.S. Army Area Clearance Family of Systems CPD, approved by the Headquarters, Department of the Army (HQDA) Revision 1, 11 March 2010. The CPD establishes a need for an Area Clearance FoS to clear anti-personnel (AP) landmines from urban areas, fields, forests, unimproved roads, riverbanks, and muddy areas. The M160 is a legacy, contingency system which transitioned to a post-Milestone B, Acquisition Category (ACAT) III Non-developmental Item (NDI) program.

1.4.1.2 APM – PackBot Family of Systems

The PackBot Family of Systems are small robotic platforms designed to provide the Warfighter with standoff to inspect and clear suspicious objects during improvised explosive device (IED) sweeps. These systems generally include a remote controlled articulated arm with a gripper and a pan/tilt color surveillance camera.

1.4.1.3 APM – TALON Family of Systems

The TALON Family of Systems are medium robotic platforms designed to provide the Warfighter with standoff to inspect and clear suspicious objects during IED sweeps. These systems generally include a remote controlled articulated arm with a gripper and a pan/tilt color surveillance camera.

1.4.1.4 APM – Route Reconnaissance and Clearance (R2C) Robot Program

The R2C program fulfills the requirements of the U.S. Marine Corps (USMC) R2C FoS CPD dated 29 July 2009. The R2C capability set is a FoS that will provide standoff capability for identification and interrogation of enemy mines, IEDs, and obstacles along routes, in the Marine Air-Ground Task Force area of operations.

1.4.1.5 APM – MARCbot IV/IV-N

MARCbot IV is a low cost, wheeled reconnaissance robot designed to provide the Warfighter with a highly mobile pan/tilt color camera.

1.4.1.6 APM – Appliqué Kits

The Appliqué Kits are robotic systems that can be used to convert fielded and future manned systems into unmanned systems. These systems are envisioned as ‘kits’ that include all of the hardware (sensors, cables, actuators, control station, etc.) and software required to fully operate and monitor the selected vehicle remotely.

1.4.1.7 APM – Common Mobility Platform (CMP)

The CMP is a 3.5-ton unmanned ground vehicle comprised of a CMP (chassis) which can carry lethal Mission Equipment Packages (MEPs), Counter-Improvised Explosive Devices (C-IEDs) MEP and sensors to include the ANS. The CMP and its MEPs will provide the maneuver platoon with an armed unmanned capability, and the maneuver company with the capability to detect, mark, and report IED. The CMP is capable of tele-operation and semi-autonomous operation through the use of a remote controller. Semi-autonomous navigation will include wireless leader/follower and waypoint navigation.

1.4.1.8 APM – Small Unmanned Ground Vehicle (SUGV) – XM1216

The SUGV, designated as XM1216, is a lightweight, soldier-portable robot capable of conducting military operations in urban terrain, tunnels, sewers, and caves. The SUGV provides Situational Awareness/Situational Understanding (SA/SU) and Intelligence, Surveillance and Reconnaissance (ISR) to dismounted soldiers enabling the performance of manpower-intensive or high-risk functions without exposing soldiers directly to the hazard. The SUGV modular design allows multiple payloads to be integrated in a plug-and-play fashion.

1.4.1.9 APM – Autonomous Navigation System (ANS) – XM155

The ANS, designated as XM155, is the mission sensor and computational package that will be integrated on the CMP (or other chassis) to provide robotic semi-autonomous capability.

1.4.2 RS JPO Liaison Officers (LNOs)

Through the use of dedicated LNOs, the RS JPO works with and maintains close relationships with Marine Corps System Command (MCSC), TRADOC, JIEDDO, REF, MCCDC and the various CoEs. The RS JPO has placed LNOs in the aforementioned key organizations to act as facilitators for the RS JPO and the robotics community. The evolution of the LNO relationships has significantly enhanced technology development efforts, requirement development efforts, and the fielding of UGVs for the Warfighter. In addition to their individual taskings, the general roles and responsibilities of the LNOs are:

- Support the exploration of capability gaps
- Ascertain the extent to which Warfighter needs can be achieved by unmanned systems
- Execute acquisition planning and interagency coordination
- Provide strategic vision for out year program efforts
- Provide mission related subject matter expertise (SME) on the acquisition and management of robotic systems and the Joint Capabilities Integration and Development System (JCIDS) process
- Serve as the user representative at ground robotic working groups, IPTs, Interface Coordination Teams, experiments, demonstrations, source selections, user juries, etc.
- Aid in the development of Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel and Facilities (DOTMLPF) analyses for robotics, as well as the Concept of Operations (CONOPS) and TTP development efforts for robotic equipped units
- Aid in the management of other cost, schedule and performance challenges associated with robotic systems

The RS JPO’s Liaison officers and supported organizations which they support are identified in Figure 2.

Figure 2. LNO Activities

Liaison Officers are strategically placed in organizations where Unmanned Ground Vehicle Systems are underway

TRADOC – Ft. Monroe, VA
- Represents the User and PM in the development and maturation of the Army Unmanned Systems ICDs, CDDs and CPDs in the ground robotics focus area
- Supports TRADOC's initiative in establishment of the UGV Campaign Plan

MCCDC – USMC Base, Quantico, VA
- Serves as a link between the USMC and the Army's Unmanned Ground Systems Requirements Agencies
- Works closely with the MCWL
- Represents the USMC unmanned systems community in JGRIT and JGRE efforts

MCoE – Ft. Benning, GA
- Supports MCOE as the lead integrator for all plans, initiatives and developments required to field ground robotic capabilities
- Supports the development of materiel requirements for the Infantry Small Unit with a focus on the integration of affordable, small and lightweight robotics capabilities

CASCOM/SCoE – Ft. Lee, VA
- Assists in the coordination and development of logistics proponency (Transportation, Quartermaster, and Ordnance) application and logistics supportability and training implications for ground robotic systems

US Army SOC – Ft. Bragg, NC
- Supports USASOC's long-term goals and initiatives to integrate unmanned capability in the ARSOF
- Commander's three fundamental ARSOF lines of effort includes: Investment, Persistent Engagement, and Operations

III Corps/FORSCOM – Ft. Hood, TX
- Represents RS JPO in the collaborative effort with FORSCOM Counter-IED Integration Cell to introduce and train Warfighters in the use of UGVs as a part of their pre-deployment and home station training

JIEDDO – Crystal City, VA
- Supports JIEDDO lead in DoD efforts to defeat the IED through Counter-IED efforts
- Support JEDDO's plans and goals in the application of robotic appliqué kits to enhance mission capabilities of some operational unit tactical vehicles

REF – Ft. Belvoir, VA
- Assist the REF in rapid fielding of UGV COTS technologies with little or no modification to units in theater for assessment
- Assist the REF in the transitioning of appropriate robotic systems to the PMs for sustainment, support and fielding

MSCoE – Ft. Leonard Wood, MO
- Supports all robotic efforts and requirement documents for the Military Police, Engineer and Chemical Schools
- Manages the training and maintenance of robots utilized to train Soldiers in conducting operations to detect and neutralize hazards from a safe area

1.4.3 RS JPO Divisions

1.4.3.1 Business Management Division

The Business Management Office (BMO) provides budget, cost, financial execution, and procurement support to the RS JPO. The office is comprised of budget, cost, and contracting personnel. BMO also manages security, site visits, clearances, property (hand receipts), phones, and facility work orders. Funding is managed across several appropriations, and all funds coming in and going out of RS JPO are reviewed for accuracy and fiscal soundness. The continuing commitment of the BMO is to ensure that PM fiscal responsibility is executed in compliance with regulations, policy, and law. Other BMO responsibilities include the following:

- Program Objective Memorandum (POM) planning and tracking
- Preparation of obligation plans
- Preparation of budget exhibits (program and resources forms)
- Execution of funds
- Credit card oversight and approval
- Transportation oversight
- Defense Travel System funding approval and oversight
- Acquisition strategies and plans
- Contract oversight and liaison with the Acquisition Center
- Systems Engineering, Testing and Analysis support planning and oversight
- Annual Review of Management Internal Controls Plan
- Military Equipment Valuation
- Preparation of annual Weapon System Review briefing packages
- Support of Annual Program Reviews to the Milestone Decision Authority (MDA)

- Should/Will Cost reporting
- Assistance with the development and review of Milestone (MS) documents for financial, cost and budgetary information
- Track cost, schedule and performance objectives for APMs

The BMO budget personnel have a number of initiatives to improve the way we do business:

- Implemented travel process change to incorporate budget review of authorizations and vouchers, which resulted in a reduction in the number of errors that cost both the government and the traveler money and hardship. This procedural change allowed the PM to better track, report and forecast future travel costs.
- Streamlined shipping procedures. In FY11, the RS JPO started utilizing Department of the Army (DA) centrally funded Transportation Account Code (TAC) codes for all Second Destination Transportation (SDT) shipments resulting in a reduction of required PM funding as well as adherence to DA centralized funding practices.
- Instituted automatic routing of credit card orders through the Budget Team prior to committing/obligating funds. This streamlined budget review of all credit card orders and ensured that the correct Element of Resource (EOR) and Job Order Number (JON) were used and funded against the correct appropriation.

The Business Management Division will be facing new challenges in the next several years:

New Financial Systems
In January 2012, the General Fund Enterprise Business System will replace legacy Army financial systems. Plans are underway to train RS JPO personnel for a smooth transition.

The RS JPO was chartered in a memo by the Army Acquisition Executive as the centralized PM with the responsibility for the acquisition life-cycle, to include budgetary and POM execution, for unmanned ground systems. As a result, the RS JPO may accept a POM for Marine Corps funding; therefore, BMO staff are learning the USMC funding systems and POM process to accept and execute the funding.

Overseas Contingency Operations (OCO) Funding Drawdown
With OND drawdown efforts underway, the shift of funding to cover the increased costs of Robotics in Afghanistan must be executed. As Operations and Maintenance, Army (OMA) OCO funding becomes more scarce, RS JPO will have to transition the funding from OCO, then to “Base dollars” then to POM for sustainment costs.

DoD Efficiency/Affordability Initiatives
OSD launched a comprehensive effort to reduce the DoD’s overhead expenditures. The goal was, and is, to sustain the U.S. military’s size and strength over the long-term by reinvesting those efficiency savings in force structure and other key combat capabilities.

The BMO’s Acquisition Team will be implementing the Defense Acquisition Executive’s (DAE) Better Buying Power initiatives in all current and future efforts. Specifically, the BMO will promote real competition at all stages of the contracting process by minimizing the use of sole-source contracts, ensuring that requirements are properly documented and limiting the period of performance in non-competitive actions.

The DAE also targets affordability and controls cost growth through several efficiency initiatives. All programs were directed to establish “Should Cost” estimates for ACAT I, II, and III PORs. In addition, all PORs must have annual portfolio Program Reviews with the MDA.

Research, Development, Test & Evaluation (RDT&E) requirements
Currently there is no RDT&E funding line in the RS JPO, except for programs that recently transitioned from PEO-I. To fulfill the Congressional goal that one third of ground vehicles would be Robotic by 2015, funding for new RDT&E efforts is necessary. Robotic integration, technology advancements, interoperability, and testing are some of the efforts that require RDT&E funding.

New Robotic Programs
The RS JPO is currently working on establishing new PORs. Life cycle cost estimates, business case analyses and program office estimates are but a few of the required documents that must be developed as part of the Milestone Decision process. With these additional functions, RS JPO must identify and manage the growth of BMO personnel due to new missions such as R2C, S-MET, Appliqué, SUGV, and other future robotic requirements.

1.4.3.2 Logistics Division
The RS JPO logistics mission is to develop the proper logistic support strategies and provide sustainment for all fielded robotic systems whether in the continental United States (CONUS) or outside the continental United States (OCONUS). All sustainment logistic activities are managed by the RS JPO's Joint Robotics Repair Fielding Activity (JRRF). Army Materiel Command was tasked by HQDA for accountability and sustainment for all Theater Provided Equipment (TPE) for Joint Forces operating in Operation Iraqi Freedom (OIF) and OEF from July 2004 until resolved. As a result, the RS JPO/JRRF provides sustainment for all unmanned ground vehicles in the U.S. Central Command (CENTCOM) area of operations as well as CONUS training centers. Alternative methods of robotic support being explored include outsourcing of parts repairs to a non-original equipment manufacturer (OEM) contractor. The JRRF will continue to develop and refine repair processes and serve as the center for technician support for all detachments and training sites. For PORs, specific requirements for meeting Warfighter support performance, and sustainment requirements for the life of the system are found in AR 700-127, Integrated Logistics Support. With the anticipated growth of PORs within RS JPO, the acquisition of future systems must comply with the Total Life Cycle Sustainment Management process to ensure reliability, availability, and maintainability.

In order to provide forward support to UGVs, the RS JPO operates multiple robotic maintenance facilities around the world; including Joint Robotic Repair Detachments (JRRD) in Iraq and Afghanistan. The JRRDs were established to fill a maintenance capability gap created by the acquisition and employment of COTS robotic systems in both theaters. These organizations operate outside of the normal Army force structure to provide pre-deployment training, issue, and repair of robotic equipment. The facilities are staffed with a mix of active duty service members, reservists and contractors.

The challenge with the fielded robotic systems is that they are not managed and maintained like other typical platforms in the Army inventory. The operational urgency of need and uniqueness of these platforms required a non-standard approach to integrating these technologies into the active force. The RS JPO sustainment strategy for the fielded robots includes improvements and upgrades to current platforms with the latest technologies. Due to the drawdown from OND, RS JPO is developing a responsible drawdown strategy that includes long term storage and/or disposition of robotic systems.

The Army lacks adequate maintenance doctrine to address the unique technologies and other sustainment issues associated with robotic systems. Robotic maintenance doctrine has not been delineated in Army doctrine. Only a small group of operators and personnel within the Army, involved with the development, testing, and acquisition of robotics technologies, are well acquainted and/or understand their impact. The RS JPO is initiating efforts to improve the process of robotic data maintenance, collection, and analysis, decreasing top sustainment cost drivers, and outsourcing repairable parts. By improving the way data is collected, analyzed and input into the Cataloging Ordering Logistics Tracking System (COLTS), the JRRF hopes to increase mean time between failures and identify systemic parts problems which will reduce the number of parts consumed. The RS JPO is currently working with the OEMs to analyze the repair versus replace cost of our top sustainment parts cost drivers to determine if the contractual Return Maintenance Actions are being utilized efficiently.

Training

Currently, the Army trains most of the skills required to support robotic technologies. However, it is neither from a systems approach nor is there a Military Occupational Specialty (MOS) identified or designated to perform this function. The RS JPO logistics training division provides training on robotic platforms associated with COTS and PORs. This includes but is not limited to: conducting operational assessments; conducting COTS and POR system operator training; and supporting doctrine and tactics training, mobile training teams (MTT) and new equipment training (NET). Training is currently provided from Ft. Leonard Wood, Missouri and the JRRF at Selfridge Air National Guard Base (SANGB), Michigan.

United States Army Forces Command (FORSCOM)

The RS JPO is working with FORSCOM to address the robotic training capability gap. This effort is still in its infancy. FORSCOM requires robotic capabilities at multiple FORSCOM home stations to assist units in the planning and execution of individual and collective robotics training as part of the “Defeat the Device” Line of Effort. This period of persistent conflict has stretched operational forces, creating a gap in the ability of combat units to plan and execute effective robotics focused C-IED training. This gap is exacerbated by the diversity of threats in the operational environment, the introduction of multiple non-standard capabilities, key personnel turnover, minimal manning during the reset phase of Army Force Generation (ARFORGEN) process and short dwell time limiting individual and collective training opportunities. The initiative is being applied to Home Station Training Lanes at designated FORSCOM installations. RS JPO, in cooperation with FORSCOM, has selected Ft. Hood as a Proof of Concept to implement this initiative. The basis for this initiative is to train the Warfighter prior to going to the Combat Training Centers. The more exposure the Warfighter gets on the robotic systems, the better they will understand the functionality, capabilities of the platforms, and how execution of missions using robotic platforms are performed.

In order to be successful in managing new robotic technologies, RS JPO must understand new system impacts and be prepared to support units employing robotic technologies in the near and long term. RS JPO will posture itself to incorporate UGVs (both COTS and POR) into standard Army Logistic Information Systems. To further support these efforts, the RS JPO must become part of the mandatory pre-deployment requirement for training robotic operators, and establish courses to work in conjunction with a unit’s ARFORGEN schedule. One alternative being explored is to establish a robotic school with TRADOC that provides trained operators on multiple platforms within one course. This course would fill the gap between FORSCOM and TRADOC, thus allowing FORSCOM to tap into a TRADOC sanctioned course that would provide them with trained operators to use robotic systems at their Home Station Training Lanes and in their ARFORGEN schedule. This would also help to reduce the logistical footprint required to maintain MTTs and equipment. As systems evolve into PORs, this course would establish the basis of the operator New Equipment Training Team.

1.4.3.3 Product Assurance, Test and Configuration Management (PATCM) Division

The mission of the PATCM Division, within the RS JPO, is to provide testing, evaluation, quality assurance, and configuration leadership to all phases of the robotic systems development, integration and deployment. PATCM's short term strategy is to continue supporting Rapid Acquisition Initiatives (RAIs) of COTS systems, such as TALON and PackBot, while supporting development of future robotic programs.

Continued support will be provided to future RAI and fleet modernization to ensure the systems are fully tested to verify safety and qualified to meet performance and reliability requirements as set forth in the System Performance Specifications. For current RAI robotic systems identified as having long term sustainment requirements (beyond current theater use), PATCM will work with the Army Test and Evaluation Command (ATEC) to develop the test and evaluation processes to support the conversion of COTS systems/PORs.

Through cooperation with ATEC, the RS JPO (PATCM) will develop strategies for the testing and evaluation of future UGVs. The range of autonomous functions will span from self-righting and return-home capabilities to fully completing a mission without human interface. Autonomous capabilities have little testing precedence and, as a result, practices and procedures on testing will need to be defined and formalized. Several efforts are currently underway to facilitate planning between RS JPO and ATEC to address issues and develop overarching test strategies.

Maturing quality metrics is another goal for PATCM. This is accomplished through a two-step process. Initial steps will involve defining key metrics, improving data recording accuracy, validating data, and reconciling internal databases with other DoD databases (COLTS, Product Quality Deficiency Report [PQDR], Product Deficiency Reporting and Evaluation Program [PDREP], Acceptance Database, etc.). Future efforts will include developing automated reporting capabilities to accurately report performance metrics of the various robotic platforms so that resources can be properly focused on key quality improvement opportunities.

Lean Six Sigma initiatives are underway within the RS JPO and PATCM will be supporting this effort by incorporating the projects with other process improvement initiatives. An initiative to better catalogue and control milestone documentation is underway within the RS JPO. It was volunteered to be the pilot program for PEO GCS with output from this effort standardizing documentation requirements throughout PEO GCS.

PATCM has recognized the need to provide consistent quality guidance in new contracting efforts. Because the preponderance of the products currently managed by the RS JPO are either COTS or NDI, it is important that our contracts provide added flexibility and increased accountability. As a direct result of lessons learned, future robotic contracts will be more quality focused. Standard contract language has been developed and will continue to be updated. Contract language will address, where appropriate:

- quality management systems
- corrective and preventive action
- configuration management
- test and evaluation
- inspection and acceptance
- warranty

Process Excellence Program (PEP)

The PEP is being developed within the RS JPO to identify, control, measure, and improve processes important to the success of the entire RS JPO. The PEP will build upon quality improvement initiatives already in place (e.g., Lean Six Sigma, Command Maintenance Management Inspection [CMMI]) and complement PEO GCS efforts through close coordination and information exchange. The PEP will add structure to the organization to help define and incorporate best practices, lessons learned and allows the organization to make decisions based on the best available data.

PATCM will facilitate this initiative by establishing an implementation plan, providing training, leading the Overarching Integrated Product Team, and providing regular updates to management. Additional Integrated Product Teams will be formed to address the key processes defined by management. At some point, each member of the organization will provide input into the program. PATCM will facilitate all the process teams to ensure the success of the program. These efforts will culminate in a defined repository for process documentation and an internal audit verifying compliance to the program.

The plan incorporates a two-phase approach. Phase 1includeds completed implementation for both the Warren and Selfridge operations by the end of the first quarter of FY12. Phase 2 will be completed by the end of FY12 and will include the remainder of the RS JPO operations: CONUS and OCONUS JRRDs, LNOs, and Huntsville. This is a highly aggressive schedule that requires dedicated resources.

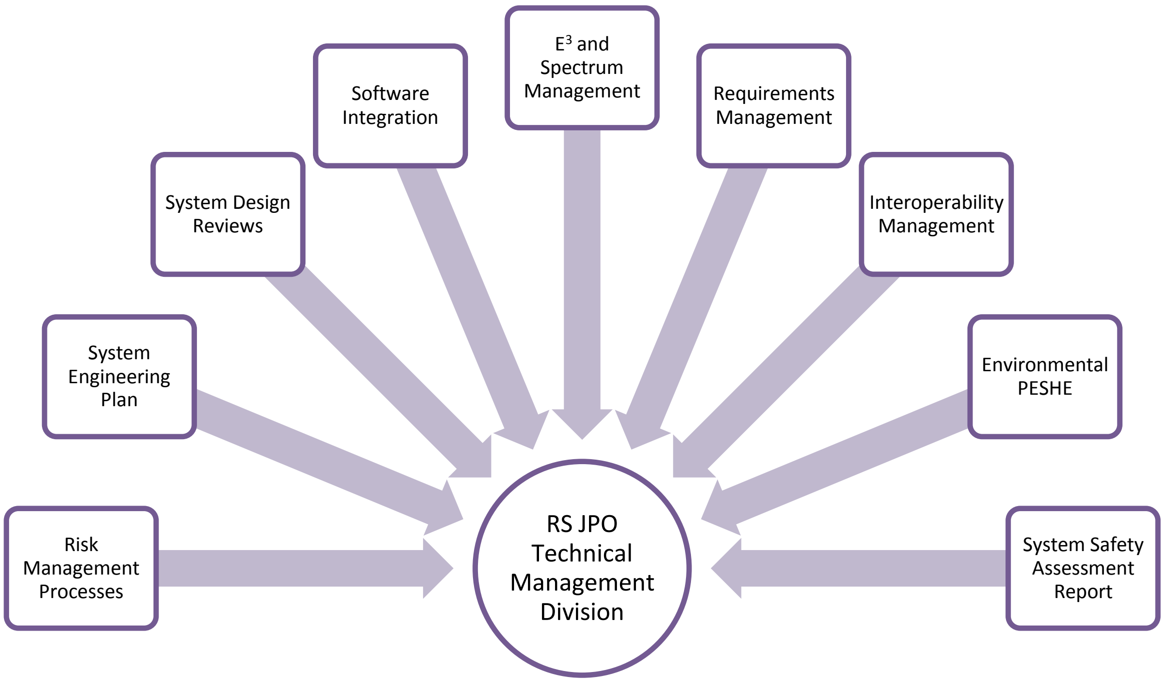
PATCM Long Term Strategy
PATCM's long-term strategy aligns with the Army Campaign Plan for Unmanned Ground Vehicles. The campaign plan requires future UGVs capabilities to include a net-centric requirement, varying degree of autonomy, and potentially weaponized platforms. Therefore, future test and evaluation will need to take into account net-centric systems, increased levels of autonomy, and armed systems. This will pose unique requirements for evaluation criteria, test methodology, and test site layout resulting in increased up-front test planning efforts. M&S will play a critical role in evaluating autonomous vehicles; physical models alone cannot provide the depth of evaluation required. The software-intensive systems will require multiple iterations of many different scenarios to a given requirement. The only economically feasible way of accomplishing this is through M&S. Models will be required to have a high degree of confidence before a robust simulation program is conducted. This will require a high level of collaboration with ATEC to ensure models used will fulfill evaluation needs through validation and verification. In addition to stand-alone robotic systems, the testing and evaluation of hybrid systems (e.g., remote operation, supervised and fully autonomous appliqué kits on existing vehicle platforms) will pose unique inter- and intra program office and joint service considerations for testing that will need to be addressed.

The PATCM goal for quality assurance is to have a robust quality metric system in place in three to five years that will continue to evolve. This system will provide a complete cradle-to-grave quality metric tracking history.

1.4.3.4 Technical Management Division
The mission of the RS JPO Technical Management (Tech Mgt) Division is to provide system engineering oversight, resources, processes, and tools to execute system engineering tasks and activities that enable the delivery of UGS capabilities which meet the Warfighter's operational needs through the use of specified performance requirements. Tech Mgt utilizes a disciplined system engineering approach to manage the engineering, design, development, integration, production and sustainment of UGVs. The fundamental goal of RS JPO's Tech Mgt Division is to transform the Warfighter's written and validated needs into sustainable products that meet those needs, optimized in terms of affordable operational effectiveness within the bounds of the cost and schedule constraints of each program.

To assist in the task of transforming the Warfighter requirements into materiel solutions the Tech Mgt Division uses several resources and tools, as illustrated in Figure 3 Technical Management Responsibilities. The breadth and depth of knowledge in the Tech Mgt Division is utilized to supply expertise to the APMs and their IPTs. Tech Mgt engineers support IPTs in the areas of requirements transformation, electromagnetic environmental effects (E^3) and spectrum management, software integration, interoperability, environmental and safety, developing systems engineering plans (SEPs) and chairing technical reviews. Risk management is a key element to the IPTs to both characterize and manage technical risks. Tech Mgt utilizes the PEO GCS standardized Risk Recon Tool and Risk Review Boards to support risk management in all program acquisitions. Enabling and enhancing the interoperability and modularity of all operational, functional, and physical interfaces is also a key focus area for Tech Mgt engineers.

Figure 3. Technical Management Responsibilities



S&T Collaboration is a fundamental area of Tech Mgt. Currently, Tech Mgt is working with the Army S&T community to identify near and far term technology capabilities to address Warfighter needs in robotic systems. These needs, which are identified in Chapter 3 Table 19, will be utilized to influence development efforts across the RS JPO portfolio. This collaborative environment will ensure that the Warfighter needs are being addressed in a timely and affordable manner. In the future, Technology Transition Agreements (TTAs) with the S&T community will establish agreements on how and what technology will be transitioned to the joint Warfighter robotic community. Future close collaboration is needed with all S&T areas of all the Services to ensure the Warfighter is receiving the best possible solution as efficiently as possible.

Safety

The near term task of addressing and overcoming safety concerns stemming from unmanned ground vehicles on the battlefield is something Tech Mgt (and the RS JPO as a whole) takes very seriously. Tech Mgt is focusing its efforts in this area by participating in safety working groups for autonomous technology where concerns from the unmanned system community at large are discussed and documented. Our short term strategy is to collect the safety concerns and solutions used to offset the risk posed in order to build a knowledge base of what approaches are effective. Empowered with this array of knowledge, Tech Mgt can incorporate requirements into materiel solutions for technologies that have been demonstrated to reduce safety concerns. A future evolution of the safety concerns with autonomy will be the integration of weapon systems which will be handled in much the same manner as described above.

Software

Software safety management and software integration are critical areas of the Tech Mgt system engineering process. Near term goals in this area include:

- Require performance specifications to include language to ensure OEMs are utilizing adequate Software Quality Assurance (SQA) processes
- Ensure Software Safety Critical items are documented in the OEM's Safety Assessment Reports
- Establish software system safety working groups for all POR systems

Far term goals include:

- Include Software System Safety analyses early in the program life cycles
- Include requirement for OEMs to be CMMI Level III or equivalent in all performance specifications
- Require a Software Development Plan for all software being developed for RS JPO

E^3 and Spectrum

The management of E^3 and Spectrum is a critical piece to the wireless operation of UGVs. Tech Mgt is responsible for defining the radio equipment attributes of UGVs based on program requirements. COTS radios are primarily used on UGVs due to the high data rate needed to support full motion video and avoid latency.

Radio equipment must be certified by Army Spectrum Management Office (ASMO) by submitting a DD-1494 form that the RS JPO sponsors on behalf of radio vendors. This is to make sure the equipment operates in appropriate, allocated frequency bands and operates within the parameters established by national and international regulations. Once the radio is certified by ASMO the RS JPO can then request frequency assignments from the Army Frequency Management Office.

Due to the inconsistency of radio spectrum usage from one nation to another and reallocation of spectrum by regulators for non-military use, radios used on UGVs need to be flexible. Recent advances in radio technology such as Software Defined Radios (SDRs) have improved the flexibility of radio systems by supporting wide or multiple frequency bands. Also internet protocol (IP) addressable radios will allow communication systems to be swapped in/out of UGVs to adapt to appropriate frequency bands.

In the near term, Tech Mgt intends to improve the RS JPO's ability to field spectrum supportable radios with continually improved performance by developing a closer relationship with the RDECOM Communications-Electronic Research, Development and Engineering Center (CERDEC). The RS JPO can leverage CERDEC's expertise in terms of communications modeling and resident knowledge.

In the long term, the RS JPO's Interoperability Effort (discussed in depth in Chapter 3) is developing a Communications Interoperability Profile (IOP). This document will include performance specifications in terms of usable frequency bands, physical connection requirements for the ability to quickly change out different radios, common messaging requirements for the selection of frequency channels and radio status messages (i.e., signal to noise ratio, power output level, etc.), and common waveform requirements. As the communications and other IOP efforts progress, the intent for the RS JPO will be to enable greatly enhanced capabilities and reduce sustainment costs through the use of highly interoperable and modular systems. This will enable modular plug-and-play payloads, interoperability between ground and air unmanned systems, connection of ground robots into the tactical network, sharing of intelligence information to distributed users, control of multiple assets, and several other advanced Warfighting capabilities

Modeling and Simulation Management

Requirements analysis and management is key to ensuring that the system design reflects the requirements for all life cycle system elements including hardware, software and environmental. In the near term, Tech Mgt intends to leverage M&S tools to make better technical decisions and avoid spending time and resources on physical analysis when appropriate. The Tank and Automotive Research, Development and Engineering Command (TARDEC) is developing a Robotic System Integration Lab (RSIL) and Virtual System Integration Lab (VSIL) which will be leveraged for M&S of integrated robot solutions using simulated radios in simulated operational environments. The RS JPO will continue feeding their M&S tool requirements to TARDEC and will collaborate with them as the solutions are identified and implemented.

In the long term, the Tech Mgt Division will increase the use of a variety of M&S tools for different purposes. The TARDEC RSIL/VSIL construct will be used to assess the IOPs' abilities to provide real interoperable solutions, as well as to assess different commercial systems' conformance to those IOPs. The capabilities of TARDEC's Concepts, Analysis, Simulation and System Integration group will be utilized for assessing the realism of requirements and to aid in the various trade studies needed by Tech Mgt systems engineers. These may include powertrain M&S, system architecture modeling, structural analysis, survivability analysis, and thermal modeling, and can be used to generate confidence in the RS JPO's ability to successfully deliver products on time and on schedule that meet Warfighter requirements. The M&S capabilities of other S&T labs within RDECOM and the other Services will be utilized as well for other areas of expertise.

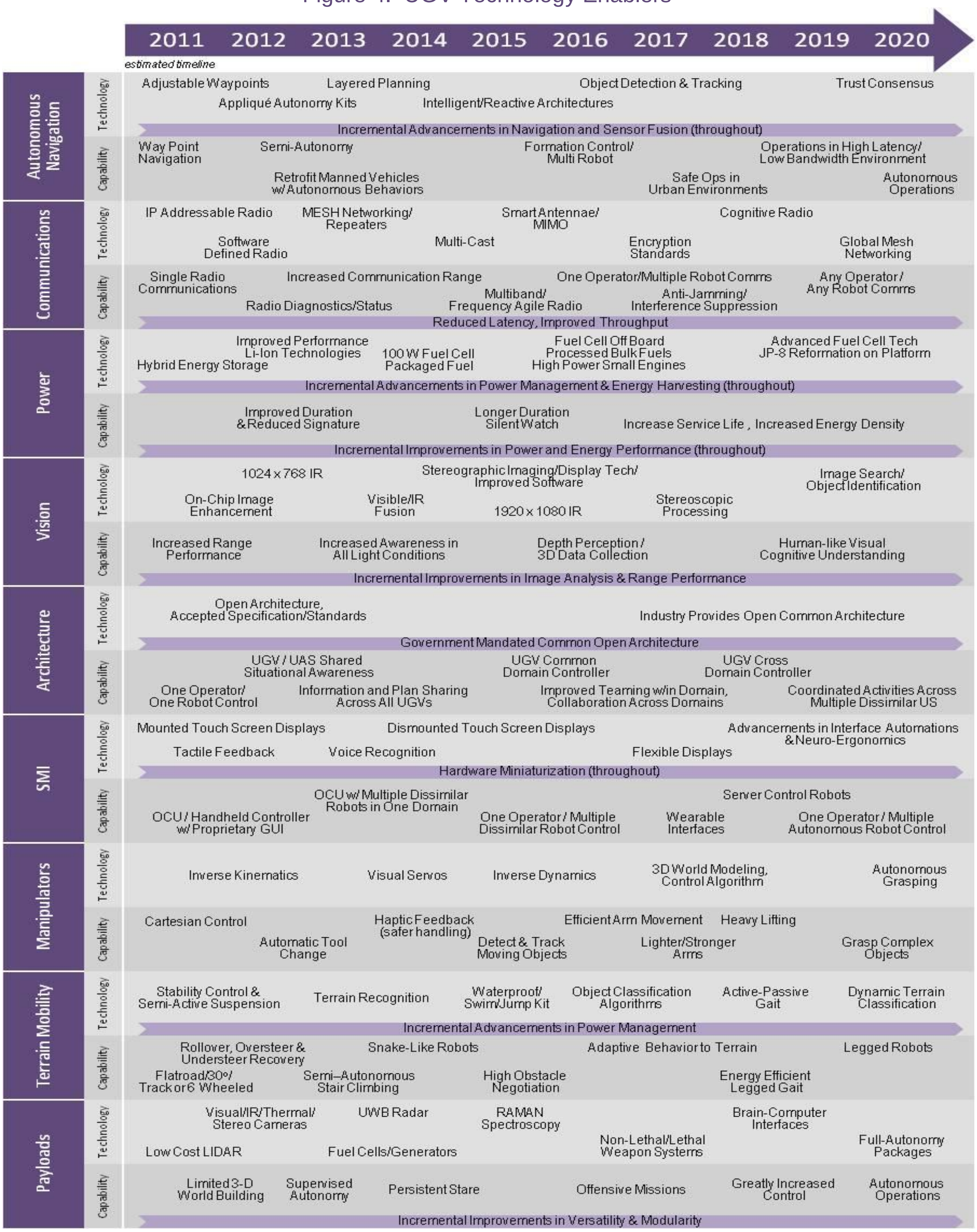
In support of the growing demand placed on increasing unmanned capabilities, a robust system engineering effort will be needed. Tech Mgt will continue to work towards the development of interoperability standards using empowered WIPTs that include representation from both government and industry. This government/industry WIPT approach has been successful in fostering a collaborative approach to the development of interoperability standards that are of mutual benefit to both government and industry.

Chapter 2: Technology Enablers/Road Ahead

2.0 Introduction

The RS JPO understands that innovation and technology will impact unmanned ground systems and may enhance the Warfighters ability to survive and adapt to the changing battlefield. The RS JPO, S&T labs, industry, and academia are continuing to work on technology advancements to enhance ground robotic capabilities.

Figure 4. UGV Technology Enablers



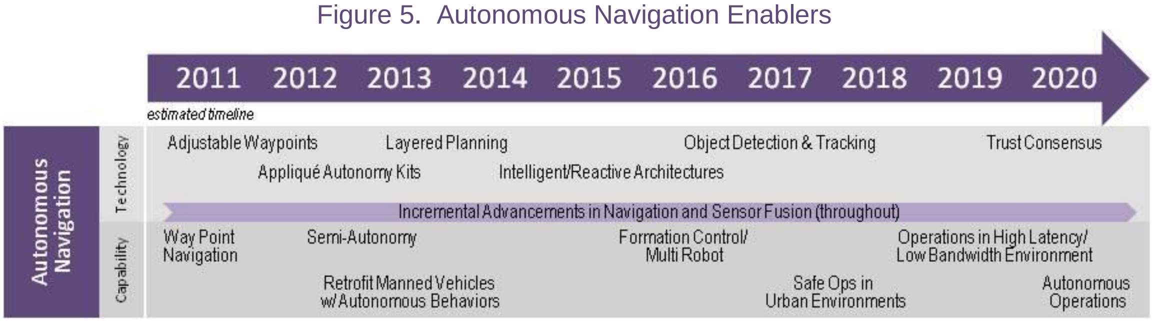
By working with Army Technology Objectives (ATO) sponsors, the RS JPO and its partner labs are aligning the S&T portfolios to the Warfighter's needs. Small businesses also play a role by working with the labs, which provide linkages and insight to upcoming technology initiatives. These efforts are the main focus of the SBIR program, where small businesses have access to government resources to conduct basic and advanced research. In addition to ATOs and SBIRs, the RS JPO hosts IPTs with a focus on standardization and Interoperability. Through these processes, the top technology enablers for Unmanned Ground Systems are identified. The top nine UGV technology enablers are:

- Autonomous Navigation
- Communication
- Power
- Vision
- Architecture
- Soldier Machine Interface
- Manipulation
- Terrain Mobility
- Payloads

The following paragraphs provide a top level discussion and a development forecast for each of the nine technology enablers. By developing, procuring, integrating and fielding unmanned ground systems, the RS JPO encourages and focuses further developments of these technologies and enhancements. This list of enabling technology is not an exhaustive list, but rather offers an illustration of the current technology and a glimpse of future capabilities for the Warfighter.

2.1 Autonomous Navigation

Figure 5. Autonomous Navigation Enablers



Description

Autonomous robots conduct tasks in unstructured environments without continuous guidance from an operator. Autonomy reduces operator workload and increases performance when communication is limited or unreliable. Object Recognition and Intelligent Navigation technologies are required to realize autonomous behaviors. These technology enablers must effectively satisfy the following capabilities:

Table 1. Autonomous Navigation Capability Needs

Object Recognition	Intelligent Navigation
Recognize combatants/non-combatants	Avoid static and dynamic obstacles
Recognize other living entities	Predict motion of dynamic objects
Recognize vehicles, roads, paths, and markers	Obey traffic regulations as appropriate

Several standards exist to define various levels of autonomy. The National Institute of Standards and Technology maintains the Autonomy Levels for Unmanned Systems Standard, which contains levels from Remote Control to Full Autonomy. A UGV may operate with various levels of autonomy based on task difficulty, environmental complexity, or required operational tempo (OPTEMPO).

Status

Autonomous Navigation is a subject of extensive research and development within both Government and Industry. Since 2009, the following activities have led to substantial breakthroughs in this technology:

Table 2. Autonomous Navigation Advancements

Major Activity	Type	Result
DARPA Challenges	Demonstration	Demonstrated long-distance autonomous waypoint following, obstacle detection and avoidance, and robotic platform endurance
MAGIC	Demonstration	Demonstrated autonomous coordination and teaming among multiple robots in operationally relevant urban scenarios
ARL Robotics CTA	Investigation	Investigated perception and intelligence for large autonomous robots
ARL MAST CTA	Investigation	Investigated autonomous air-ground teaming between small robots
CAST	Program	Matured autonomous leader-follower technologies in convoys
NAUS ATO	Program	Matured autonomous formation control and UGV self-security
SOURCE ATO	Program	Matures technologies that enable autonomous UGVs to safely operate within urban environments among humans, animals, and vehicles
AEODRS	Program	Matures autonomous navigation for Navy EOD robots
ACS, RIK, ROS, 4D/RCS	System	A set of intelligent architectures for small-robot navigation
ANS	System	A perception and control system for large UGV Programs of Record
AMDS	System	A set of payload modules that enable small autonomous robots to find, mark, and neutralize explosive devices

Industry has also demonstrated applications of autonomous driving over thousands of miles of highway, and during open-pit mining operations. Automobiles have also commercialized several autonomous driving aids such as stability control, adaptive cruise control, and self-parking. Many autonomous navigation technologies will likely mature through advancements in semi-autonomous behavior within the automotive industry.

Future Trends

Safety is a critical concern and one of the most significant issues autonomous vehicles must overcome before they can be widely accepted and fielded. Currently, autonomous vehicles operate within restricted areas in which all operators are fully aware of the vehicles' limitations. Before operation in crowded urban environments can happen, advancements in navigation and sensor fusion algorithms are needed to allow robots to distinguish humans from other objects, negotiate complex terrain, and operate. Programs such as Supervised Autonomy to Neutralize and Detect IEDs (SANDI) and Squad Mission Support System (SMSS) that are being used in the area of responsibility, are helping to evolve current technology into robust proven systems.

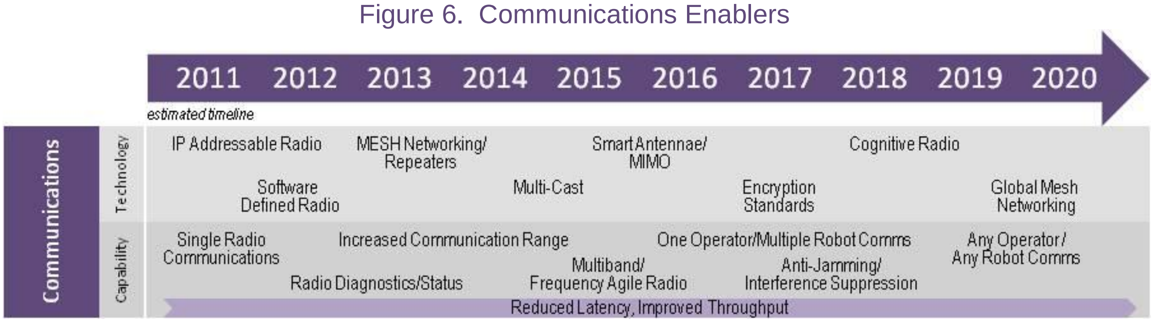
Obstacle detection is a significant capability required in order to enable the next level of advancement in Autonomous Navigation. Advancements in robotic perception and understanding enable the development of obstacle detection; and *a priori* knowledge via maps or object templates. In the long-term, such capabilities will be applied toward obstacles.

Manned vehicle platforms are prime candidates for semi-autonomous behaviors integration because of their proven reliability and prevalence in the field. In the near-term, the S&T Community are expected to accelerate efforts to develop technologies that retrofit manned vehicles with appliqué autonomy kits. The Autonomous Mobility Appliqué System (AMAS) Program is a prime candidate for such investments as it tackles appliqué autonomy at both the algorithmic and architectural levels.

In the near-term, the S&T Community should continue investments in odometry and decision support technologies to enable waypoint navigation. The S&T Community should continue to integrate semi-autonomous behaviors on small robots; and it should continue to integrate supervised autonomous behaviors onto large platforms.

2.2 Communications

Figure 6. Communications Enablers



Description

The communications link is a subsystem of the UGV that passes data between the operator control unit (OCU) and the robot processor. This is accomplished via wireless radio link or a tether. Tether communications is accomplished either over a fiber-optic cable or twisted wire, with the former being more common for UGVs as it is less susceptible to Radio Frequency (RF) jammed environments. Tether communications is usually employed when the RF environment is harsh or if transmission of RF signals is not desired.

Both communications systems provide the necessary electronics and logical interface to pass the data between the OCU and the robot processor. Current UGV systems use a closed loop link that does not share information with other networks. The OCU transmits commands and audio to the robot while the robot transmits status messages, video, and audio. The importance of this communication link cannot be over emphasized as the operator must maintain control of the robot at all times. Loss of the communications link will cause the robot to cease operations and could force the operator to be exposed to dangerous situations to re-establish robotic communications. Future autonomous capabilities, such as return to home or safe location, may alleviate concerns associated with the loss of communications.

Until recently, wireless radio communications for UGVs typically utilized three distinct radios to provide the following capabilities:

Table 3. Communications Capability Needs

Radio Capability	Description
Data Transmission	Transmits control signals from Operator to UGV
Video Transmission	Transmits analog video from UGV to Operator
Emergency Stop	Transmits signal to disable UGV

The use of separate radios to support different communications adds a level of complexity to the system and affects the size, weight and power requirements. By digitizing, encoding the video, and combining the voice and data over a single data stream, information can be transmitted over a single radio channel; simplifying the wireless communications. Radio technologies are generally designed to balance requirements in latency, bandwidth, and signal propagation. Radio Frequency Interference (RFI) from other emitting sources (including other UGVs) as well as the reduction of the number of available RF channels has led the S&T community to develop more advanced communication technologies for UGV usage.

Status

Many of the currently available UGVs utilize radios that are highly integrated into the robot architecture. These radios are generally limited to a frequency band (sometimes to a single frequency channel) which makes coordination of spectrum in CONUS and OCONUS challenging if not impossible, requiring significant hardware or software changes in order to meet spectrum guidelines. In addition, many UGV systems use unlicensed frequency bands (e.g., 2.4 GHz) that are susceptible to interference as other WiFi systems can operate in the same band with no protection. Due to interference concerns and incompatibility with Counter Remote Control Improvised Explosive Device (RCIED) Electronic Warfare (CREW), many of the fielded Army and USMC UGV assets have undergone communication radio system upgrades to new frequency bands. Higher frequency bands can support wider channel bandwidths and high data rates required for real-time teleoperation video transmission. However, higher frequencies do not propagate as well as lower frequencies and limits communications range in Line-of-Sight (LOS) and Non-Line of Sight (NLOS) conditions. The Institute of Electrical and Electronics Engineers (IEEE) 802.11 standard is widely used for implementing wireless local area network (WLAN) computer communication and is used by some UGV radios, as the over-the-air modulation techniques work well in multi-path environments and support high data rate transmissions.

Government and Industry have recently created radio technologies to increase range, networking capabilities, and RF flexibility. The table below illustrates some of the technology development efforts in the radio communications field undertaken in the last two years by both Government and Industry labs.

Table 4. Communications Advancements

Major Activity	Type	Result
DARPA MNM	Program	Matures technologies to adapt to environment and mission yet provide higher data rates along a robust data link
JTRS HMS	System	A communication network for dismounted Soldiers, sensors, and UGVs
JTRS, WIN-T	System	A set of communication networks and waveforms for manned vehicles
CDL, DDL	System	A set of data links for air-ground communication with OSRVT

Modern radios can transmit information to several target receivers simultaneously in a process called multi-cast. This process transmits information with equal quality as older single-cast technologies; and it enables collaborative behaviors to develop between robots. Many small robots and OCUs, by their nature, have low antenna heights that make radio links susceptible to multipath fading, and thereby drastically reduce radio link range and reliability. But, waveforms such as Orthogonal Frequency Division Multiplexing (OFDM) or Coded-Orthogonal Frequency Division Multiplexing (COFDM) are resilient to multipath fading and support high data rates for video transmission. OFDM and COFDM are robust in multipath environments and increase wireless range performance on UGVs. Some radios also employ frequency-hopping spread spectrum technologies that rapidly switch between different frequency channels to make the radio link less susceptible to interference and more difficult to detect.

Future Trends

In order to create more interoperable networks, UGV radios will need to support multiple waveforms and span wider frequency ranges. The continued enhancement of SDR and Smart Antenna technologies will increase the multiband capability and range of radios. These technologies will enable the radio to suppress interference or RF jamming while improving desired signal levels. These enhancements will promote Cognitive Radio (CR) technology that will adapt to the RF environment by selecting the best modulation format and frequency to support the information being relayed. On the future battlefield, UGVs will multi-cast images securely to troops and be capable of relaying data from one asset to another through a dynamic network of nodes and relays. Operators will also have the capability to assign control of payloads to secondary operators.

SDRs and Smart Antennas will increase the multi-band properties and range performance of radios. These technologies enable radios to overcome or suppress RFI and simultaneously improve signal levels. Defense Advanced Research Projects Agency's (DARPA's) Wireless Network After Next (WNaN), will likely mature CR technologies that select the frequency and modulation formats to transmit particular types of information in real-time. In the future, UGVs will also securely multi-cast information to Warfighters and relay data from one asset to another via Mesh Networks. Mesh Networks (or Mobile Ad-Hoc Networks [MANET]) technologies are self-configuring unstructured wireless networks of mobile devices in which any node can be a radio repeater that extends the range between the OCU and the robot. They can be exploited to improve NLOS communications within buildings and around obstacles without exposing the robot operator to danger.

To enable advancements in communications technology, the S&T Community should accelerate efforts to develop modeling software for radio communications and networks. Such software is required to validate radio interfaces and designs within a mature trade space; and, it enables researchers to evaluate emerging technologies such as CR and Mesh Networks. Emerging UGV requirements to operate within buildings or other enclosed spaces will further increase the need for modeling.

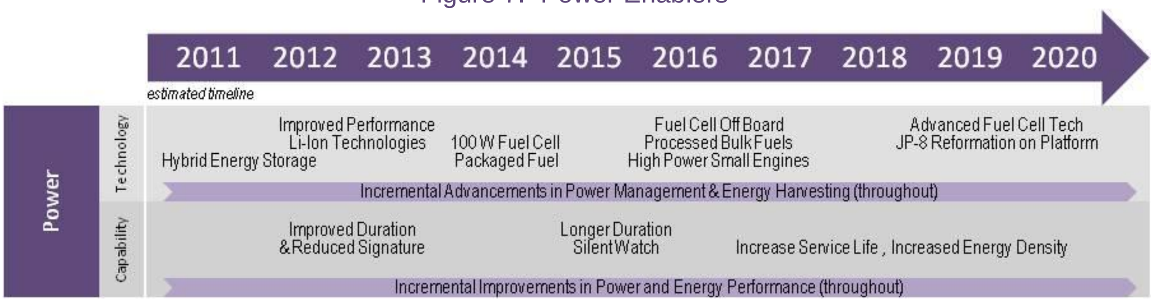
In addition, the S&T Community should accelerate investments to develop multi-cast communication technologies. Multi-robot coordination is a force multiplier that allows Soldiers to increase situational awareness; and multi-cast technologies allow semi-autonomous and autonomous collaboration between robots to exist. The S&T Community should continue efforts to develop radios with frequency-hopping characteristics that mitigate risks from RFI.

Requirements to increase interoperability between UGVs and unmanned aircraft systems (UASs) and thereby increase situational awareness represent a major shift in Army communications. Yet, radio equipment today is heavily integrated onto UGVs; and it is highly specialized to the UGV Manufacturer. As a result, the S&T Community should continue efforts to build common subsystems to enable plug-and-play functionality such that specific missions dictate radio capabilities. IP version 4 (IPv4) is the common IP standard used on IP addressable devices of UGVs, however, IPv4 addresses are projected to run out and UGV systems will need to migrate to IP version 6 (IPv6) to support the increased demand.

Ultimately, UGV wireless communications will connect to the Global Information Grid (GIG) network and will be ubiquitous enabling users to use their cell phones to control a robot from distant locations anywhere. An ongoing effort by the DoD next generation radio communication system is the development of the Joint Tactical Radio System (JTRS), which will provide wireless connectivity and interoperability for ground mobile, man portable, maritime and airborne forces operating within the GIG. The JTRS Handheld/Manpack/Small Form Fit (HMS) program provides embedded communication that is targeted to support unmanned aerial vehicle (UAV) (Class I), Non Line-of-Sight-Launch System (NLOS-LS), Land Warrior, SUGV, unattended ground sensor (UGS), and Intelligent Munitions Systems (IMS).

2.3 Power

Figure 7. Power Enablers



Description
Current UGVs require energy dense, rechargeable, and reliable power sources in order to efficiently operate. These power sources must satisfy the size and weight constraints of the host platform, and they must satisfy a broad set of environmental and safety requirements.

The following power technologies may be used to match a given Use Profile:

Table 5. Power Use Profiles

Energy Storage	Energy Harvesting	Fuel Cells	Engines
Lead Acid/Ni-Cd	Kinetic	Solid Oxide	Gasoline
Lithium Ion	Solar	Proton Exchange Membrane (PEM)	Diesel/JP-8

A set of power technologies might also be hybridized to better match a UGV Use Profile. Such technologies will enable robots to conduct persistent stare and silent watch operations.

Status
A significant amount of research and development in both Government and Industry have been devoted to the areas of energy storage, fuel cells, and small internal combustion engines. Since 2009, the following activities have led to incremental improvements in this technology.

Table 6. Power Advancements

Major Activity	Type	Result
TARDEC ATO-M	Program	Matured domestic manufacturing capabilities for advanced Lithium Ion cell technologies and improved power and energy density

NPS ATO-D	Program	Matured 10-kW diesel engine APU for Abrams at TRL 6
TARDEC Rotary Engine	Program	Matured 9-kW small rotary engine in an APU for Abrams at TRL 5
TARDEC Propane SOFC	Program	Matured fuel cell technologies to enhance batteries on small robots to extend mission duration between 150 - 250 W
TARDEC JP-8 Fuel Cell APU	Program	Matured fuel cell and reformation technologies to enable fuel cells to operate off of JP-8 fuel and deliver near-silent operation at 10 kW
TARDEC Advanced Batteries	Program	Matures Lithium Ion and advanced cell technologies to improve energy and power density, safety, cost and standard form factors

At present, small UGVs derive power almost exclusively from Li-Ion batteries. Any advancement in this area closely follows the consumer electronics and power tool industries. Rechargeable Lithium Ion batteries have a wide military acceptance on small UGVs, and have been replacing the use of Lead Acid and Nickel Cadmium batteries. As a result of the switch to Lithium Ion batteries, mission duration and mission standby times for small UGVs have increased.

Power technologies for medium UGVs have largely been derived from the commercial engine markets and tend to use gasoline and/or ultra low sulfur diesel fuels. Medium sized UGVs will need to better align themselves logistically by adopting the battlefield jet propellant 8 (JP-8) fuel standard. This work includes the development of JP-8 fuel cells and internal combustion engines that are designed with reduced acoustic signatures, high operational efficiencies, high power density and improved reliability.

Advancements in power technologies for large UGVs also closely follow industry with the automotive industry being the primary influence. These advancements include the development of electric vehicles, hybrid vehicles, and increasingly efficient engines. At present, high-power energy storage devices (such as batteries and super capacitors) can propel a full-sized vehicle for up to forty miles. These technologies exist in production environments for automobile-sized vehicles.

Future Trends

In the near-term, Lithium-chemistry batteries will continue to experience incremental improvements in power and energy performance. In addition, fuel cells will enhance and reinforce battery usage and may eventually serve as a replacement for batteries on small UGVs. While current fuel cell technology for UGVs focuses on packaged fuels (such as propane), future technologies will enable the use of JP-8 fuel, reducing the Army’s logistical burden. These technologies hold significant promise, but breakthrough advancements in power generation and storage technologies are unlikely in the short term. With the development and implementation of better power management technologies, UGVs will be able to increase the efficiency of existing power sources by a factor of 2x in some missions.

It is expected that cell and battery technologies will increase in power and energy density at the cell and battery system levels. Current lead acid systems are in the 30-50W-hr/kg range. Trends from Nickel-Cadmium to Nickel-Metal Hydride to Lithium-ion are extending the range from 45W-hr/kg to the 150 W-hr/kg range. It is expected that the targets for energy density will increase to ~400W-hr/kg over the next five to ten years with novel electrodes, electrolytes, and separators becoming available.

The S&T laboratories are expected to continue to leverage the automotive Electric Vehicle (hybrid, plug in hybrid) battery industry to support and drive military battery development. However, the DoD will likely have to lead efforts to Militarize emerging battery technologies to allow for operation in extreme environmental conditions (i.e., to temperatures as low as -46°C and as high as +71°C).

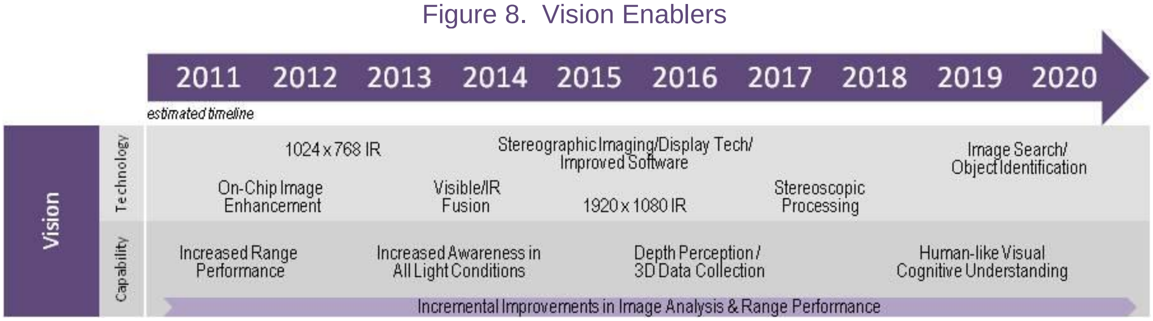
Government and industry labs will diverge on the development of engines based on JP-8 fuel. While industry will continue to develop more efficient gasoline and diesel fuel engines, the Army has adopted an overarching policy to transition all ground vehicles to JP-8 fuel.

The development of internal combustion engines and fuel cells for auxiliary power units for combat vehicles is expected to continue in the Army labs. Current technology has shown that internal combustion engines (ICEs) for robotic platforms are capable of operating on military JP-8/diesel fuel #2 (DF2) fuels for relatively short durations. The future expectations are to widen the operational temperature ranges and enhance the reliability for military applications. The trade-off between compact size and reliability in this class of engines will continue to be minimized. The acoustic signature of ICEs will continue to be reduced with the development of active noise control techniques.

Current fuel cell technologies are hydrogen based systems, which is not a battlefield acceptable fuel. In order to solve this issue, the labs are working to develop fuel reformers to allow fuel cells to be compatible with military fuels. Packaging a fuel reformer and a fuel cell into a confined space will continue to be a challenge. Over the next five to ten years, high power density engines and fuel cells will mature to the point of integration into UGVs to enhance near silent operation and allow for longer mission durations without refueling.

2.4 Vision

Figure 8. Vision Enablers



Description
Vision provided on ground robotics is comprised of the imaging sensor, lighting, optics, and the OCU display. Imaging sensors operate in one of following three spectrums:

Table 7. Vision Spectrums

Spectral Band	Description
Visible	Captures images visible to the human eye in full color
Near Infrared (NIR)	Captures images in low light for stealth operation and provides a monochrome or grayscale image
Thermal Infrared	Captures images without any light by responding to the latent heat radiated by all objects at temperatures above absolute zero

Visible and NIR imaging sensors use standard COTS silicon charged coupled device (CCD) or complimentary metal-oxide semiconductor (CMOS) technology, and are widely available at low cost. With selective filtering, the same sensor can provide both visible and NIR images. Lights are generally included for additional illumination above ambient. Thermal imaging sensors use specialized focal plane arrays which respond to the longer wavelengths of thermal energy. While these systems are lower in resolution and much more expensive (7x to 10x) than their visible and NIR counterparts, thermal sensors provide the advantage of being able to see images obscured to visible sensor systems (such as in fog, smoke, dust, and complete darkness). Optics and lenses are used to focus the image onto the sensor and provide zoom capabilities for user adjustments to the field of view (FoV) and magnification of the image. Images acquired by the camera systems on the robot are compressed and sent over the data link to the OCU, where they can be viewed by the robot operator.

Status

Vision is a subject of significant research and development within both Government and Industry. Since 2009, the following activities have led to significant improvements in this technology:

Table 8. Vision Advancements

Major Activity	Type	Result
DARPA Challenges	Demonstration	Demonstrated obstacle detection and avoidance, visual odometry, lane detection, and sensor fusion
ARL Robotics CTA	Investigation	Investigated stereoscopic vision and terrain classification technologies
DARPA LAGR	Program	Matured vision-based navigation and learning technologies
SOURCE ATO	Program	Matures vision technologies that enable UGVs to safely operate within urban environments among humans, animals, and vehicles

UGVs are generally equipped with imaging systems that vary in resolution, range, and field of view. The following specifications are the imaging characteristics for what is typically found in fielded UGVs:

Table 9. Vision Specifications

	Visible	Infrared
Pixel Resolution	768 x 494	320 x 240
Field of View	40° H x 30° V	40° H x 30° V
Frame Rate	30 Hz, 60 Hz	15 Hz, 30 Hz
Detection Range	225 m to NATO Man Target	300 m to NATO Man Target
Zoom	3X to 26X	None

Numerous algorithms exist to improve the quality of information generated by imaging systems. On-chip color enhancement, contrast enhancement, image stabilization, and noise reduction are mature examples. Image sharpening and lens rectification algorithms will also mature very soon. Intelligent vision algorithms are the subject of intense research; but are not yet sufficiently mature to field. Such algorithms include object detection, recognition, and identification; object tracking and tagging; human intent analysis; visual odometry; sensor fusion; and terrain classification. Advancements in these technologies will likely reap significant benefits to UGVs.

Streaming video displayed on OCUs is typically degraded from the camera output due to the constraints of wireless data transmission. Digital images transmitted to the OCU over a wireless data link are often compressed because of radio bandwidth limitations. MPEG-4 (commonly used by COTS UGVs) compression takes the video image and breaks it into smaller data packets that are broadcast individually over the air. If the radio signal is weak or noise is present, the data packets can be lost or corrupted, which results in latency and degraded images.

Future Trends

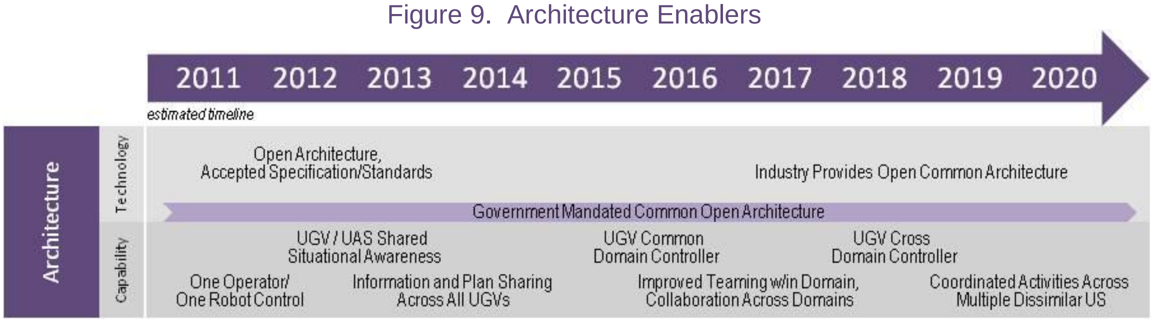
Improved imaging will be achieved with the integration of evolutionary technology developments mostly driven by the commercial and industrial sectors. H.264 advanced video encoding developed for Blu-Ray and other high definition video reduces the bit rate requirement for wireless transmission. This video compression methodology enables an increased number of pixels for more image detail or wider fields of view (including 360° images). With continued advancement and increased commonality of visible and infrared technologies, significant opportunities exist to fuse information from multiple spectral bands to increase situational awareness. Sensor fusion represents a major milestone in robotic vision that has broad application on both robots and manned platforms. The S&T community should accelerate investments in sensor fusion technologies.

In the mid-term, stereoscopic imaging technologies will enable UGVs to develop maps and detect obstacles in real-time. Such technologies are particularly useful in gripper control, as monocular imagers cannot effectively present depth information to enable delicate object manipulation. Stereoscopic technologies have also proven to increase situational awareness; and the S&T community will continue to investigate such technologies and their application to small robots. In addition, the S&T community needs to continue to develop technologies that increase dynamic range from imagers to increase awareness in all light conditions.

In the long-term, intelligent vision algorithms will likely experience tremendous improvements in capability. Many advanced algorithms in the coming years will continue to be developed for defense and security applications with mobile telephonic and commercial search applications driving the development. Opportunities exist to develop partnerships with the mobile telephonic and commercial search industries to leverage developments of these technologies. The S&T community needs to foster and mature these partnerships in research to develop and transition advanced robotic vision technologies to the field.

2.5 Architecture

Figure 9. Architecture Enablers



Description

A Systems Architecture describes the structure and behavior of a given system. It includes a functional description of hardware and software components as well as the interfaces between such components. An open architecture is one in which the interfaces are comprised of open standards, have no proprietary constraints, and enable the upgrading, swapping, and adding of components.

High-level UGV architecture includes, at a minimum, the following components and interfaces:

Table 10. Architecture Interfaces

Functional Components	Major Interfaces
Robotic Platform	Power Interface
Robotic Payload	Payload Physical and Message Interface
Data Transmission Link	Data Transmission Interface (frequency and waveform)
OCU	Human/Machine Interface (HMI)

The RS JPO owns and manages the Systems Architecture for Programs of Record whereas the OEM generally controls the COTS and NDI system architectures. Owning the systems architecture ensures the RS JPO is able to incorporate interoperability, control software/hardware modifications and upgrades for POR systems.

Status

Architecture is a subject of significant research and development within Government and Industry. Since 2009, the following activities have led to significant breakthroughs in this technology:

Table 11. Architecture Advancements

Major Activity	Type	Result
RS JPO Interoperability Effort	Interface Definition	A set of interface, messaging, and protocol requirements that will drive interoperability and modularity in all future RS JPO managed systems
MAGIC	Demonstration	Demonstrated autonomous coordination and teaming architectures in operationally relevant urban scenarios
AEODRS	Program	Modular architecture based on SAE AS5684 for Navy EOD robots
ACS, RIK, ROS, 4DRCS	System	A set of intelligent architectures for small-robot navigation
VICTORY	System	An architecture that enables C2 and interoperability on manned vehicles

At present, COTS robotic system manufacturers tend to maintain their own proprietary architecture. These manufacturers employ a variety of interface standards, including portions of the Society of Automotive Engineers (SAE) AS-4 family of standards (formerly Joint Architecture for Unmanned Systems [JAUS]) and Standardization Agreement (STANAG) 4586. These architectures are not managed by the RS JPO.

The RS JPO, in close collaboration with industry and other government agencies, is creating IOPs based on SAE AS-4 and other standards to enable disparate interfaces to communicate with one another. These IOPs define interoperability on platforms, payloads, communications, and controllers. As technologies mature, the RS JPO will add capabilities such as autonomy behaviors and other technologies to these IOPs. These profiles will assist APMs by providing direction in the acquisition of future UGV PORs, the upgrade of currently fielded systems, and the evaluation/acquisition of COTS components.

Future Trends

In general, robotic architectures currently focus upon individual UGVs, but over time, such architectures will likely tend toward multi-robot coordination and control applications. Initial applications of multi-robot coordination will be limited to a single domain, but are expected to expand across multiple domains and into manned-unmanned teams. Efforts to coordinate with friendly coalitions will likely occur in parallel. The TARDEC Coalition Warfare Project (CWP) (a proposed FY12-start) enables interoperability with Canadian robots based on the RS JPO developed IOPs and a similar North Atlantic Treaty Organization (NATO) effort. The CWP will allow for coordination across a broader coalition.

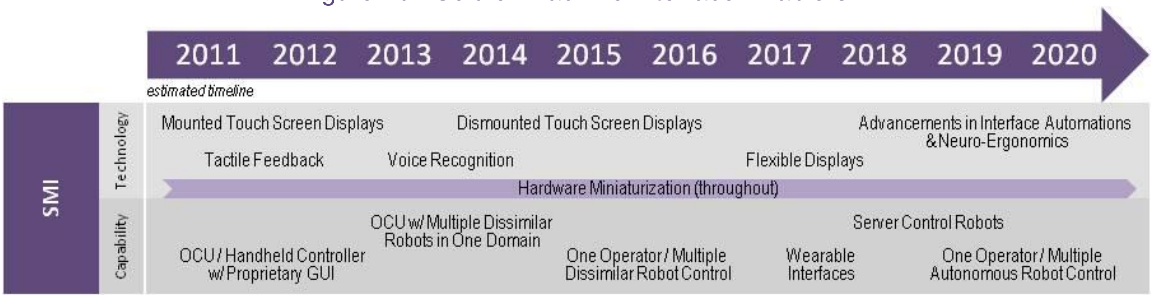
Communications technology advancements will help to enable multi-robot coordination. Multicast radios will likely improve this coordination and as such the S&T community should accelerate investments in multi-cast communication and other similar technology advancements. In general, technology development is not expected to be a major inhibitor to the adoption of multicast and other advanced technologies. Requirements must be developed and standard communications protocols must be agreed upon to enable advancements in multi-cast communications and multi-robot controls.

An anticipated UGV architecture requirement will be the requirement to interface with tactical and enterprise networks such GIG. ASA (ALT) has defined a strategy for realizing a Common Operating Environment (COE) network, into which UGVs are anticipated to interface. While achieving this interface would entail significant acquisition challenges in terms of information assurance planning, it would provide significant opportunities for increasing the capabilities of UGVs for Warfighters. For example, a Warfighter equipped with COE-connected mobile devices can search for applications that are needed to conduct the mission, to include UGV video feed and sensor-control applications. Additionally, geospatial models and other data structures available in the COE could aid significantly in enabling UGVs to optimally navigate autonomously. These types of operations could reduce the amount of computing power necessary on platforms and OCUs, and may reduce the wireless communication bandwidth required in UGV radios.

The Army will continue to increase coordination between ground and air domains. Although UAS and UGV systems are be based on different standards (STANAG 4586 for large UAS and SAE AS-4/JAUS for UGVs), it is feasible for future systems to use an inward (ground) facing SAE AS-4/JAUS protocol and an outward (air) facing STANAG protocol to interoperate. STANAG 4586 is optimized for air system requirements and is highly reliable, but has a high latency format due to large message sizes. SAE AS-4 is optimized for UGV requirements with its somewhat degraded reliability, but low latency format for handling smaller message sizes. Additionally, as UGVs become more accepted and embedded in the force structure, interoperability with manned ground systems will be necessary. It is anticipated that Program Executive Office for Command, Control and Communications – Tactical's (PEO C3T) Vehicular Integration for C4ISR/EW Interoperability (VICTORY) standard will provide the interoperable interfaces for communicating with manned ground systems. RS JPO's interoperability profiles will eventually need to define the protocols for interfacing with VICTORY-based systems

2.6 Soldier-Machine Interface (SMI)

Figure 10. Soldier Machine Interface Enablers



Description

Soldier Machine Interfaces (SMI) are the physical devices (primarily operating controls and video displays) that give Soldiers the ability to perform their mission in a safe and effective manner. SMIs enable the operator and UGVs to interact with one another. SMIs allow soldiers to both control and acquire situational awareness from UGVs. These interfaces have to be usable and visible in all the environmental conditions that the Soldier will face while in combat. Soldier machine interface programs have shown to improve soldier performance through the use of automations and more intuitive screen design.

Future developments in the area of soldier machine interface will have to address simultaneous task completion and interoperability standards for common icons, graphics, alerts and controls and other areas.

Status

SMI is a subject of strong research and development in both government and industry labs. Currently the number of tasks that the soldier has to perform while on a mission is increasing, providing more stress and mental workload in complex environments. It is very difficult for the soldier to operate multiple controls and be able to process information on multiple screens. Programs are currently under development to help reduce the mental and physical strain that the soldier has to go through while performing essential mission tasks. Since 2009 the following activities have led to incremental improvements in this technology:

Table 12. Soldier Machine Interface Advancements

Major Activity	Type	Result
ARL HRED CAN CTA	Investigation	Investigates neuro-ergonomics for mounted and dismounted Soldiers
HRI ATO	Program	Matured indirect vision driving and mobility aids
IMOPAT ATO	Program	Matures situational awareness and indirect vision driving technologies
SPAWAR MOCU	System	An unmanned vehicle and sensor operator control unit for Navy robots

RDECOM has also developed advanced control aids such as point-and-click destination setting, path projection, high-level command interfaces, and sensor slew-to-cue to improve semi-autonomous operation with UGVs. The S&T community is also developing mitigation technologies to overcome latency in control and video acquisition. In the future, such technologies will enable SMIs to simultaneously control multiple UGVs in coordinated operations.

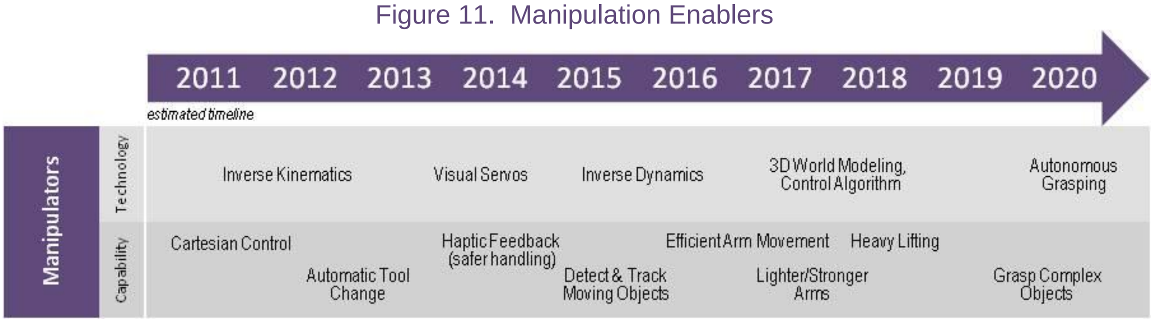
Numerous ongoing programs focus on the need to develop one controller that performs numerous tasks on a UGV. This eases the mental strain caused by performing different operations with dissimilar controllers. A single controller enables the Soldier to control and observe more than one dissimilar unmanned ground vehicle with the same interface display and control function mapping. The High Definition Cognition ATO (TARDEC and Army Research Laboratory [ARL] joint ATO) works to monitor the state of the Soldier in an operational environment to help make the crew station adaptable to the Soldier to increase operational efficiency.

Future Trends
Gamepads have often been used to operate UGVs but in recent years the S&T community has shifted its SMI development efforts toward touch-screen displays. The touch-screen displays enable Soldiers to both control and receive video information from their robots. SMIs will likely be developed for mounted touch-screen displays before dismounted and flexible displays are developed. The future of SMI also includes the continued development and refinement of voice control/recognition systems, advanced reconfigurable head up displays, 3D displays and other general display technologies. Haptic controls for enhanced perception to what the robot is doing and experiencing will become available and integrated into the SMI. These controls take advantage of the users' sense of touch by applying forces, vibrations and/or motions to the user as a feedback mechanism.

Advanced neuero-ergonomic technology and techniques will allow for driver brainwave, heart rate and eye tracking monitoring. The Brain Computer Interaction Technologies (BCIT) ATO (joint TARDEC/ARL ATO, FY13 start) will develop technologies which will enable soldier performance prediction by using advanced algorithms to monitor a soldier's brain signal for indicators of performance state degradation over time. BCIT ATO also will develop technologies that have adaptive tutoring, which will monitor brain signals to detect states associated with lack of learning and automatically adjust training strategies to best match soldier states. Text to speech conversion systems will allow soldiers the ability to select different languages and voices (i.e., male/female) to operate different controls, or send different messages. The S&T community needs to continue to develop networked controllers that use standard message sets to send information over radio. Such controllers use both military and low-cost commercial hardware to provide a flexible, reliable, and secure communications and control framework. These controllers enable dismount soldiers to more effectively interact with robots in a dynamic operational environment. Creative interoperability techniques and technologies will allow soldiers to operate both unmanned aerial vehicles and unmanned ground vehicles using one controller.

2.7 Manipulation

Figure 11. Manipulation Enablers



Description
Manipulation technologies enable robots to lift and reposition objects of various sizes or shapes. UGVs within a military context must generally conduct manipulations on objects that are unique and yet to be encountered.

Advancements in manipulation typically focus upon manipulator hardware and controls. Significant efforts are applied to design end-effectors such as grippers, claws, and shovels that enable successful manipulation with multiple joints and force feedback capabilities. Manipulators may also exhibit semi-autonomous behaviors to assist the operators during critical operations.

Status
Manipulation is a subject of strong research and development within both Government and Industry. Since 2009, the following activities have led to incremental improvements in this technology:

Table 13. Manipulation Advancements

Major Activity	Type	Result
ARL Robotics CTA	Investigation	Investigated actuation techniques, intelligent gripping, and coordinated manipulation
AEODRS	Program	Matures autonomous manipulation for Navy EOD
DARPA ARM	Program	Matures autonomous arm control and gripping capabilities

Robotic manipulation currently exists in the form of robotic forklifts, front end loaders, specialized platform toolkits, and manipulator arms. Most of the currently fielded manipulators are controlled by operators who move each joint manually and independently. Many of these joints are powered by electric motors, however hydraulic and pneumatic actuators have been utilized. The systems are primarily employed for moving/displacing, lifting, and placing objects, as well as turning door knobs, operating tools and assisting in platform mobility. Most manipulation is currently limited to small EOD and engineering platforms. These manipulators can also utilize small, simple tools designed for use with specific systems.

Additional DoD and industry efforts are focusing on the development of rapidly interchangeable end-effectors with hydraulic force feedback capabilities and complex manipulation capabilities.

Future Trends
Future technology developments, both near and long term, will greatly enhance manipulation capabilities. Inverse kinematics will allow the operator to provide the desired location of the end effector, while having the robot move the joints (rotation and translation) to reach the desired end state. This capability will allow Cartesian control (fly-the-end-effector) of the manipulator. Fly-the-end-effector technology is widely used by robots in industrial applications where the additional sensors and processing power are more readily available. Experiments have successfully demonstrated this capability on robots, with some new software packages (Aware 2 PackBot) implementing "fly-the-camera." In addition, this technology is directly related to pre-defined poses and the ability to perform automatic tool change.

Visual servoing is a technique using feedback from visual sensors (cameras, light detection and ranging [LIDAR]) to control features of the robot. This technique monitors and adjusts based on the image, and not the manipulator's location. This methodology allows for variation in the manipulator hardware and grasping technology without it affecting the end placement. This capability will enable semi-autonomous control by allowing the robot to make adjustments based on the desired outcome.

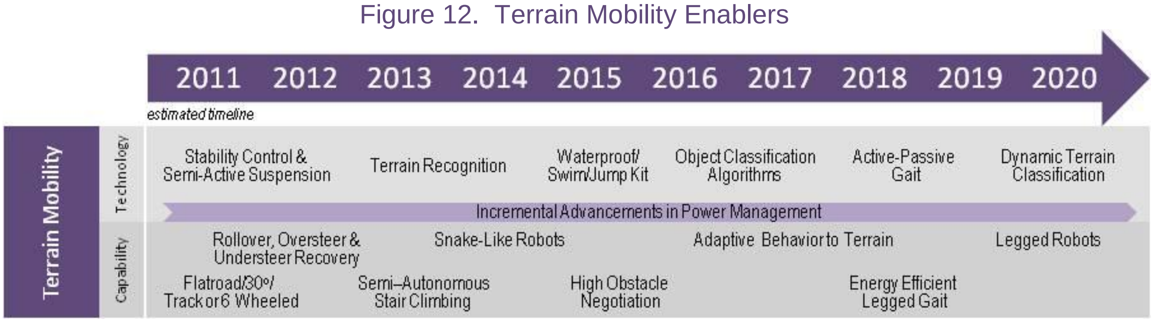
Haptic feedback provides additional information to the operator based on the sense of touch and feel carried out through the controller. As an example, haptics can give an indication of the weight or firmness of an object. By providing additional information to the operator, finer grasper control and a better understanding of the items being manipulated can be achieved. Haptic feedback is becoming commonplace in Industry and is widely used in game controllers, cell phones and medical environments.

Inverse dynamics involve knowing the desired movement, and calculating the correct forces required to generate that movement. Whereas inverse kinematics calculate the geometry (angles, distances), inverse dynamics calculate the forces, velocities, and accelerations to travel a desired path. This calculation can be quite complex, as manipulator weight, object weight, and even robot orientation with respect to gravity can have an effect on the forces required. As the size of the manipulator and load increase, and the speed of the manipulator increases, inverse dynamics become more important. Several large industrial robots currently use inverse dynamics in their control methodologies. However, their operating environments are much more stable and they have access to more computing power. As computing power and sensors increase, the ability to add inverse dynamics to robotic systems will also increase.

As the robot is able to build a more advanced 3D model of the world, the manipulator's ability to autonomously move and grasp will increase. The use of multiple manipulators on a single platform will also be possible though coordination in the 3D model. Additionally, advances in physical components and control algorithms will increase the ability of the manipulators in an attempt to approach human-like motion. There are several laboratory experiments that show this is possible, and provide manipulator teams a direction for the future.

2.8 Terrain Mobility

Figure 12. Terrain Mobility Enablers



Description
Terrain Mobility enables robots to negotiate difficult terrains and obstacles. Such terrains and obstacles include:

Table 14. Terrain Mobility Terrain and Obstacles

Terrains	Obstacles
Paved roads, dirt roads	Curbs, potholes, puddles
Grass, brush, rocks	Ditches, bushes, rocks
Sand, shallow water	Stairs

UGVs typically use tracks and wheels to enable mobility. In general, tracked and wheeled robots utilize the following control systems:

Table 15. Terrain Mobility Control Systems

Control System	Description
Ackermann steering	Used in automobiles to steer inside front wheels more than outside front wheels
Skid steering	Used in tracked and wheeled systems to spin in place
Omni-directional steering	Used in robots to spin in place with less degradation to wheels

Technologies such as semi-active suspension, stability control, and integrated vehicle dynamics enhance terrain mobility characteristics for UGVs.

Status

Terrain mobility is a subject of significant research and development within both Government and Industry. Since 2009, the following activities have led to significant breakthroughs in this technology:

Table 16. Terrain Mobility Advancements

Major Activity	Type	Result
ARL MAST CTA	Investigation	Investigated ground maneuverability and mode transitions
ARL Robotics CTA	Investigation	Investigated terrain representation and multimodal locomotion.
UGCV	Program	Matured intrinsic mobility capabilities through irregular terrains
S-MET	Program	Matures payload carrying and dismount following capabilities
DARPA LS3	System	A legged robot with improved mobility over irregular terrain
SMSS	System	A six-wheeled robot that carries payloads and follows dismounts
Crusher, APD	System	A set of six-wheeled robots with intrinsic mobility in irregular terrains

In general, the smallest available robots travel on wheels, and they typically ride in urban or indoor environments upon smooth surfaces. Most small robots use tracks to improve off-road mobility and obstacle negotiation. Large UGVs tend to employ wheeled and tracked skid-steer systems; but add-on autonomy kits have been integrated on manned vehicle platforms that employ Ackermann steering technologies. Basic controls for these technologies are highly mature; but relatively new technologies such as semi-active suspension and stability control enable UGVs to ride upon more difficult terrains at higher speeds.

Legged robots have continued to improve through research. The DARPA Legged Squad Support System (LS3) robot is the leading system for legged mobility; and two legged systems will be available for evaluation in June 2012. The LS3 is approximately 400 pounds; and it supports twenty-four hour missions on a broad set of difficult terrains. The LS3 robot contains four legs; but several research projects have also begun to examine bipedal locomotion. In addition, snake-like robots have been developed to attain mobility in niche environments such as sewers or culverts. These snake-like robots have been used on several occasions during disaster relief operations.

Future Trends

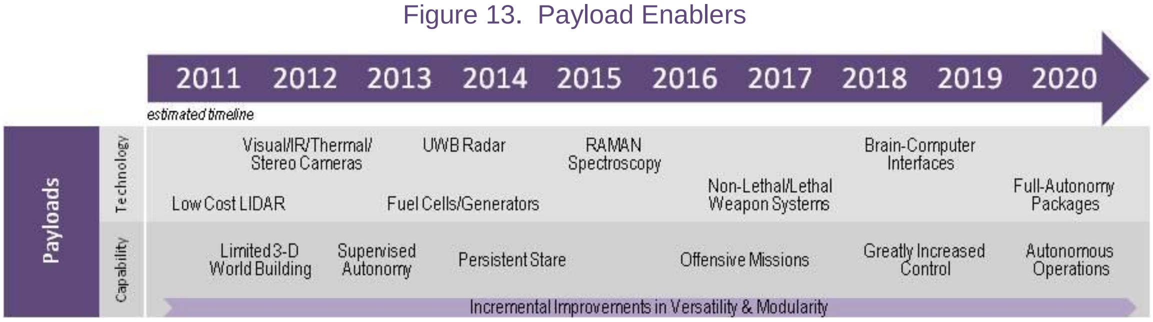
Tracked and wheeled mobility will continue to dominate the robotics trade space for many years. Legged mobility will likely remain in research for much of the coming decade; but once matured, these systems may radically increase mobility in relation to current platforms. Such robots will likely have wide application on future battlefields. Snake robots will likely remain suitable for only niche environments and are not envisioned to be widely employed in combat situations.

Dynamic balancing algorithms are fairly mature, but significant research will be required to mature efficient gaits (i.e., the robots' walking style). At present, most legged robots maintain active gaits; but living creatures typically possess active-passive gaits to improve efficiency. Since legged robots require large amounts of energy to operate, innovation in power technologies will be required to fully mature legged robots. As such, the S&T Community should continue efforts to develop effective power management technologies.

Modern platforms exhibit sufficient mobility to conduct next-generation autonomous applications, including leader-follower operations within convoys and semi-autonomous control of small robots in urban environments. As a result, continued advancements in fielded mobility will likely arise from developments in terrain and obstacle recognition. Such technologies enable the robot to adapt its parameters to improve mobility performance in both autonomous off-road applications and following dismount. As such, the S&T Community should continue efforts to apply advanced terrain and obstacle recognition algorithms that improve mobility on current platforms.

2.9 Payloads

Figure 13. Payload Enablers



Description
Payloads may be considered from the point of view of the message communication, network access, operational, or functional frameworks. The message communication framework allows for payloads to be defined as to whether they receive defined messages or raw inputs. The network access framework defines payloads on the basis of their ability to be accessed via the network (either Open or Closed). The operational framework defines payloads as internal system payloads (fuel and temperature sensors), external operational payloads (cameras, LIDARs, etc) and add-on mission modules payloads (chemical, biological, radiological and nuclear [CBRN] sensors, etc). The functional framework approaches payload definitions from their interactions with the environment; they are classified as sensors, emitters, or actuators. For the purposes of this Roadmap, payloads are discussed from the 'functional' point of view. The Interoperability WIPT will continue to research, develop and review payload definitions as UGV technologies continue to mature. Special consideration on how to characterize batteries and other power sources, as well as control mechanisms is still under development and expected to be defined in the near future. Robotic payloads are categorized as follows:

Table 17. Payload Types

Payload Type	Description
Sensors	Any equipment that gathers information from the environment
Emitters	Any equipment that interacts with environment by leaving host platform
Actuators	Any equipment, powered or unpowered, that interacts with the environment without leaving host platform

The following table provides examples of Sensors, Emitters, and Actuators:

Table 18. Payload Examples

Sensors	Emitters	Actuators
Visual Sensors	Obscurant producers	Manipulator arms and Grippers
Ranging Sensors	Counter-IED systems	Track flippers and flipticulators
Acoustic Sensors	Lethal/Non-lethal systems	Push and pull attachments

Demands for increased capabilities on UGVs will require the development of robust and versatile robotic payloads. As such, robotic payloads must be developed with versatility and modularity in mind.

Status

Nearly all fielded robots include a sensor to enable driving and navigation. Visual sensors (day-time color, near infrared, and thermal infrared systems) are now often required for standard robotic missions, such as EOD, personnel or vehicle inspection, and route clearance. Ranging sensors (LIDAR, radio detection and ranging [RADAR], and sound navigation and ranging [SONAR]) have been integrated onto many robots to support autonomy and ISR. RDECOM is intently focused upon efforts to fuse information from visual and ranging sensors to improve robotic world models and increase situational awareness. RDECOM is also developing additional payloads (ground-penetrating RADARs and spectroscopic sensors) to detect buried command wires and IEDs.

Many currently fielded UGVs are (or may be) equipped with emitters in the form of lights, speakers, obscuration producers, and CREW systems. RDECOM has been developing lethal and non-lethal payloads for a number of years. Several prototype systems have been developed that are capable of deploying a lethal and non-lethal capability. These include the use of M240/M249 machine guns, as well as the Anti-Personnel Obstacle Breaching System and Venom V-10 systems.

Manipulator arms, grippers and pan/tilt mechanisms have become common payloads on most fielded UGVs. Additional advancements have been made in the development of push and pull attachments. These include the development and fielding of the Tangle Foot kit, various rollers and plow attachments. The RDECOM-developed Tangle Foot kit is a low-cost, purely mechanical counter-tripwire system consisting of a rake device pulled behind a UGV, and a fiberglass pole attached to the body of the robot. RDECOM and the REF are working to develop and assess mechanical roller devices for several small to medium class systems. Actuators have also been developed to enhance increase SA. One example is the Situational Awareness Mast (SAM). The SAM is a collapsible/expandable 8' long triangular-shaped metal mast with internally threaded electrical cables to allow for an antenna or camera to be mounted to the top of the mast. This actuator may provide a much higher field of view of its surrounding (if camera is installed on SAM). The SAM was successfully incorporated into the Omni Directional Inspection System (ODIS) UGV.

Future Trends

As UGV missions continue to expand, the requirements placed on UGVs will constantly rise. There is an ongoing push to increase UGV autonomy, with a current goal of “supervised autonomy,” but with an ultimate goal of full autonomy. These requirements necessitate the continual development of more advanced sensor UGV payloads. Future payloads must be cognizant of the platform’s size, weight and power constraints as well as overall system practicality and usability.

Payloads must be versatile and modular to extend the mission capacity of host platforms. Such payloads must support the use of common physical and software interfaces. As such, the S&T Community should continue to define interoperable interfaces; and, it should continue to include additional payload connection ports to further increase modularity.

The development and incorporation of a lethal capability has been demonstrated on numerous systems; however, the safety and political ramifications of lethal systems has not been fully addressed and resolved.

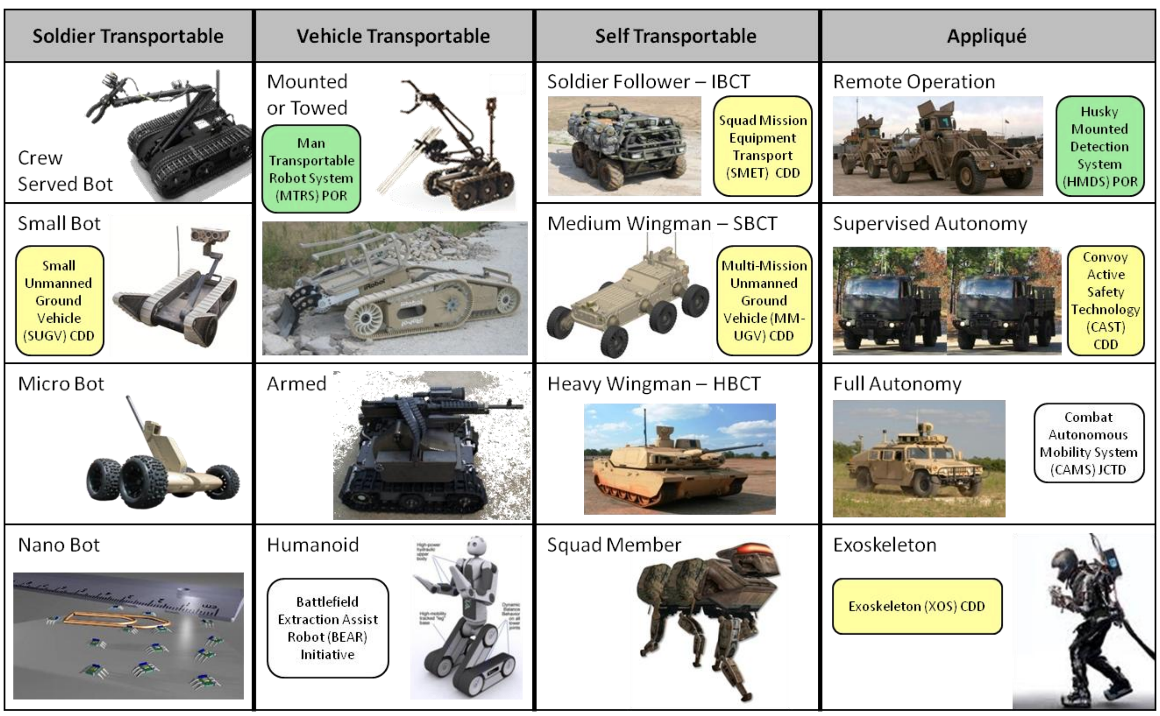
Chapter 3: UGV Modernization Strategy

3.1 Army UGV Campaign Plan

TRADOC and unmanned system users recognized a need for an overarching strategy to aid in the development of future unmanned assets. As a result, the Army Unmanned Systems (Air, Ground, Maritime) ICD (2010-2035) was approved November 2009, providing a single over-arching strategy for modular, interoperable, coordinating, and collaborating unmanned systems across the Warfighting Functions. The first effort undertaken since the approval of the ICD was to develop an Unmanned Ground Vehicle Campaign Plan. The U.S. Army UGV Campaign Plan provides a strategy to guide UGV developments and employment as described in Figure 14, Army UGV Campaign Plan, while offering enhanced soldier protection from conventional and non-conventional threats. The Army UGV Campaign Plan:

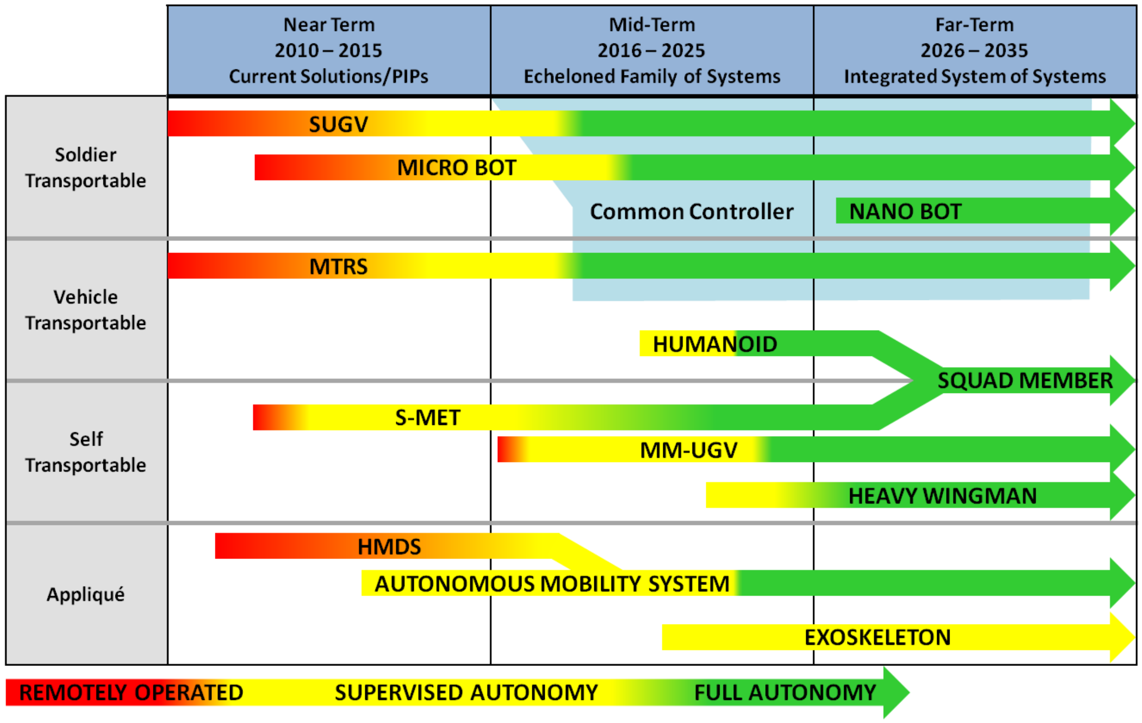
- Supports the full spectrum of military operations through a UGV Class of Vehicles (CoV) concept with mission module payloads enabled by non-proprietary open architecture standards
- Has UGV CoV deployed over a 25-year time frame divided into near-term, mid-term, and far-term
- Evolves and integrates today’s specialized UGVs into a UGV CoV enhancing effectiveness and efficiencies
- Calls for the continued evolution from tele-operation to semi-autonomous (near- and mid-term) to collaborative unmanned system warfare (far term).

Figure 14. Army UGV Campaign Plan



On the following page, Figure 15, Army Capability Timeline, identifies the U.S. Army UGV capability timeline supported by the UGV Campaign Plan.

Figure 15. Army Capability Timeline



The ICD and Campaign Plan are defined by the four robotic areas described below.

1. **Soldier Transportable CoV.** The soldier transportable CoV is defined as a UGV system with weight not exceeding 35 pounds and with forms that allow them to be carried by Soldiers or Marines for extended periods of time over varying terrains. Examples are the SUGV and Mini-EOD discussed in Appendix A. Crew served platforms weighing more than 35 pounds may also be included in this class of vehicles. The majority of soldier transportable systems are used for surveillance, reconnaissance missions, and standoff IED detection and defeat. Requirements for soldier transportable systems are expected to call for smaller, lighter, more capable systems with longer endurance and a common controller. Future capabilities for this CoV will include throwable and microbot systems. Throwable and microbot systems may be further defined by reduced size and weight and used for around-the-corner, building and room ISR, and silent watch missions. Continued advancements in antenna design, autonomy, miniaturization, power sources, and control mechanisms are required in order for these capabilities to be fully realized. The main barriers currently facing soldier transportable systems are the absence of a common compact controller and the development of an architectural framework that will permit a high degree of autonomy
2. **Vehicle Transportable CoV.** Vehicle transportable unmanned systems are heavier and require a prime mover for transportation to and from a mission. Currently fielded examples of vehicle transportable systems in the RS JPO inventory include the TALON, PackBot, MARCbot, and the M160. The M160 is used for mine neutralization and area clearance, whereas the TALON is employed for IED detection, defeat and route clearance missions. Future requirements for vehicle transportable systems are expected to include more advanced, reliable and autonomous area and route clearance robotic vehicles as well as humanoid like systems. Continued advancements in autonomy (to include intelligence understanding and decision making), power systems, and enhanced mine detection and neutralization techniques and methods are needed. Some of the barriers facing the

vehicle transportable class of vehicles include improved mine detection and neutralization, enhanced autonomy, intelligence understanding, and decision making

3. **Self Transportable CoV.** Self transportable systems are, by definition, systems that can move under their own power, up to road march speeds, without assistance from a prime mover or other sources. Self transportable systems are not manned systems with appliqué kits applied, rather they are systems that have been developed explicitly as unmanned vehicles. Self transportable systems are envisioned to provide a wide range of capabilities to the Warfighter. These capabilities may include the advent of a robotic wingman, the continued development of mine detection and neutralization platforms, as well as vehicles to serve as robotic 'mules' (Common Mobility Platform) to take on multiple soldiers' loads. Continued advancements in autonomy, sensors and sensor fusion are required in order for these capabilities to be realized. Multiple experiments and demonstrations are currently being developed to demonstrate capabilities for self transportable systems. These events will serve as risk reduction efforts and will help provide direction to the S&T communities. The main barriers currently facing self transportable systems are increasing the level of autonomy, terrain mobility, obstacle detection and recognition at tactical speeds
4. **Appliqué CoV**. The Appliqué COVs are systems that can be used to convert fielded and future manned systems into unmanned systems. This class may also include the future development of exoskeleton systems that will serve to enhance an individual soldier's inherent, natural capabilities. These systems are envisioned as 'kits' that include all the hardware (sensors, cables, actuators, control station, etc.) and software required to fully operate and monitor the selected vehicle remotely. Current systems under development that fall into this CoV include the ANS, SANDI, and Autonomous Mine Detection System (AMDS). Candidate vehicle systems for kit development cover the entire range of current and future Army and Marine Corps vehicle fleets and include small forklifts, High Mobility Multipurpose Wheeled Vehicles (HMMWVs), Family of Medium Tactical Vehicles (FMTVs), Huskys and Mine Resistant Ambush Protected (MRAP) vehicles. The appliqué kits can be used to project the force forward as well as removing the Soldiers and Marines from some of the dull, dirty and dangerous missions. These systems will be initially used for convoy, C-IED, and ISR missions. Key advancements are required in the areas of autonomy, processing, size, weight and power (SWaP), sensor development, and sensor fusion for this CoV to be fully matured. Additional barriers to appliqué systems will be safety and soldier acceptance

3.2 RS JPO Technology Needs Analysis

The RS JPO has conducted a Technology Needs Analysis to support meeting the goals outlined in the UGS Campaign Plan as a way to help focus Government labs, Industry and academia S&T research efforts. The list of needs, identified in Table 19, is prioritized according to what technology growth is needed to meet future capability requirements for CoV identified in the Campaign Plan. The list of operational needs was developed using requirements from robotic CDDs, CPDs, JUONS/ONS documents as well as the Unmanned Ground Systems ICD. The list is intended to give S&T labs direction on where RDT&E funding could be best invested. Additionally, in the case where funding is in jeopardy, the Needs Analysis potentially provides S&T labs a technology transfer path to justify their program budget.

The Needs Analysis includes some technologies that are already being developed by Government or Industry. Each of the technology needs may include near, mid and far term development goals. During the development of these technologies, S&T communities should be mindful of the size, weight and power impacts to surrogate vehicles as well as the individual ground robotic systems. Across all the robotic technology development efforts, S&T labs should strive to obtain Government Purpose Rights on all software code, as well as collaborate with the ground robotics test community on test procedures and safety requirements to increase their familiarity with autonomous ground robotic systems.

Table 19. Technology Needs

Priority	Technology Area	Technology Needs
1	Autonomy	Looking for improvements in the various levels of autonomy from semi-autonomous, supervised and fully autonomous capabilities. The capability is needed in area clearance, route clearance (marks and detects), convoy, soldier-follower, manned/unmanned teaming, situational awareness and navigation in a GPS denied environment. Also for route detection, planning, and maneuver capabilities over soldier passable terrain.
1	Obstacle detection and Avoidance	Paired with autonomy in that sensors and methods of control are necessary to detect and identify obstacles and manage navigation across soldier passable terrain, and vehicle routes, i.e., convoy.
2	Interoperability	Hardware and software interfaces IAW RS JPO interoperability profiles; capable of integrating payload modules without interfering with other existing components (plug-and-play).
2	Commonality	The appliqué kits for converting tactical wheeled vehicles into robotic platforms must include a “Kit A" and "Kit B”. The Kit A is the brains and should be common across the fleet. The Kit B is platform specific and may include such things as sensors, camera's, GPS and IR lights and actuators.
3	Increased NLOS and LOS capability (COMS)	Reliable capability is needed to extend LOS and NLOS control especially in complex/urban terrain, culverts, and underground. Capability must be able to provide extended network and communication capability.
3	Improved Culvert Interrogation Ability	The capability for robots to operate in the subterranean level, in culverts 24 inches in diameter, and for extended distances is needed. The capability could be used with tether, autonomy, radio relays, or other technologies.
4	Frequency Spectrum Adaptability	Frequency Spectrum Adaptability – The frequency range of the UGV emitters must be flexible enough to adapt to changes in DoD and non-DoD frequency spectrum allocations, as well as being capable of being used in civilian bands, both in the continental U.S. and overseas. Additionally, multiple UGVs must be capable of operating in the same area without degradation of control or operational effectiveness. Must be CREW compatible.
5	Extended Mission Duration	Capability is required to extend the various missions of UGVs. Robots must be capable of providing persistent stare capability for extended mission durations. Robots must operate in increasing range and mission duration while reducing impact to the Soldier's burden. Continuous operation for 7-24 hours without recharging power supplies is desired. This does not necessarily mean extended battery life; the capability could be achieved through other means.
6	COMSEC Encryption Capability	Robots must possess embedded capability to encrypt/decrypt or encode/decode using approved techniques with existing COMSEC equipment up to experimental techniques applicable to NSA certification criteria.
6	Net-Ready KPP	Robots must be able to enter and be managed in the network, and exchange data in a secure manner to enhance mission effectiveness.

Priority	Technology Area	Technology Needs
7	Common Controller	This capability need varies from a controller capable of controlling four or more UxVs to a controller capable of controlling numerous plug-and-play payloads. Any controller needs to be lightweight, and readable in full direct sunlight and moon-less night (with night vision goggles).
8	Improved Optics	Capability needed for sensors systems that allow faster detection in all lighting conditions (including those with limited visibility such as dust, rain, and fog) at increased standoff distances, with lower detection error rates.
9	Health Management System	Capability to utilize Condition Based Maintenance Plus; HMS will provide information for the logistics Common Operating Picture to assist commanders with fore-casting supply requirements, combat power, and maintenance needs. Current robots do not include this capability.
10	Render Useless Mechanism	The capability is needed for a render-useless mechanism that can be initiated from a distant control source.
11	Layered, Escalating Defense Mechanisms	Capability needed for non-lethal intrusion prevention, and layered, escalating self defense capability.
12	Audio Directional Detection	Sensors systems needed that allow faster detection at increased standoff range, with lower detection error rates and increased mission duration (improvement on current capability).
13	Explosive Detection	Capability needed for a modular (plug-and-play) capability to detect explosive hazards IAW explosives library.
14	Embedded Training Capability	Capability for platform specific individual (operator/maintainer) tasks within live, virtual, and constructive environments with collective training capability (up to Battalion level) for FSO- mission essential tasks within live, virtual and construc-tive environments.
15	Location Reporting	Capability needed to provide platform location as a distance and direction reading from the operator's position with greater accuracy showing direction of move-ment, and sensor orientation to the operator.
16	Integrated Tool Kit	Capability to utilize an integrated tool kit is needed. Manipulator arm selects tool for end-effector.
17	Dismounted Mission Enabl-ing Robotics	Capability to enable robots as co-combatants with increased intelligence and durability.

3.3 RS JPO Priorities

As the RS JPO pushes forward to meet the robotic needs of the Warfighter, we recognize the need to modernize and enhance fielded robotic systems. Currently, the RS JPO manages systems that are in all phases of the acquisition life cycle, bringing rise to many unique opportunities and challenges. Sustaining and improving the currently fielded fleet is one of our top priorities. Along with this stated priority is the application of lessons learned to emerging POR to ensure today's shortfalls are addressed in tomorrow's materiel solutions. Overarching all of these goals is the duty to provide unmanned ground systems that are multi-mission, have modular payloads, and are able to work within a teaming environment. To achieve these goals, the RS JPO is leveraging both internal and external talents through established working relationships with all four Services' technology bases and by identifying near, mid and long term needs for UGVs.

3.3.1 Modernization

Fleet management and modernization are critical for UGS as shrinking defense budgets will reduce the number of approved and resourced robotic capability documents. Leveraging currently fielded systems through modernization will allow for the Warfighter's needs to be addressed as new robotic systems are brought online through the CDD and CPD process.

Numerous improvement efforts have been developed and are currently underway across the fleet of RS JPO fielded systems. Many of the systems in the field are early 21st century designs with software and payloads that feature 10 year old technologies. Sustainment of these systems has revealed some instances where a slight change in the design or the addition of a part can drastically reduce failures. As an example, the PackBot system was experiencing inoperable payloads as a result of bent payload pins. By working with the OEM, the Payload Pin Alignment Insert (a plastic insert) was developed to protect against pins bending when payloads were reinstalled. This system modification has been issued to the field with positive feedback.

The RS JPO maintains a consistent strategy to leverage fielded systems to the maximum extent possible. Limited software and hardware upgrades are being applied to systems like the TALON 3B and PackBot 510 to provide more modernized and enhanced capabilities. As mission needs change, the strategy is to further enhance systems capabilities by the addition of improved payloads and optics. The following paragraphs provide an overview of the short term improvement/ modernization plans for several of the currently fielded systems.

PackBot Modernization

Multiple variants of the PackBot have been fielded, including the PackBot 500 EOD, PackBot 500 FIDO, and PackBot 510 FasTac. Modernization of the fleet is underway to baseline the configuration to a common platform with plug-and-play payload variants based upon mission requirements. The common platform will be a FasTac 510 with Aware 2 software. Aware 2 provides resolved motion, preset poses, improved graphic user interface (GUI), snapshot to memory, and enables the plug-and-play modularity of multiple different payloads configured for the PackBot chassis. Phase I of this upgrade includes:

- 500 series robots (FIDO and EOD) will be upgraded to the 510 chassis and Amrel OCU, keeping the existing three link arm, FIDO sensor (if equipped), tracked flippers, and shipping case,
- Existing FasTac robots will also be upgraded to Aware 2. The FasTac payloads (Camera Arm Manipulator [CAM], Short Arm Manipulator [SAM], and untracked flippers) will be retained with the robot,
- Additional payloads will be procured for the upgraded FasTac, and optionally provided according to the mission requirements
    - The 510-series three link arm (Manipulator 1.0) in shipping case
    - Enhanced Awareness Package payload provides a wide angle driving camera with light emitting diode (LED) lighting and a speaker/microphone
    - Tracked flippers.

Future modernization of the platform will be pursued with incremental development and fielding of modular payloads compatible across the platform. Capabilities being considered include:

- COFDM radio for improved LOS/NLOS range

- Wide Angle Robotic Vehicle Vision System (WARVVS) camera for super wide angle video imaging (180o FoV)
- Thermal camera for use at night, in fog, or in dust
- User Assist Package (UAP) for the following user assist behavior
    - Retrotraverse (on command and loss of comms)
    - Self-righting
    - Global Positioning System (GPS) mapping with Auto-Trak
    - Gripper Force Feedback
- Taller antenna on robot chassis for improved radio range
- Improved lighting for long distance viewing at night

Features being considered for a future block upgrade to the software include:

- Ad hoc Mobile Mesh Network with radio repeaters
- Improved video compression and network drivers for enhanced video
- Embedded reliability functions, including a one-hour meter for all processor-controlled payloads and on-board prognostics
- OCU-Initiated calibration of all payloads

MARCbot Modernization

The MARCbot has been fielded since 2004, with 850 robots deployed. In 2008, the system was upgraded to replace the control and video radios with a single digital radio at a higher frequency (due to the jamming frequencies when used OCONUS). The custom suitcase controller was replaced with ruggedized notebook personal computer (PC) and game-style hand held controller. Upgrade kits were procured to convert the entire fleet of MARCbots to MARCbot IV-Ns. In 2010, a radio upgrade kit was developed to convert the MARCbot IV-N wireless data link to the unlicensed frequency band for training in CONUS when the Army Spectrum Office disallowed the frequency employed OCONUS. Upgrade kits were procured for all robots used at CONUS sites. Both upgrades are being handled in-house at the RS JPO JRRF and JRRDs.

Future modernization being considered for this platform includes a software upgrade to a more capable version of the robot's operating system which will provide the following additional features:

- Line of sight radio range improvement of 50% through better network drivers
- Extension of the Non-line of sight range around physical barriers (daisy chain the robots) with radio repeaters enabled by the ad hoc mobile mesh network software (MANET) in the upgrade
- Collaboration between operators with all equipment on the mesh network visible and controllable by all operators
    - Shared video and pictures
    - Live chat via text messaging
    - Data file transfer between OCU nodes and bridging to external nodes
    - GPS location information of robots (military grid reference system [MGRS] coordinates and Falcon View and Google Earth maps)
- Plug-and-play modularity for devices with an IP interface (cameras, sensors, and audio) for future expandability and obsolescence mitigation

TALON Modernization

Modernization for the TALON robotic system has been ongoing over the last several years. As the workhorse for the Route Clearance (RC) teams, users of the TALON are consistently requesting greater capabilities and increased operational readiness time. The operation of the TALON during Route Clearance missions has increasingly become more of a mounted mission, as users have become dependent on the safety of armored vehicles. Deployment of the TALON system onto the ground can now be accomplished without a soldier dismounting from the safety of their RG 31Mk5E vehicle. The Robotic Deployment System (RDS) outfitted on the RG 31 MK5E vehicle remotely stows and deploys the TALON to allow the completion of a RC mission. Moreover, the RS JPO has worked with the TALON OEM to develop a remote power on/off capability (CATNAP) for the RDS in order to conserve power during RC travel time when the TALON is stowed. The RDS and CATNAP capabilities are currently being fielded to RCP RG31MK5E trucks through PM Assured Mobility Systems.

Similar to the PackBot modernization effort, the configuration of RS JPO TALON robots is being baselined to a common platform configuration. Currently the RS JPO manages two different TALON configurations; TALON 3B and TALON 4. The TALON modernization plan calls for all TALON 3Bs to be converted to the TALON 4 configuration. The TALON 4 has greater capability and better modularity.

The TALON system has experienced modernization efforts, similar to those mentioned above, in the following areas:

- Radio technology
- BB 2590 battery tray in lieu of the OEM Lead Acid batteries
- Increased situational awareness through the WARVVS 180° wide angle robot camera

Future modernization efforts for the TALON may cover the following technology areas:

- Improved manipulator arm capability to allow for rotation of the arm at the base chassis
- Improved NLOS radio capability
- Wireless rechargeable station

Mini EOD Modernization

The Mini EOD has been a key component for the OEF EOD mission due to its light weight and compact size that allow it to be stored and carried in a soldier's rucksack. The Mini EOD is largely being used for the dismounted EOD missions in OEF. Usage of the Mini EOD has shown that the monocle display can lose its effectiveness depending on the user, as well as the type of environment it is used in. Efforts are underway to increase the effectiveness of the monocle display to eliminate glare issues as well as increase the number of adjustment features for the eye piece to accommodate different user preferences. By switching out the current tactical eyewear used with different glasses, the direct light glare experienced by some users has been virtually eliminated. Additionally, the off-the-face reflection from the eyewear lens is eliminated by the use of a Tac Eye boot and black-out selective lens cover. The adapter solution described is a single modification kit that retains monocle compatibility with both pairs of protective eyewear. The monocle modification kit will be evaluated by a variety of users to ensure the solution will fully correct the issues experienced by users.

Due to the Mini-EOD being the newest system fielded with limited quantities and User feedback, there is a limited modernization plan at this time. Some of the items being considered for modernization are:

- Secondary video output – allow for second video monitor to be used
- Heads down display to increase unit situational awareness
- Arch Camera – ruggedization to reduce failures of being used as a lift point
- Manipulator Arm – improve quick disconnect feature
- Increased NLOS radio communication capability

Small Unmanned Ground Vehicle (SUGV) Modernization
The SUGV is a teleoperated, man-packable, robotic vehicle intended for Military Operations in Urban Terrain (MOUT) and subterranean areas. The SUGV POR was initiated in 2009 and has since undergone the acquisition development cycle of design, develop, test and requirement verification. The SUGV acquisition strategy divided the development of key capabilities into two incremental phases referred to as Increment 1 (INC1) and Increment 2 (INC2). The SUGV system is envisioned to be capable of filling multiple Army roles that require the extension of the perception and influence of the dismounted Soldier. The variety of tasks includes reconnaissance, surveillance, and the application of numerous modular payloads.

Each of the test iterations of the SUGV revealed a small number of capabilities needing refinement in order to satisfy the Combat Developer's requirements. INC1 of the SUGV program system underwent its first characterization testing in FY09. Over 50 improvements were made following FY09 and FY10 tests, including an improved head/latch design, redesigned and strengthened neck structure, ruggedized camera, repositioned microphone, and increased communications ranges to over 900m. In February 2010, the SUGV INC1 successfully conducted qualification testing at Aberdeen Proving Ground to demonstrate that improvements made (as a result of FY09 and early FY10 characterization testing) effectively resolved the identified issues. The INC1 SUGV employs the following capabilities:

- Day/night/thermal cameras
- Laser range finder
- Infrared illuminator
- GPS
- Two-way speaker and microphone
- Ruggedized handheld controller

Future Modernization
The SUGV INC2 has a significant amount of enhancements and features over the INC1 version. INC2 SUGV enhancements are identified below:

- Upgraded software (Aware 2.0)
- Higher capacity central processing unit
- Militarized head – increased ISR capability
- Target location
- National Security Agency (NSA) approved radio
- Tether/spooler payload
- CBRN payload
- Electronic – Tactical Engagement Simulation System (E-TESS) payload
- Manipulator arm

Anti-Personnel Mine Clearing System, Remote Control (M160) Modernization
The M160 will undergo a modernization plan through the integration of product improvements. Future enhancements to the M160 system will follow a structured System Engineering (SE) process to identify and implement the optimal mix of capability enhancements to be incorporated. This process will be conducted by the IPT with guidance and coordination with the Maneuver Support Center of Excellence (MSCoE). Some possible improvements include:

- Development of a remote hitch attachment (vehicle recovery capability)
- Improvement of the mine clearance rate through continued development of the flail tool (chains and hammers)
- Development of an improved electronics package to include the use of additional sensors
- Implementation of lane and explosive marking systems
- Implementation of a common controller with updated video and communication

Prioritization of these and other improvements will be evaluated based on costs, capability improvements, operational effectiveness, and sustainment impacts.

In summary, the operation and sustainment of RS JPO systems referenced above has resulted in a vast amount of knowledge collected with regard to the use of systems, failures experienced, and additional capabilities desired. This knowledge has created a unique opportunity for the RS JPO to leverage lessons learned from current sustainment efforts and apply them to emerging PORs. RS JPO will continue to improve and modernize the currently fielded UGV fleet. This strategy will ensure an increase in operational life for each platform, decreasing the operation and sustainment cost.

3.3.2 Emerging Requirements and Risk Reduction Efforts

One of the key components for the RS JPO's strategy of developing and fielding the most technologically advanced and capable systems involves tracking, observing, and conducting assessments on emerging technologies and concepts. Operational type assessments provide valuable insight into the potential utility of prototype systems and technologies from a Warfighter perspective. The insight provided also affords the opportunity to identify and manage risk areas in emerging PORs or other R&D activities. A successful assessment may also lead to the development of a validated and funded urgent needs statement. Previous operational assessments have lead to the development and fielding of robotic tool kits, enhancements to manipulation, tele-operation, and advanced optics for small robots. Risk reduction assessments, such as the Safe Operations of Unmanned Systems for Reconnaissance in Complex Environments (SOURCE) ATO, SANDI and SMSS, have shown that their perspective technology is reasonably mature and identified areas where further refinement is needed to reach the full set of capabilities required by the User. Identified below are the projected PORs where the RS JPO is actively tracking and involved with the risk reduction assessments.

Autonomous Mobility Appliqué System (AMAS):
AMAS is envisioned as an add-on kit that will functionally enable existing manned vehicles to be converted to optionally manned, unmanned, or mixed manned and unmanned modes of operation. Virtually all tactical combat vehicles are candidates for AMAS kit development. AMAS is comprised of an "A Kit" and a "B Kit." The A Kit includes the hardware box with the processing and decision-making software and payload control functions and will be common across all AMAS platforms. The B Kit includes platform specific cables, hardware, actuators, sensors and additional software as necessary to interface between the A Kit, platform's mission payloads, and the platform's environment. The AMAS CDD is currently in draft form with approval expected in late FY11. AMAS will leverage the lessons learned from a plethora of previous robotic kit development assessments (i.e., Route Runner, Rabbit, Combat Autonomous Mobility System [CAMS] and Convoy Active Safety Technology [CAST]). As part of AMAS risk reduction efforts, the RS JPO is currently involved in the operational assessment of SANDI.

Supervised Autonomy to Neutralize and Detects IEDs (SANDI)
The SANDI program is an unmanned vehicle system designed to provide a standoff capability in route clearance and convoy missions by operating in front of manned vehicles. The remotely operated unmanned vehicle can act as a stand-alone Victim-Operated IED (VOIED) system or support a variety of neutralization payloads and detection sensors. SANDI is capable of operating at higher speeds than traditional tele-operated vehicles. The SANDI program is currently undergoing an assessment in OEF to help establish the limitations of current sensor fusion technologies when employed in a tactical environment. Additionally, through the deployment of the SANDI platform in an operational environment, we increase Warfighter familiarity and acceptance of large unmanned vehicles on the battlefield. This familiarization may reduce some of the common safety concerns associated with large unmanned vehicles. It is envisioned that the AMAS POR

will heavily leverage the ANS POR, SANDI, and other appliqué risk reduction programs the RS JPO has been associated with over the last 15 years.

Squad Multi-Purpose Equipment Transport (S-MET)

S-MET will provide the ground combat Soldier a surrogate, squad-sized unmanned platform, which will serve as a utility and cargo transport for dismounted small unit operations. The concept of the S-MET is to carry the approach march load of a squad and do so without negatively impacting the squad's operations. The S-MET will have the capability of operating in all types of terrain while in three control regimes; tele-operation, semi-autonomous and autonomous.

A current concept platform being used as a risk reduction is the SMSS is an unmanned platform primarily designed to serve as a utility and cargo transport for dismounted small unit operations. The vehicle is meant to lighten the load of the nine- to 13-man squads or teams by carrying their equipment, food, weapons, and ammunition (up to 1,200 pounds) on unimproved roads and cross-country terrain. The SMSS systems have participated in both a Military Utility Assessment (MUA) and an independent evaluation in mountainous terrain. Results of both the assessment and evaluation identified needed improvements and further development in technologies in order to meet the requirements in the S-MET CDD. The results of the MUA were used to inform the CDD and its development to ensure it is written with clear, reasonable and feasible requirements in relation to current and near future technologies. Both of the evaluations were also beneficial to the RS JPO, as it informed a decision for the program office to send two SMSS vehicles into OEF for a Forward Operating Assessment for further risk reduction and requirements validation.

Other efforts have been and currently are being used as risk reduction efforts in relation to the S-MET requirement. The Multifunctional Utility Logistics Equipment (MULE), Autonomous Expeditionary Support Platform (AESP), Squad Robotic Support Utility Vehicle (SRSUV) are current concept platforms that are being leveraged for risk reduction purposes through various testing and demonstrations.

Multi-Mission Unmanned Ground Vehicle (MM UGV)

The MM-UGV will provide the maneuver platoon with an armed unmanned capability, and the maneuver company with the capability to detect, mark, and report IEDs. The MM-UGV consists of two variants explained below:

- The lethal variant has the capability to locate and destroy enemy platforms and positions in any operational environment. It can provide Reconnaissance, Surveillance and Target Acquisition functionality from an over watch position, providing the ability for direct fire support that will allow Soldiers to remain in a covered/concealed position. It can be maneuvered semi-autonomously or by tele-operation, based on the operational tempo using the ANS. The MM-UGV articulating suspension allows it to traverse complex terrain
- The C-IED variant will provide the maneuver company with the capability to detect, mark, and report IEDs. The C-IED variant will deploy an array of sensors to enhance IED detection and a manipulator arm to probe suspected locations. The C-IED platform will mark and report the IED, allowing follow-on units to bypass the IED. The C-IED can be operated by tele-operation or semi-autonomously to maximize safe stand-off distance for the Soldier

The CMP chassis is serving as a risk reduction effort to the development of the MM UGV variants. The CMP chassis provides superior mobility, built around advanced propulsion and articulated suspension system. The testing and refinement of the CMP chassis will enhance the MM UGV's ability to negotiate complex terrain, obstacles, and gaps that mounted and dismounted troops will encounter. Examples of specific risk reduction activities being conducted on the CMP include engine lifetime testing, mobility and non-pneumatic tire testing. Results from testing done on the CMP will be leveraged to ensure success in meeting MM UGV high risk requirements.

3.3.3 Interoperability

Interoperability is integral to the success of missions using unmanned systems, and represents a long term objective of the RS JPO and its stakeholders. The urgent needs in theater and corresponding rapid acquisition approach during recent years have resulted in a current fleet of robotic systems that generally do not interoperate with each other or with external systems. Additionally, current systems are not optimized to share information into other domains beyond UGS. As payloads, sensors, software, and computing devices are anticipated to evolve much faster than the base platforms, creating interoperable interfaces for enhanced modularity represents an opportunity to minimize future life cycle costs and adapt rapidly to changing threats or new available technologies. The Combat Developer community is also calling for interoperability as a critical element to the future UGS fleet. Based on these concerns and opportunities, the RS JPO has initiated a strategic effort to develop the necessary elements for achieving interoperability.

The RS JPO Interoperability IPT has been formed with representation from a variety of agencies who possess the critical expertise required to define an integrated and optimized path toward interoperability. The IPT's objective is to define interoperability standards for integration across UGS, while leveraging the interoperability efforts of the UAS community and the NAVEODTECHDIV to the greatest extent possible. The scope for this effort includes defining the following:

- Open architecture and interfaces
- Common control standards
- Communications data link standards
- Modular payload interfaces
- Conformance, verification, and validation criteria

The Interoperability IPT will establish, adopt and apply interoperability standards for UGS by working closely with the Combat Developers, the S&T community, and private industry. The SAE Standard AS-4 (JAUS) will form a basis for the interoperability architecture.

Interoperability Methodology

The RS JPO intends to achieve these objectives through the development and use of IOPs. These IOPs will contain a set of interface definitions and requirements for physical, electrical, software, control, data, communications, and human elements, as well as implementation guidance for SAE AS-4/JAUS message sets.

The following overall process is being utilized for the development and application of the IOPs:

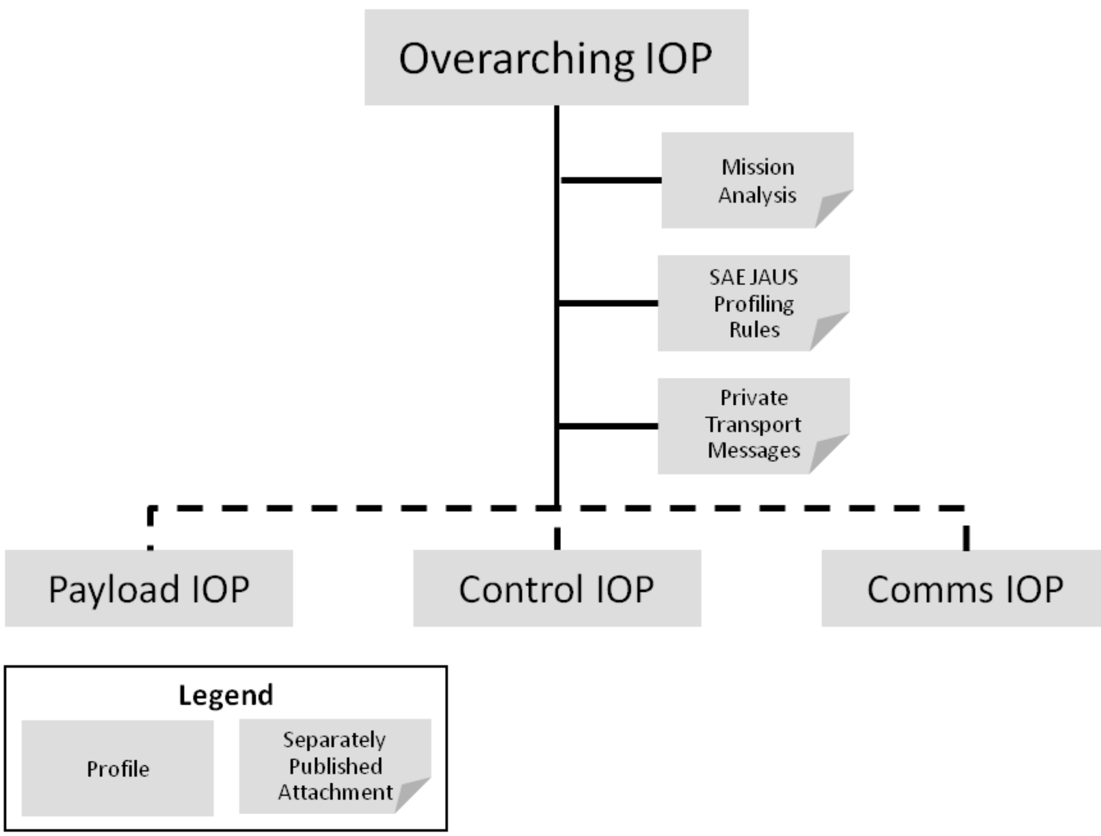
- Develop and refine Mission Profiles and Use Cases – a summary of operational requirements and how UGS are currently being used
- Decompose to understand Functional Requirements – a listing of what functions the UGS fleet must perform, in relation to interoperability
- Develop IOPs to define software and hardware interfaces – this will lead to the publishing of the IOPs themselves
- Refine IOPs over time to outpace TRADOC requirements and technology advancements – an annual publishing of IOPs is planned, starting with IOP V0 by the end of FY11
- Utilize RSIL to Validate IOPs and Assess Conformance to them – this will be used in confirming that the IOPs ensure interoperability as planned, and in determining commercial vendors' level of compliance with the IOPs

- Implement IOPs in Performance Specifications for UGV Acquisitions – this will ensure that the actual fielded system acquisitions are interoperable

The IOPs consist of a series of documents, depicted in
Figure 16 – RS JPO Interoperability Profiles (IOPs) Hierarchical Structure:

- Overarching IOP – Defines platform level mobility, network, messaging and environmental requirements, and their conformance/validation criteria
- Mission Analysis Attachment – Includes a summary of operational requirements and use cases
- SAE JAUS Profiling Rules Attachment – Includes specification, clarification, and implementation guidance on the SAE JAUS standards
- Private Transports Attachment – Includes guidance on the formulation of messages not currently within the SAE JAUS message sets
- Payload IOP – Defines payload classifications, standards, requirements, and conformance approach
- Communications IOP – Defines communication standards, requirements, and conformance approach
- Control IOP – Defines Operator Control Unit logical architecture, standards, requirements, conformance approach, and command and control messages

Figure 16. RS JPO Interoperability Profiles (IOPs) Hierarchical Structure

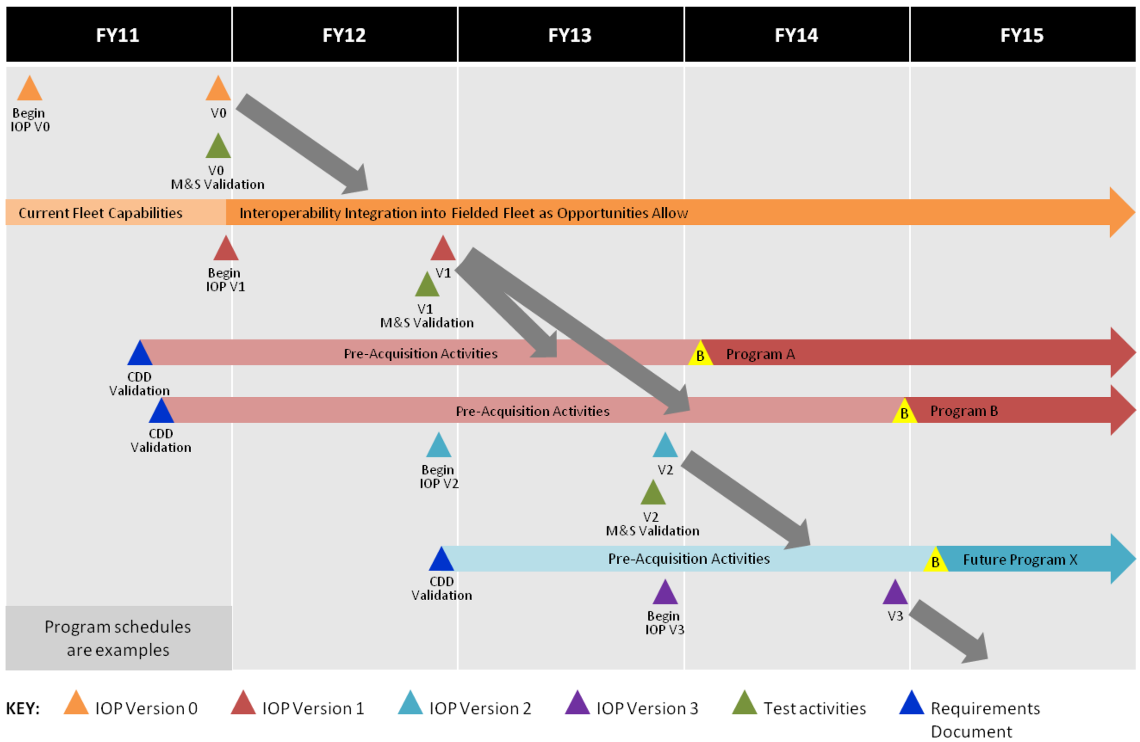


In November of 2010, a government/industry WIPT structure was stood up in order to strengthen the long term collaboration and synchronization of ideas, and to formally develop the IOP V0 package. The WIPT structure includes representatives from a variety of government organizations, as well as industry volunteers from over 35 companies. These individuals are divided into

Overarching, JAUS Profiling, Payload, Control, and Communications WIPTs, with the mission of publishing the IOPs and updating them over time.

Schedule
As indicated in Figure 17 – RS JPO I IOP Adoption Process in Defense Acquisition Framework, IOP V0 will be published by the end of FY11. The scope of IOP V0 is limited to capabilities that are currently common to fielded systems. Fielded platforms will be modified to comply with IOP V0 if opportunities present themselves for modification of existing systems, in terms of requirements and funding. During FY12, IOP V1 will be published, which will include an expanded set of capabilities, consistent with those capabilities in the nearest term emerging PORs. Those PoRs will then be required to comply with IOP V1. The process will continue each subsequent FY, with IOP V2 being published in FY13 affecting future PoRs at that time, and so forth.

Figure 17. RS JPO Interoperability Profile (IOP)
Adoption Process in Defense Acquisition Framework



Implications to Stakeholders
The decision for the RS JPO to pursue this interoperability approach will have a number of implications to UGS stakeholders. For the RS JPO, realization of these interoperability objectives will mean a lowered life cycle cost for systems over time, as it will broaden the base of competition and change the industrial landscape. Additionally, it will give the RS JPO the ability to rapidly adapt its systems in reaction to changing user requirements and technological advances over time. This means enhanced capability for the Warfighter and reduced cost to the taxpayer.

For the Combat Developer community, the results of this interoperability effort will mean realization of the capabilities envisioned in the Unmanned Systems ICD and related requirements documents.

For industry, this interoperability approach means that companies with business models that favor closed-architecture products will ultimately either lose market share or need to adapt their business strategies. For companies who have business models based on open architecture and non-proprietary interfaces, or for those who want to market their payloads to a larger variety of OEMs, this means an opportunity for increased business.

As the RS JPO/Army continues to transition systems and capabilities into the hands of the Warfighter, interoperability matures and will result in a standard scalable capability allowing manned and unmanned platforms to operate between tele-operation and semi-autonomous modes.

3.4 Conclusion

In Summary, as the RS JPO/Army continues to transition systems and capabilities into the hands of the Warfighter, interoperability matures and will result in a standard scalable capability allowing manned and unmanned platforms to operate between tele-operation and semi-autonomous modes. Acquisition and life cycle costs are expected to decrease due to fewer platform types and increasing quantities. Some specialized UGV systems will still be required for emerging requirements but should share common sub components when possible. The long-term capability gaps as well as the RS JPO UGV strategy, are evolving to address the need for systems to be transportable (vehicle, self, soldier) and improving robotic appliqué kits.

Appendix A: RS JPO Systems/Programs Portfolio

A1 Anti-Personnel Mine Clearing System, Remote Control (M160)

OCU

M160 Platform

Mission: Area Clearance and Route Clearance missions
User Service: U.S. Army
Manufacturer: DOK-ING D.O.O., Demining and Manufacturing, Zagreb, Croatia

Program Description:
The Anti-Personnel Mine Clearing System, Remote Control (M160) is a component system in the Area Clearance FoS that responds to the U.S. Army Area Clearance Family of Systems CPD, approved by HQDA Revision 1, 11 March 2010. The Area Clearance FoS provides the capability for current and future Joint and Army Forces to clear the full range of anti-personnel (AP) mines quickly and safely to support operational deployments. The FoS will be employed at Division and Corps levels and generally task-organized with the Engineer Brigade or Combat Support Brigade. The M160 is a legacy, contingency system which transitioned to a post-Milestone B, ACAT III Non-developmental Item program.

The M160 is an improved version of the COTS DOK-ING MV-4A. Integration of performance improvements to the MV-4A mechanical, electronics and control and communications subsystems increased reliability and durability resulting in the production of the DOK-ING MV-4B model.

An authorized nomenclature and model record number for the Anti-Personnel Mine Clearing System; Remote Control MV-4B was released by the Standardization Branch on 04 March 2010. The new model number, M160 has replaced the OEM model number (MV-4B).

The M160 tracked combat engineer vehicle is designed for teleoperation by Soldiers from either mounted or dismounted positions to neutralize AP mines by destroying or detonating them with its rotating flail head. It has been proven to be reliable and very effective in clearing AP mines and explosives in OND and OEF. The vehicle will continue to be improved through the modernization plan to provide stand-off protection to soldiers as areas are cleared of AP mines.

System Characteristics:
Size .... 209" L x 80.1" W x 58.3" H (Flail arms extended)
Weight (robot) .... 12,184 lbs
Weight (OCU) .... 10 lbs
Endurance .... 2-7 hrs (depending on fuel consumption rate)
Max Speed .... 3.1 mph (5kph)
Engine .... 275 hp Perkins Turbo Diesel engine

Payloads: N/A

Capabilities:
- Clearing capacity is 500-2000 square meters per hour depending on terrain
- Capable of clearing a path 68 inches wide and up to 8 inches in depth
- Four cameras (one on each side, front camera has an IRIS Control and Zoom capability)
- OCU has video capability

Program Events and Associated Timelines:
- Log Demo: Completed in September 2010
- Initial Operational Test and Evaluation (IOT&E) Event: 28 November 2010 – 10 December 2010
- Program of Record Safety Confirmation received – 23 February 2011
- MDA Program Certification (MS C): 3rd Qtr FY11
- Full Materiel Release/Type Classification Standard: 1st Qtr FY12
- First Unit Equiped: 2nd Qtr FY12
- Initial Operational Capability (IOC): 3rd Qtr FY12
- Full Operational Capability: 1st Qtr FY13
- Fielding: 48 Systems are currently fielded with an additional 17 systems fielded by FY14 which will meet the Army Acquisition Objective total of 65

Sustainment Plan:
The M160 will be fielded to Active Duty, National Guard, and Reserve units from 2011 to 2014. Supportability for the M160 System is outlined in the Supportability Strategy, dated June 2010. M160 Supply and maintenance support will be provided by the JRRF, at JRRDs and the OEM, until transitioned to the Standard Army Supply System and Organic Maintenance in late FY14.

The RS JPO is currently conducting a Type I Business Case Analysis (BCA) to determine if the M160 system is a potential candidate for Performance Based Logistics (PBL). The BCA will support RS JPO management in determining the best use of organic/commercial partnering resources for sustaining the M160 system.

A2 PackBot Family of Systems

	 EOD	 FasTac
OCU	**PackBot 510 chassis**	

Mission: Provide the Warfighter standoff for missions involving explosive or hazardous materiels, reconnaissance, and other Combat Engineer missions
User Service: U.S. Army and U.S. Marine Corps
Manufacturer: iRobot Corporation, Bedford, MA

Program Description:
The PackBot is a small, teleoperated, tracked robotic platform. The family of vehicles was designed to inspect and clear suspicious objects during IED and EOD missions. The robot provides a safe standoff distance for the Soldier performing an explosive residue detection, interrogation and removal of suspicious objects. The system includes a remote controlled articulated arm with a gripper and a pan/tilt/zoom color surveillance camera with ultra low-light capabilities. The robot operates at speeds up to 5.8 miles per hour, enabling fast, tactical maneuvers.

The first fielded PackBot robots were the PackBot 500 and the PackBot FIDO, both with a 3-link arm with gripper for manipulating and carrying objects and a proprietary suitcase controller (Portable Command Console (PCC) for the OCU. The arm extends 80", and can lift 10 pounds at full extension and 30 pounds close to the chassis. The head, shoulder and gripper independently rotate a continuous 360 degrees with an auto-focus, 312X zoom color camera that enables the robot to identify, lift, carry, and manipulate small objects. The fully integrated FIDO sensor is used for explosive detection.

A smaller, lighter version of the PackBot was later fielded for route reconnaissance missions. The PackBot FasTac has two smaller arms (SAM, CAM), flippers without tracks, and a smaller, lighter weight, ruggedized PC for the OCU. The FasTac uses a modern version of the original PackBot 500 chassis (the PackBot 510) with a higher frequency embedded radio. The CAM has three degrees of freedom with the same highly capable color zoom camera seen on the 3-link arm, and can extend 29" to view heights up to 41". The SAM has four degrees of freedom with continuous wrist rotation and 185 degrees shoulder pitch. It extends 42" and can lift five pounds at full extension. A software upgrade on the PackBot 510 platform to Aware 2 enables plug-and-play interoperability of all 500 and 510 series payload on the FasTac chassis.

System Characteristics:

	PackBot 500 (3-link arm, PCC)	PackBot 510 (CAM & SAM OCU)
Size	27" L x 20" W x 16" H	27" L x 20" W x 12" H
Weight (robot)	68 lbs	53 lbs
Weight (OCU)	41 lbs	13 lbs
Lift Capacity	10 lbs full extension; 30 lbs close	5 lbs full extension; 15 lbs close
Endurance	3 to 4 hrs	3 to 4 hrs
Max Speed	Up to 5.8 mph	Up to 5.8 mph

Payloads (options):
- Fiber optic spooler
- FIDO explosive detector
- Water bottle charge disrupters
- Enhanced awareness package (compatible with FasTac arms only)
- Thermal camera
- Comm select radio (PackBot 500 series only)
- BB2590 battery cradle upgrade (PackBot 500 series only)

Capabilities:
- Carry/place explosive charges
- Detect explosives such as RDX, TNT, PETN
- 312x zoom (26X optical, 12X digital)
- Both white and NIR LED arrays for illuminating in all ambient light conditions
- Camera mounted on a slip ring, and can rotate continuously 360 degree
- Modular chassis capable of accommodating a number of different payloads
- Ability to traverse rough outdoor terrains as well as operate in urban environments
- Trackless flippers can be upgraded to tracked flippers

Program Events and Associated Timelines:
RS JPO maintains a fleet of PackBot systems in support of OEF and OND operational and CONUS/OCONUS training requirements identified through an ONS or JUONS.

For the PackBot FIDO, no new requirements exist, and the PackBot 500 chassis is no longer available from the manufacturer. Current PackBot FIDO and EOD robots will be upgraded to the PackBot 510 chassis with Aware 2 software for ongoing sustainment. Future requirements can be met by utilizing the 510 chassis with plug-and-play modularity of the Aware 2 software. Payloads from existing PackBots are modular with the upgraded chassis, and can be used along with any new payloads developed to meet mission needs.

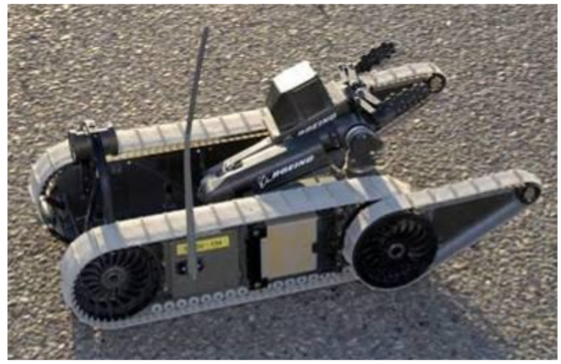
A Safety Confirmation was received in March 2008 for the FasTac system. All FasTac robots will be upgraded to the Aware 2 software in 2011.

Sustainment Plan:
The PackBot was designated by the Capabilities Development for Rapid Transition process as sustain for wartime and will continue to be sustained until overseas contingency operations cease.

The current sustainment for the PackBot FoS is provided by CONUS and OCONUS JRRDs. The JRRDs either replace the entire inoperable robot or replace the broken component and ship it back to the manufacturer for repair.

A3 Mini-EOD

OCU



Mini-EOD

Mission: Identify and neutralize IEDs
User Service: U.S. Army, U.S. Marine Corps, U.S. Navy, U.S. Air Force
Manufacturer: The Boeing Company (Prime) with iRobot Corporation (Sub)

Program Description:
The Mini-EOD system supports a JUONS to assist in EOD operations requiring a smaller robot. The Mini-EOD identifies and neutralizes roadside bombs, car bombs, and other IEDs and is specially designed for locating, identifying and disarming explosive and incendiary devices, and collecting forensic evidence.

The Mini-EOD is a small, lightweight, Modular Lightweight Load-carrying Equipment (MOLLE) pack transportable vehicle operated from a wearable OCU. The Mini-EOD uses a chassis with four cameras allowing a forward/rear facing Wide-Field of View (WFOV), gripper, and body chassis view while utilizing BB-2557 batteries. The Mini-EOD uses a manipulator arm. Together, the vehicle and OCU weigh less than 35 lbs, and can be stowed in a military rucksack or MOLLE pack.

System Characteristics:
Size .... 24" L x 18" W x 11" H
Weight (robot) .... 30 lbs
Weight (OCU) .... 4.4 lbs
Endurance.................................. 90 min
Max Speed................................. 5.8 mph

Payloads:
- Manipulator arm
- Arch camera
- Front and rear cameras
- Lights

Capabilities:

- 360 degree pivotal arm that can lift ten pounds with a reach of two feet beyond the body of the robot
- Capable of moving over most types of terrain
- Night and low-light capable
- Identify and neutralize roadside bombs, car bombs and other IEDs
- Capable of collecting forensic evidence
- Rucksack/MOLLE pack portable
- Wearable OCU
- Capable of 5.8 mph with 5-lb payload

Program Events and Associated Timelines:
More than 320 Mini-EOD systems are being sustained CONUS/OCONUS.

Sustainment Plan:
Mini-EOD systems are currently being fielded in support of contingency operations and are supported only through OCO funding. As a result, no long term sustainment strategy has been developed.

Current sustainment for the Mini-EOD is provided by CONUS and OCONUS JRRDs. The JRRDs either replace the entire inoperable robot or replace the broken component and ship it back to the manufacturer for repair.

A4 TALON Family of Systems

	
OCU	**TALON IIIB and TALON IV (Base Configuration)**

Mission: Engineer Support/Reconnaissance and Surveillance missions
User Service: U.S. Army
Manufacturer: QinetiQ North America, Waltham, MA

Program Description:
The TALON IIIB and IV platforms provide commanders the ability to detect, identify, and neutralize suspected explosive hazards using a tele-operated system. The platforms utilize an articulated arm and gripper, multiple illuminated cameras, a pan/tilt surveillance camera, long range radios, and a ruggedized OCU to execute missions. Additional capabilities available for the TALON IV Engineer include three infrared (IR) cameras, a 300:1 color zoom with wide-angle camera, and a JAUS-compliant design that allows for modular plug-and-play upgrades.

System Characteristics:

	TALON IIIB	TALON IV
Size	34" L x 22.5" W x 11" H	34" L x 22.5" W x 11" H
Weight (robot)	160 lbs	168 lbs
Weight (OCU)	45 lbs	44 lbs
Lift Capacity	10 lbs full extension; 30 lbs close	5 lbs full extension; 15 lbs close
Endurance	3 hrs	4.5 hrs
Max Speed	5.2 mph	5.2 mph

Payloads (Standard [S] and Optional [O]):
- 2-stage manipulator arm w/ wrist gripper (S)
- Extendable pan/tilt/zoom video camera (S)
- Analog video (S)
- COFDM video (O)
- FIDO sensor (O)
- CATNAP remote power on/off system (O)
- Battery tray for BB2590 Li-Ion batteries (O)
- Quick disconnect universal mounting bracket (O) [TALON IV only]
- Hazardous material sensor suite (O) [TALON IV only]
- 2-channel explosive firing circuit (O) [TALON IV only]
- WARVVS camera (O) [TALON IV only]

Capabilities:

- Explosive ordnance disposal using the attached gripper
- Extended detection ranges using the heat contrast detection cameras, night navigation system, and visual cameras
- Fiber optic tether in the event of unusable RF links

Program Events and Associated Timelines:

RS JPO maintains a fleet of TALON IIIB and IV systems in support of OEF and OND operational and CONUS/OCONUS training requirements identified through an Operational Needs Statement or Joint Urgent Operational Needs Statement.

Sustainment Plan:

TALON systems are currently being fielded in support of contingency operations and supported only through OCO funding. As a result no long term sustainment strategy has been developed. There is a desire in RS JPO to move towards a uniform fleet to reduce sustainment footprint and configuration management issues.

In order to sustain the current fleet of TALON systems in theater today, the current sustainment is provided by CONUS and OCONUS JRRDs. The JRRDs either replace the entire inoperable robot or replace the broken component. A plan is in place in order to provide RS JPO the ability to ship broken components back to the manufacturer to have them repaired.

A5 MARCbot

	
MARCbot IV + OCU	**MARCbot IV-N + OCU**

Mission: MARCbot serves as a wheeled reconnaissance robot designed to provide the Warfighter with a remote, look only capability.
User Service: U.S. Army and U.S. Marine Corps
Manufacturer: Applied Geo Technologies, Inc., Choctaw, MS

Program Description:
The MARCbot IV-N is a low-cost IED investigation capability used by U.S. Army and U.S. Marine Corps personnel to provide standoff investigation of suspected IED emplacements. MARCbot IV-N uses an articulating arm to maneuver a camera into position to confirm or deny a suspected IED. The robot is not equipped with a manipulator arm or gripper for manipulating or lifting objects. The ability to confirm IEDs reduces the number of IED false alarm calls and allows the patrol or convoy to proceed with minimal exposure to hostile environments. The MARCbot IV-N is an upgrade to the previously fielded MARCbot IV. All fielded MARCbots will be upgraded to the MARCbot IV-N configuration. Modifications include a digital radio at a higher frequency and improved OCU that consists of a ruggedized PC with game-style hand held controller. The U.S. Government has purchased a Technical Data Package (TDP) with Government purpose rights for the MARCbot IV-N.

System Characteristics:
Size .... 24" L x 19" W x 13.5" H
Weight (Robot).......................... 35 lbs
Weight (OCU) .... 9.5 lbs
Endurance.................................. 4 hrs
Max. speed................................. 5 mph

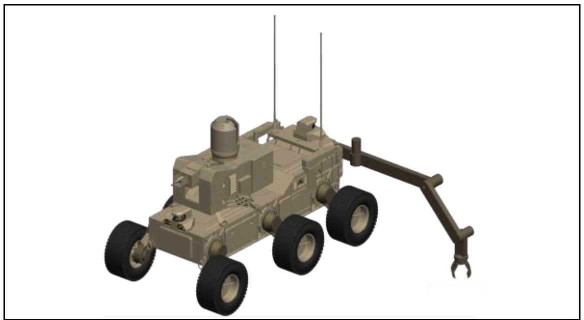
Payloads:
- Retractable pan and tilt color camera with near-infra red LED lighting for low light imaging

Capabilities:
- Remote observation distance greater than 100 meters
- Low-light camera and LED arrays for nighttime mission capability
- Pan/tilt camera can be raised to 3 feet and extended to 1.2 feet to inspect container and other obstacles

Program Events and Associated Timelines:
MARCbot IV-N received a Safety Confirmation (SC) on 26 August 2008. The contractor delivered an additional 496 MARCbot IV-Ns to supplement the already existing 850 MARCbot IVs. These additional units will be used to support OND, OEF, Foreign Military Sales, and training and spares. All current MARCbot IVs will be upgraded to the MARCbot IV-N configuration with the installation of the Line Replaceable Unit (LRU) radio/OCU upgrade kit.

Sustainment Plan:
Systems fielded under JOUNS. The MARCbot is currently designated as a wartime sustained system and will continue to be sustained until OCO ceases.

A6 Common Mobility Platform (CMP)



MM UGV

Mission: Route Reconnaissance and Counter IED Detection
User Service: U.S. Army
Manufacturer: TBD, via full and open competition of the EMD contract

Program Description:
The CMP is a 2.5-ton armored UGV base platform that provides space, weight, power, cooling, and network interfaces for current and future medium self transportable UGV mission equipment payloads. The CMP provides semi-autonomous and tele-operation based maneuver and supports complex mobility requirements across the range of military operations (ROMO). The CMP can accommodate payloads of up to 2300 lbs.

Systems Characteristics:
Size .... 177.3" L x 90" W x 89.4" H (141" H to top of highest antenna)
Weight (CMP) .... 7, 325 (includes 2,000 lbs payload)
Weight (OCU) .... TBD
Endurance.................................. 250 km
Max Speed................................. 65 kph
Engine....................................... 135 HP Multi-Fuel Diesel Engine

Payloads:
Lethal Variant
- M240 machine gun
- JAVELIN missiles
- M66mm Smoke Grenade Launcher
- Electro-optical/infrared sensor
- ANS

C-IED Variant
- Multi-spectral threat sensors
- Air detection system
- High definition cameras
- Robotic manipulator arm
- ANS
- Marking system
- IED reporting system

Capabilities:

- Semi-autonomous operations: step of 1m and gap of 1.8m
- Dash speed: 0-48 kph in 12 seconds
- Open and rolling terrain: 35+ kph (on off-road course)
- Hard surface speed: 65 kph (on concrete surface)
- Move on route (MOR): blind MOR, MOR with perception
- Non-line of sight vehicle control
- Sling Load 2 per CH-47
- C-130/C-17 Air-Droppable

Program Events and Associated Timelines:

- CMP CDR 1st Qtr FY11
- CMP FDR – 3rd Qtr FY11
- CMP Software CDR – 1st Qtr FY12
- CMP Test Readiness Review (TRR) – 4th Qtr FY12
- First CPM delivery (2) – 1st Qtr FY13

Sustainment Plan:

Maintenance planning will be performed in accordance with the Army's two-level maintenance (2LM) concept. The operators and combat repair teams will be responsible for field-level maintenance. Field maintenance consists of operator (crew) maintenance on the actual end item in the tactical area (80%), and maintenance done by the combat repair team (20%).

The MM-UGV maintenance concept is within the U.S. Army guidelines of a 2LM concept. The current philosophy is that field-level maintainers will remove and replace failed MM-UGV LRU and Line Replaceable Modules (LRMs) in accordance with operator and maintainer tasks contained within the MM-UGV Interactive Electronic Technical Manual (IETM). The replaced LRMs, IPM, LIPM, MMWR, and GPS/INS are to be returned to the contractor for repair.

A7 XM1216 Small Unmanned Ground Vehicle (SUGV)

SUGV

Mission: Situational Awareness and ISR for the dismounted Soldier
User Service: U.S. Army
Manufacturer: iRobot Corporation, Bedford, MA

Program Description:
The SUGV is a light weight, Soldier-portable, UGV capable of conducting military operations in urban terrain, tunnels, sewers and caves. The SUGV provides SA/SU and ISR to dismounted Soldiers enabling the performance of manpower intensive or high-risk functions without exposing Soldiers directly to the hazard. The SUGV modular design allows multiple payloads to be integrated in a plug-and-play fashion. The SUGV is capable of carrying up to four pounds of payload weight.

Systems Characteristics:
Size .... 30" L x 17.2" W x 6.5" H (stowed), 26" H (extended)
Weight (robot) .... 35 lbs
Weight (OCU) .... 15 lbs
Endurance .... 6 hrs
Max Speed .... 6.2 mph
Engine .... N/A

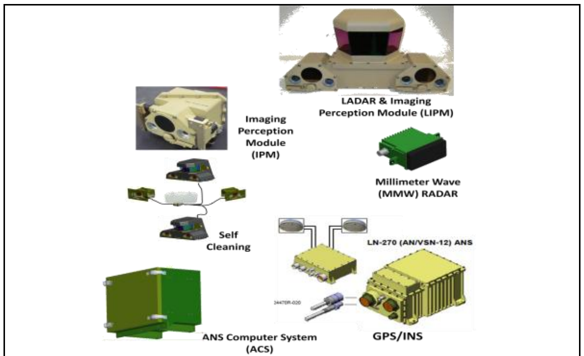
Payloads:
- COTS Sensor Head
  - Day/night/thermal cameras (Increment 1)
- Laser range finder (Increment 1)
- IR illuminator (Increment 1)
- GPS (Increment 1)
- Two way speaker and microphone (Increment 1)
- Ruggedized handheld controller (Increment 1)
- Militarized sensor head (Increment 2) (replaces COTS sensor head)
  - Improved day/night/thermal cameras
  - Inertial measurement unit
- NSA approved radio (Increment 2)
- Tether/spooler (Increment 2)
- CBRN (Increment 2)
- E-TESS (Increment 2)
- Manipulator arm (Increment 2)

Capabilities:
The SUGV provides SA/SU and ISR

Program Events and Associated Timelines:
- 1st Brigade fielding, 3rd QTR FY11
- 2nd Brigade fielding, TBD
- 3rd Brigade fielding, TBD
- INC2 Critical Design Review (CDR), 4th QTR FY11

Sustainment Plan:
Contractor Logistics Support for the first three years

A8 XM155 Autonomous Navigation System (ANS)



ANS

Mission: Force Application, Logistics, Force Support
User Service: U.S. Army
Manufacturer: General Dynamics Robotic Systems (GDRS), Westminster, MD

Program Description:
ANS, designated as XM-155, is the mission sensor and computational package that will be integrated on the CMP to provide robotic semiautonomous capability. The ANS will meet the requirements defined in the draft MMUGV CDD for mobility and safety of an UGV platform. The ANS primary system components are: Laser Detection and Ranging (LADAR) Imaging Perception Module (LIPM), Imaging Perception Module (IPM), Millimeter Wave Radar (MMWR), GPS/INS, self-cleaning system, precision timing module, and the ACS. ANS provides GPS/INS for core navigation, targeting support and timing. ANS provides the sensors and software processing for unmanned operations for day, night, all weather conditions and the platform mobility control for on/off roads, cross country, complex terrain, and dynamic, unstructured environments such as urban road networks. MMWR provides tracking in rain, smoke, or fog along with an early warning for approaching vehicles with high closing rates while the LIPM and IPMs provide obstacle avoidance, human detection, and situational awareness. ACS provides System of Systems Common Operating Environment (SoSCOE) interface, path planning, video processing, hardware sensor processing, object processing, and platform speed and curvature commands. The ANS software development baseline is a three-phase approach. Phase 1 supported simulation and early prototypes using external waypoints at limited speeds. Phase 2 will support early testing and demonstration of ANS capability with prototype operational hardware on current force platforms to reduce risk and improve performance. Phase 3 will meet all requirements for platform speed, terrain types, and operational modes: move-on-route, leader-follower, aided tele-operation, and tele-operation. ANS will provide the hardware and software for unmanned navigation required for UGV platforms to be fielded under this program element and future manned and unmanned ground vehicles. In July 2009, the ANS effort associated with Manned Ground Vehicle (MGV) integration was terminated; however, the ANS program is prepared to work requirements generated by the Ground Combat Vehicle program.

Systems Characteristics:
Size .... Varies with configuration
Weight (robot) .... Varies with configuration
Endurance................................. Same as host vehicle
Max Speed................................ Same as host vehicle (up to 65 kph)
Engine...................................... Same as host vehicle

Payloads: N/A

Capabilities:
- Enables host vehicle to conduct missions autonomously
- GPS/INS core navigation, targeting support, and timing
- Alternative routes
- Day/night capability and all weather
- Vehicle position data
- Conduct semi-autonomous navigation, remote operations
- Detect positive and negative obstacles
- Mobility control for on/off roads, cross country and complex terrain
- Support for situational awareness

Program Events and Associated Timelines:
- ANS CDR – completed March 2010
- Hardware and Phase I software delivery – scheduled for April 2012
- Phase II software delivery – scheduled for October 2012
- Production Readiness Review – scheduled for December 2012

Sustainment Plan:
Maintenance planning will be performed in accordance with the Army's 2LM concept. The operators and combat repair teams will be responsible for field-level maintenance. Field-level maintenance consists of operator (crew) maintenance on the actual end-item in the tactical area (80%), and maintenance done by the combat repair team (20%).

ANS will be provisioned as a Class IX secondary item to its host platform. ANS PBL will be addressed as part of the host platform PBL requirements. PBL is the preferred approach for executing affordable product support so that the accountability and responsibility for the integration of support elements is linked to specific Warfighter performance requirements for weapon system readiness and operational capability. Support for ANS prototype systems will be provided by RS JPO, the Principle System Integrator (PSI), and contractors. It is envisioned that the OEM will provide sustainment support in conjunction with the Principle System Provider (PSP).

Appendix B: Acronym List

.... #
4D/RCS......................... 4 Dimension/Real-time Control System

.... A
ACAT .... Acquisition Category
ACS.............................. Alternate Control System, ANS Computer System
AEODRS....................... Advanced EOD Robotic System
AMAS........................... Autonomous Mobility Appliqué System
AMDS........................... Advanced Mine Detection System
ANS .... Autonomous Navigation System
AP .... Anti-Personnel Mine(s)
APD.............................. Autonomous Platform Demonstrator
APM .... Assistant Project Manager
APU.............................. Auxiliary Power Unit
ARCIC .... Army Capabilities Integration Center
ARFORGEN .... Army Force Generation
ARL .... Army Research Laboratory
ARM .... Autonomous Robotic Manipulation
ARSOF.......................... Army Special Operation Forces
ASA(ALT) .... Assistant Secretary of the Army for Acquisition, Logistics and Technology
ASMO .... Army Spectrum Management Office
ATEC .... Army Test and Evaluation Command
ATO .... Army Technology Objectives
ATO-D .... Army Technology Objective - Demonstrator
ATO-M .... Army Technology Objective - Manufacturing

.... B
BCA .... Business Case Analysis
BCIT............................. Brain Computer Interaction Technologies
BMO............................. Business Management Office

.... C
C^2 .... Command and Control
CAM .... Camera Arm Manipulator
CAMS........................... Combat Autonomous Mobility System
CAN .... Cognition and Neuro-ergonomics
CASCOM .... Combined Arms Support Command
CAST .... Convoy Active Safety Technology
CBRN .... Chemical, Biological, Radiological and Nuclear
CCD .... Charged Coupled Device
CDD .... Capability Development Document
CDL.............................. Common Data Link
CDR .... Critical Design Review
CENTCOM .... US Central Command
CERDEC .... Communications-Electronics Research Development & Engineering Center
C-IED .... Counter Improvised Explosive Device
CMMI .... Command Maintenance Management Inspection
CMOS .... Complimentary Metal Oxide Semiconductor
CMP .... Common Mobility Platform
CoE .... Center(s) of Excellence

COE .... Common Operating Environment
COFDM .... Coded Orthogonal Frequency Division Modulation
COLTS .... Catalog Ordering Logistics Tracking System
COMSEC .... Communications Security
CONOPS .... Concept of Operations
CONUS .... Contiguous United States
COTS .... Commercial-off-the-Shelf
CoV .... Class of Vehicle(s)
CPD .... Capability Production Document
CR................................. Cognitive Radio
CRADA .... Cooperative Research and Development Agreement
CREW .... Counter Remote Control Improvised Explosive Device Electronic Warfare
CTA .... Collaborative Technology Alliance
CWP.............................. Coalition Warfare Project

.... D
DA................................. Department of the Army
DARPA .... Defense Advanced Research Projects Agency
DDL............................... Digital Data Link
DoD .... Department of Defense
DOTMLPF .... Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel and Facilities

.... E
E^3 .... Electromagnetic Environmental Effects
EO/IR .... Electro-Optical/Infrared
EOD .... Explosive Ordnance Disposal
EOR .... Element of Response
E-TESS .... Electronic – Tactical Engagement Simulation System

.... F
FORSCOM .... United States Army Forces Command
FoS .... Family of Systems
FoV .... Field of View
FUE............................... First Unit Equipped
FY .... Fiscal Year

.... G
GHz............................... Giga Hertz
GIG .... Global Information Grid
GPS .... Global Positioning System
GUI................................ Graphic User Interface

.... H
H .... Height, Horizontal
HBCT .... Heavy Brigade Combat Team
HMI .... Human/Machine Interface
HMMWV .... High Mobility Multipurpose Wheeled Vehicle
HMS.............................. Handheld/Manpack/Small Form Fit
hp .... Horsepower
HQDA .... Headquarters, Department of the Army
HRED............................ Human Research Engineering Directorate
HRI .... Human Robot Interaction
Hrs .... Hours

Hz................................. Hertz

.... I

IAW .... In Accordance With
IBCT............................. Infantry Brigade Combat Team
ICD .... Initial Capabilities Document
ICE............................... Internal Combustion Engine
IED .... Improvised Explosive Device(s)
IEEE............................. Institute of Electrical and Electronics Engineers
IETM .... Interactive Electronic Technical Manual
IMOPAT .... Improved Mobility and Operational Performance through Autonomous Technologies
IMS............................... Intelligent Munitions Systems
INS .... Inertial Navigation System
IOC............................... Initial Operating Capability
IOP .... Interoperability Profiles
IOT .... Initial Operational Test
IOT&E .... Initial Operational Test and Evaluation
IP.................................. Internet Protocol
IPM............................... Imaging Perception Module
IPT .... Integrated Product Team
IR .... Infrared
ISR .... Intelligence, Surveillance, and Reconnaissance

.... J

JAUS .... Joint Architecture for Unmanned Systems
JCIDS .... Joint Capabilities Integration and Development System
JCTD............................ Joint Capability Technology Demonstration
JGRE .... Joint Ground Robotics Enterprise
JGRIT .... Joint Ground Robotic Integration Team
JIEDDO .... Joint IED Defeat Organization
JROC .... Joint Requirements Oversight Counsel
JRRD .... Joint Robotic Repair Detachment(s)
JRRF .... Joint Robotics Repair and Fielding Activity
JTRS............................ Joint Tactical Radio System
JUONS .... Joint Urgent Operational Needs Statement(s)

.... K

kW .... Kilowatt
kph .... Kilometers per hour

.... L

L .... Length
LADAR.......................... Laser Detection and Ranging
LAGR .... Learning Applied to Ground Robots
Lbs .... pounds
LED .... Light Emitting Diode
LIDAR .... Light Detection and Ranging
LIPM............................. LADAR Imaging Perception Module
LNO .... Liaison Officer
LOS .... Line of Sight
LRM .... Line Replaceable Module
LRU .... Line Replaceable Unit
LS3............................... Legged Squad Support System

.... M

m .... Meter
M&S .... Modeling and Simulation
MAGIC .... Multi Autonomous Ground-robotic International Challenge
MANET .... Mobile Ad-Hoc Network
MARCORSYSCOM ...... Marine Corps Systems Command
MAST .... Micro Autonomous Systems and Technology
MBT .... Main Battle Tank
MCCDC .... Marine Corps Combat Development Command
MCoE .... Maneuver Center of Excellence
MCSC .... Marine Corps Systems Command
MCWL .... Marine Corps Warfighting Laboratory
MDA .... Milestone Decision Authority
MDD .... Milestone Documentation Decision
MGRS .... Military Grid Reference System
MGV .... Manned Ground Vehicle
MIMO .... Multi Input Multi Output
Min .... Minutes
MM-UGV .... Multi-Mission Unmanned Ground Vehicle
MMWR .... Millimeter Wave Radar
MOCU .... Multi-Robot Operator Control Unit
MOLLE .... Modular Lightweight Load-carrying Equipment
MOS .... Military Occupational Specialty
MOUT .... Military Operations in Urban Terrain
mph .... Miles per Hour
MRAP .... Mine Resistant Ambush Protected
MS................................ Milestone
MSCoE .... Maneuver Support Center of Excellence
MTT............................... Mobile Training Teams
MUA .... Military Utility Assessment

.... N

NATO .... North Atlantic Treaty Organization
NAUS .... Near Autonomous Unmanned Systems
NAVEODTECHDIV ...... Naval EOD Technology Division
NDI .... Non-Developmental Item
NIR................................ Near Infrared
NLOS .... Non-Line of Sight
NLOS-LS....................... Non Line of Sight Launch System
NSA............................... National Security Agency

.... O

OCO .... Overseas Contingency Operations
OCONUS .... Outside the Continental United States
OCU .... Operator Control Unit
ODIS .... Omni-Directional Inspection System
OEF .... Operation Enduring Freedom
OEM .... Original Equipment Manufacturer(s)
OFDM .... Orthogonal Frequency Division Multiplexing
OIF .... Operation Iraqi Freedom
OIPT.............................. Overarching Integrated Product Team
OMA.............................. Operations and Maintenance - Army
OND .... Operation New Dawn

ONS .... Operational Needs Statement(s)
OPTEMPO .... Operational Tempo
OSD .... Office of the Secretary of Defense
OSRVT .... One System Remote Video Terminal

.... P
PATCM .... Product Assurance Test and Configuration Management
PBL .... Program Base Line
PC .... Personal Computer
PCC .... Portable Computer Console
PdM .... Product Manager
PDREP .... Product Deficiency Reporting and Evaluation Program
PEO C3T .... Program Executive Office – Command, Control and Communications - Tactical
PEO GCS .... Program Executive Office Ground Combat Systems
PEO-I .... Program Executive Office – Integration
PEP .... Process Excellence Program
PETN .... Pentaerythrite Tetranitrate
PI .... Product Integrator
PM .... Program Manager(s)
POM .... Program Objective Memorandum
POR .... Program(s) of Record
PQDR .... Product Quality Deficiency Report

.... R
R&D .... Research and Development
R2C .... Route Reconnaissance and Clearance Robot
RADAR .... Radio Detection and Ranging
RAI .... Rapid Acquisition Initiatives
RAMAN .... Regional Atmospheric Measurement and Analysis Network
RC .... Route Clearance
RCIED .... Remote Control IED
RDECOM .... Research, Development and Engineering Command
RDS .... Robotics Deployment System
RDT&E .... Research, Development, Test and Evaluation
RDX .... Hexahydro-Trinitro-Triazine
REF .... Rapid Equipping Force
RF .... Radio Frequency
RFI .... Radio Frequency Interference
RFP .... Request for Proposal
RIK .... Robotic Intelligence Kernel
ROS .... Robotic Operating System
RS JPO .... Robotic Systems Joint Project Office
RSIL .... Robotic System Integration Lab

.... S
S&T .... Science and Technology
SA .... Situational Awareness
SAE .... Society of Automotive Engineers
SAM .... Short Arm Manipulator, Situational Awareness Mast
SANDI .... Supervised Autonomy to Neutralize and Detect IEDs
SANGB .... Selfridge Air National Guard Base
SBCT .... Stryker Brigade Combat Team
SBIR .... Small Business Initiative Research

SC .... Safety Confirmation
SCoE .... Support Center of Excellence
SDD .... System Development and Demonstration
SDR .... Software Defined Radio
SDT .... Second Destination Transportation
SE .... System Engineer
SME .... Subject Matter Expert
S-MET .... Squad Multi-Purpose Equipment Transport
SMI .... Soldier – Machine Interface
SMSS .... Squad Mission Support System
SOC .... Special Operations Command
SOFC .... Solid Oxide Fuel Cell
SONAR .... Sound Navigation and Ranging
SoSCOE .... System of Systems Common Operating Environment
SOURCE .... Safe Operations of Unmanned Systems for Reconnaissance in Complex Environments
SPAWAR .... Space and Naval Warfare Systems Command
SQA .... Software Quality Assurance
SRSUV .... Squad Robotic Support Utility Vehicle
STANAG .... Standardization Agreement
SU .... Situational Understanding
SUGV .... Small Unmanned Ground Vehicle
SWaP .... Size, Weight and Power

.... T

TAC .... Transportation Account Code
TARDEC .... Tank and Automotive Research, Development and Engineering Center
TDP .... Technical Data Package
TNT .... Trinitrotoluene
TPE .... Theater Provided Equipment
TRADOC .... Training and Doctrine Command
TRL .... Technology Readiness Level
TTP .... Tactics, Techniques and Procedures

.... U

UAM .... Universal Antenna Mount
UAP .... User Assist Package
UAS .... Unmanned Aircraft System(s)
UAV .... Unmanned Aerial Vehicle
UGCV .... Unmanned Ground Combat Vehicle
UGS .... Unmanned Ground System(s)
UGV .... Unmanned Ground Vehicle(s)
UMS .... Unmanned Systems
USASFC .... United States Army Forces Command
USASOC .... United States Army Special Operations Command
USMC .... United States Marine Corps
UWB .... Ultra-Wideband

.... V

V .... Vertical
VICTORY .... Vehicular Integration for C4ISR/EW Interoperability
VOIED .... Victim Operated IED
VSIL .... Virtual System Integration Lab

.... W

W .... Watt, Width
W/kg .... Watts per Kilogram
W/L .... Watts per Liter
WARVVS .... Wide Angle Robotic Vehicle Vision System
W-hr/kg .... Watt Hours per Kilogram
W-hr/L .... Watt Hours per Liter
WIN-T............................ Warfighter Information Network- Tactical
WIPT .... Working Integrated Product Team
WLAN............................ Wireless Local Area Network
WNaN .... Wireless Network After Next