Report to Congress

Development and Utilization of Robotics and Unmanned Ground Vehicles

Office of the Under Secretary of Defense,
Acquisition, Technology and Logistics,
Portfolio Systems Acquisition,
Land Warfare and Munitions,
Joint Ground Robotics Enterprise

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Executive Summary

This report responds to Congressional direction to provide information on twelve areas of interest in Department of Defense (DoD) robotics and unmanned ground vehicle (UGV) systems development efforts, including:

- Describing the uses of robotics systems in current world-wide operations
- Past and future Departmental investments, research and development plans
- Industrial base assessments
- How the Department is organized to exploit the promise of robotics technologies in support of warfighter needs

- **Current Military Operations**
  UGVs, in varying sizes to meet mission capability requirements, are today saving lives and providing critical supporting capabilities in current military operations worldwide. Included in the mix is a diverse combination of prototypes, commercial off the shelf (COTS) purchases, and fielded systems supporting our Joint forces in a variety of mission areas, including improvised explosive device (IED) detection and defeat, reconnaissance, explosive ordnance disposal (EOD) and force protection (FP).

- **Major Acquisition Programs**
  Developments in robotics and UGV system capabilities support current major defense acquisition programs of the Department of Defense (DoD) with the most obvious program being the Army's Future Combat Systems (FCS) Brigade Combat Team (BCT). In support of the FCS effort, Modeling and Simulations (M&S) have demonstrated that Armed Robotic Vehicles (ARV) supporting the Mounted Force have improved the survivability of Manned Ground Vehicles (MGV) and contributed significantly to the targeting of enemy forces. Furthering robotic developments, Service laboratories have conducted core research to enable levels of autonomous mobility needed for both current and future systems. The Joint Ground Robotics Enterprise (JGRE, formerly the Joint Robotics Program (JRP)) has supported and continues to support technology maturity efforts that have enabled the fielding of the first generation of robotic UGVs providing a range of current force capabilities.

- **Department Programs and Activities (FY2004-FY2012)**
  There has been a steady increase in research and development activities, Service requirements, Congressional interest, and overall robotics investments since 1990. As technologies have matured, more systems have been fielded, and prototypes have made it into user hands for evaluation. Projections of total current and future DoD investments over the period FY2006-2012 approach $1.7B. DoD plans for near-term robotics investments are focused to leverage rapidly maturing robotics technologies and to meet rising warfighter capability needs for better UGVs.

- **Long Term R&D**
  The military importance of UGV technology is increasing rapidly. UGVs and other robotics now have capabilities to perform missions that are dirty, dull, and dangerous. Science and Technology (S&T) focus is being placed on near and far term research and development (R&D). Research efforts will transition to acquisition programs that will be integrated into the Army, Marines, Air Force, and Naval ground fleets and are described in greater detail in this section. Multiple avenues of technology development and maturation in such areas as mobility, platforms, autonomy, human machine interactions and interfaces, and integration with other UGV and manned systems are being employed to increase the level of DoD unmanned ground system and robotics capabilities.

- **Planned Demonstrations and Experimentation**
  Experimentation at the component or subsystem level is integral to DoD Research, Development, Test and Evaluation (RDT&E) activities and is included in program planning. Emphasizing the importance of demonstrations and experimentation, areas of interest have emerged from warfighter experiences with ground and aerial unmanned systems. The Department intends to explore areas of interest with additional analytic rigor. Included areas of interest are the allocation of spectrum across Services and robotic platforms, the potential for common controllers across the Services and multiple platforms, interchangeable payloads, and collaborative engagements. Along with appropriate supporting demonstrations and experimentation to further programs, an increasingly joint approach to robotics application development, fielding, and fighting is being formed.

- **Robotics or UGV Capabilities Development Organizations**
  A listing is provided of the current DoD organizations participating in the development of new robotics or UGVs and their missions in those efforts.

- **Collaborations with Industry, Academia, other Governmental and Non-Governmental Organizations**
  Collaborative efforts have been a main strategy for development in the ground robotics domain. Furthering levels of collaboration, the JGRE has pursued and is pursuing an active strategy of promoting synergistic collaboration jointly across the Services, with academia, and with industry. Strategic partnerships with government organizations and industry continue to be developed to leverage funding, share technology advancements, accelerate research, development and fielding of solutions, promote synergy across the DoD unmanned systems (UMS) community, and to promote interoperable systems. Collaborative partnerships and teaming initiatives facilitate a focus of resources on basic research in S&T areas likely to produce robotics technology breakthroughs.

- **Short and Long-Term Industrial Base Assessment**
  Challenging robotics technologies are characterized as having significant technical and production risk. Government oversight of production planning and capability is merited. Several unmanned system and robotic developers have demonstrated capable production lines and post-production support systems for the UGVs they have provided for current operations. Rapid prototyping and technical data package transition to industry has been successful for urgent warfighter requests. An FCS Industrial Capabilities Assessments (ICA) found that the industrial base demonstrated the ability to provide unmanned ground systems for System Development and Demonstration (SDD) and is satisfactorily planning for initial production and full-rate production in support of the FCS (BCT) program. For longer term Industrial Base capabilities, future ICAs will better characterize the available technology, manufacturing practices, and capabilities of the industrial base.

- **Progress towards the Goal of Unmanned Ground Combat Vehicles Force Structure Levels**
  The Defense Department is well on its way towards meeting the goal established by the Floyd D. Spence National Defense Act for 2001. By the end of calendar year 2006, DoD will have deployed nearly 4,000 UGVs in support of current operations. UGVs today are clearly proving their effectiveness in current operations, saving lives while supporting operational force tempo requirements. Unmanned capabilities will continue to expand both in quantities deployed and in mission areas supported, to include combat service and Service support.

- **International R&D and Military Capabilities**
  A number of U.S. allies, including Canada, South Korea, Japan, Australia, Germany and the United Kingdom are currently conducting R&D activities directed towards developing military capabilities for robotics and UGVs. Areas of research include focuses on perception, integration for robotic systems, autonomy, control systems for robotic applications, data communications systems, man-machine interfacing and planning, artificial intelligence for robotic systems, and platform related technologies such as weaponization.

- **Role and Placement of the Joint Robotics Program**
  On pages 70-71 of the Robotics subparagraph of the Conference Report to the DoD Appropriations Act, 1989 (Public Law 100-463), H. Rpt. 100-1002, the conferees noted that the Services' robotics programs lacked coordination, and expressed the intent that "The Deputy Secretary of Defense for Tactical Warfare Programs should assume the role of focusing these technology efforts"... and should submit a master plan by May 1, 1989 addressing Department initiatives to advance joint robotics programs. On page 96 of the Conference Report to the DoD Appropriations Act, 1990 (Public Law 101-165), H. Rpt. 101-345, under Title IV-Research, Development, Test and Evaluation, subparagraph Robotics, the conferees directed the "consolidation

of DOD-related robotics funding into one program under the control of the Office of the Secretary of Defense (OSD)", and directed "funding of $21,599,000 in the RDT&E, Defense Agencies account for the new joint program."

The DoD response was to create the JRP, now known as JGRE. The role of the JGRE has remained to (1) provide oversight on the consolidation of efforts; (2) concentrate on establishing definitive robotics operational capabilities; and (3) pursue critical technologies to satisfy capability needs. During FY2006, the JRP expanded its scope to remain ahead of the changing conditions brought about by greater warfighter understanding of how to employ robotics in operational environments and significant advances in robotic technology maturity. This reorientation will take advantage of needs identified in the Department's 2005 Quadrennial Defense Review (February 2006) for institutional emphasis on enterprise-wide approaches versus organization-specific focuses. The JGRE portfolio remains within the Office of the Under Secretary of Defense (OUSD), Acquisition, Technology and Logistics (AT&L), Portfolio Systems Acquisition and under the Deputy Director for Land Warfare and Munitions (LW&M).

- **Mechanisms for Coordinating Development and Demonstration Funding**
  Funding and oversight processes established by the JGRE are designed to complement and dovetail with Joint and Service funding and prioritization processes. Investment decisions are informed by documented user capability requirements well as other sources. In its role of oversight, the JGRE continuously reviews draft and final Appropriations and Authorizations to identify and coordinate its oversight role. With this knowledge base, the Enterprise Director initiates and manages DoD wide engagements with program leads to influence support of robotics and unmanned ground vehicle development.

In answering the specific questions taken from Public Law 109-163, the National Defense Authorization Act for Fiscal Year 2006, the Department describes the current status of robotics development, responsive JRP support to the Global War on Terror (GWOT), and ongoing Departmental positioning to satisfy future needs in an integrated manner across unmanned ground, air, and naval domains.

Following is the Public Law section requiring this report:

Public Law 109–163 (January 6, 2006)
National Defense Authorization Act for Fiscal Year 2006 (H.R. 1815)
Sec. 261. Report on Development and Use of Robotics and Unmanned Ground Vehicle Systems.

(a) REPORT REQUIRED – Not later than nine months after the date of the enactment of this Act, the Under Secretary of Defense for Acquisition, Technology, and Logistics shall submit to the congressional defense committees a report on the development and utilization of robotics and unmanned ground vehicle systems by the Department of Defense.

(b) ELEMENTS – The report required by subsection (a) shall include the following:

(1) A description of the utilization of robotics and unmanned ground vehicle systems in current military operations.
(2) A description of the manner in which the development of robotics and unmanned ground vehicle systems capabilities supports current major acquisition programs of the Department of Defense.
(3) A description, including budget estimates, of all Department programs and activities on robotics and unmanned ground vehicle systems for fiscal years 2004 through 2012, including the Joint Robotics Program and other programs and activities relating to research, development, test and evaluation, procurement, and operation and maintenance.
(4) A description of the long-term research and development strategy of the Department on technology for the development and integration of new robotics and unmanned ground vehicle systems capabilities in support of Department missions.
(5) A description of any planned demonstration or experimentation activities of the Department that will support the development and deployment of robotics and unmanned ground vehicle systems by the Department.
(6) A statement of the Department organizations currently participating in the development of new robotics or unmanned ground vehicle systems capabilities, including the specific missions of each such organization in such efforts.
(7) A description of the activities of the Department to collaborate with industry, academia, and other government and nongovernmental organizations in the development of new capabilities in robotics and unmanned ground vehicle systems.
(8) An assessment of the short-term and long-term ability of the industrial base of the United States to support the production of robotics and unmanned ground vehicle systems to meet Department requirements.
(9) An assessment of the progress being made to achieve the goal established by section 220(a)(2) of the Floyd D. Spence National Defense Authorization Act for Fiscal Year 2001 (as enacted into law by Public Law 106–398; 114 Stat. 1654A–38) that, by 2015, one-third of operational ground combat vehicles be unmanned.
(10) An assessment of international research, technology, and military capabilities in

robotics and unmanned ground vehicle systems.

(11) A description of the role and placement of the Joint Robotics Program in the Department.

(12) A description of the mechanisms of the Department for coordinating pre-systems development and demonstration funding for robotics and unmanned ground vehicle systems.

Introduction

BACKGROUND: Congress has long identified robotics as a special area of interest, for example, on pages 70-71 of the Robotics subparagraph of the Conference Report to the DoD Appropriations Act, 1989 (Public Law 100-463), H. Rpt. 100-1002, the conferees noted that the Services' robotics programs lacked coordination, and expressed the intent that "The Deputy Secretary of Defense for Tactical Warfare Programs should assume the role of focusing these technology efforts"... and should submit a master plan by May 1, 1989 addressing Department initiatives to advance joint robotics programs. On page 96 of the Conference Report to the DoD Appropriations Act, 1990 (Public Law 101-165), H. Rpt. 101-345, under Title IV-Research, Development, Test and Evaluation, subparagraph Robotics, the conferees directed the "consolidation of DOD-related robotics funding into one program under the control of the Office of the Secretary of Defense (OSD)", and directed "funding of $21,599,000 in the RDT&E, Defense Agencies account for the new joint program."

The Defense Department response was to create the Joint Robotics Program (JRP). As a result of this interest and the efforts by the Department, the forces operating in theater today will employ nearly 4,000 robots by the end of calendar year 2006. These robots are accomplishing high risk missions while simultaneously reducing the loss of life and limb among the Service members serving in European Command (EUCOM), Iraq, Afghanistan, and other Central Command (CENTCOM) locations. Today's battlefield environment unequivocally demonstrates the military utility of robotics applications in combat. More and more robots are being destroyed or damaged in combat instead of Servicemen and women being killed or wounded, and this is the preferred outcome. As robotics technologies proliferate and applications spread to other mission areas in combat service and Service support, robotics will play an increasing role in the success of a broadening range of future force missions. The Department is responding to these trends by positioning itself to further exploit the promise of robotics technology.

PURPOSE: The Department responds to Congressional direction in the National Defense Authorization Act for FY2006 (Public Law 109-163) by providing the Congressional defense committees a report on the development and utilization of robotics and unmanned ground vehicle (UGV) systems.

SCOPE: The Department addresses robotics and UGV systems, including:

- Utilization in current military operations
- Development in support of major acquisition programs
- Department programs and activities for FY2004-FY2012
- Long term Research and Development (R&D)
- Planned demonstrations or experimentation activities

- Departmental organizations' roles and missions
- Collaborations with industry, academia, other governmental and non-governmental organizations
- Short and long-term assessment of the robotics industrial base
- Assessment of progress towards achieving the statutory goal of one third of operational ground combat vehicles being unmanned
- Assessment of international R&D and military capabilities
- The role and placement of the JRP in the Department
- Mechanisms for coordinating pre-systems development and demonstration funding

(1) <u>A description of the utilization of robotics and unmanned ground vehicle systems in current military operations.</u>

Unmanned ground vehicles (UGVs) today are saving lives and providing critical supporting capabilities in current military operations worldwide. A diverse combination of prototypes, commercial off the shelf (COTS) purchases, and fielded systems support our Joint forces in a variety of mission areas, including: improvised explosive device (IED) detection and defeat, scout, explosive ordnance disposal (EOD), force protection (FP), countermining, unexploded ordnance (UXO) clearance, and more. UGV platforms in use today are sized to meet mission capability requirements and range from a hand-launched Throwbot prototype weighing less than a pound, to large systems like the Abrams Panther mine clearing vehicle weighing in at over forty tons. From the onset of the Global War on Terror (GWOT), employment of available UGVs and new capability needs from our forces have been rising steadily. Numbers of UGVs procured and deployed by Department of Defense (DoD) have increased from less than a hundred in 2001 to a number that will approach the 4,000 mark by the end of calendar year 2006.

In late 2003, Central Command (CENTCOM) initiated urgent and compelling requests for support to defeat the improvised explosive device (IED) threat. The Joint Ground Robotics Enterprise (JGRE) Program Managers (PMs) developed a plan that would rapidly provide a significant increase in capability through using small robotic COTS vehicles for EOD forces. Because no single vendor was able to provide the required number of systems needed in the short amount of time available, the JGRE Managers identified five separate vendors that could provide systems quickly beginning in February 2004. System fielding continues today to meet system quantities that have increased dramatically as a result of the deployed systems exceeding operational expectations and broader demand from deployed forces.

The Navy's EOD Technology Division (NAVEODTECHDIV), Space and Naval Warfare (SPAWAR) Systems Center - San Diego (SSC San Diego), the Robotic Systems Joint Project Office (RS JPO), and the Technical Support Working Group (TSWG) provided initial system contracting efforts. The Joint Services EOD served as the program operational technical representative, representing the interests of deployed EOD forces, conducting system assessments, and acting as the EOD advocate to obtain the additional resources necessary to rapidly increase the number of fielded systems. The RS JPO then began providing Total Package Fielding, operation and maintenance training, and system sustainment.

The collaborative efforts of JGRE Managers and industry partners helped ensure a near-term response to a growing threat and began fielding the needed capabilities in only three months. No one agency or industry could have accomplished this alone; it took the collaborative application of thirteen years of JRP lessons learned plus the cooperative efforts fostered by the JGRE to get the needed capabilities to the warfighter.

In January 2005, Army Materiel Command (AMC) designated the RS JPO as the single focal point "in-theater" maintainer for UGVs for all Services. The RS JPO's Joint Robotic Repair Facility (JRRF) now supports all unprogrammed (ONS, JUONS, etc.) and programmed robots in theater funded by GWOT dollars. JRRF facilities are located at Camp Victory, Al Taquadim, Forward Operating Base (FOB) Spiecher, Iraq and Bagram Air Base, Afghanistan, and Embedded Repair Teams (ERTs) sustain robots at the forward edge of battle areas utilizing Joint Service reservists.

A summary of UGVs in current military operations follows:

- **All Purpose Remote Transport System (ARTS)**
  The U.S. Air Force's (USAF) ARTS is a fielded, low-cost, survivable robotics platform (8100 lbs.) capable of remote operations in various mission profiles. The system can remotely employ an array of tools and attachments to detect, assess, and render safe large IEDs and large-vehicle bombs as well as clear UXO from prepared areas. In addition, the system employs a variety of advanced navigation, control, and sensing systems. There are 74 ARTS systems currently fielded. The ARTS is manufactured by Applied Research Associates – Vertek Division out of Randolph, VT.

- **BomBot**
  The USAF-developed and Joint EOD-fielded BomBot is a low-cost, expendable robot for IED neutralization. It's a small, fast, off-road remote control vehicle equipped with a small explosive charge delivery system, and is remotely controlled using either video feedback or simply line-of-sight radio. In employment, a BomBot is driven to an IED; a C4 explosive charge is dropped from the vehicle, which is then driven away, if practical, before the charge is remotely detonated. There are 1,020 BomBot systems currently fielded as of July 2006 with an additional 822 systems scheduled to be delivered this year. The BomBot is currently being manufactured by Innovative Response Technologies in Fairmont, WV.

- **DOK-ing MV-4**
  The MV-4 system is a Mechanical Anti-Personnel Mine Clearing System (MAPMCS) that uses a chain flail and hammers to mechanically defeat anti-personnel (AP) Mines. This system has been procured by the Army to meet the Robotic Combat Support System (RCSS) requirement as a formal Army acquisition program providing current mine clearing capability. Systems are currently deployed in Afghanistan to perform countermine operations, and in Iraq to perform Army engineer route clearance missions. Twenty-one systems have been procured to date from the DOK-ing company of Croatia.

- **Dragon Runner**
  Dragon Runner is a joint development effort between the Marine Corps Warfighter Lab and Carnegie Mellon University (CMU). Dragon Runner is a man-portable system that is completely contained in a single backpack (robot, operator control unit, and control computer). It is used by the Marine Corps for route clearing, building clearing, and trip-wire investigation operations. With its dump body attachment, Dragon Runner is capable of delivering charges to a designated location for remote detonation of IEDs. There have been 12 systems procured, with 10 currently fielded, and an additional order of 4 systems is under development as of August 2006. CMU created a spin-off company to produce the Dragon Runner, Automatika, located in Pittsburgh, PA.

- **EyeBall R1**
  EyeBall R1 is a throwable unmanned ground sensor that is self-righting and provides 360° situational awareness through a low-light capable camera and an audio sensor. EyeBall R1 can be attached to a pole or lanyard, providing visual access to areas above walls, around corners, or below the position of the operating unit. EyeBall R1 is an Israeli-designed system, licensed to Remington Technology Division, in Rockville, MD, for distribution in the U.S. and Canada. Currently, six systems are procured, with three systems involved in an operator assessment.

- **Man-Transportable Robotic System (MTRS) MK 1 MOD 0 (PackBot EOD) and MK 2 MOD 0 (TALON)**
  The MTRS is a fielded Joint Service EOD robotic system for use by Army, Marine Corps, Navy and Air Force EOD technicians. The MTRS provides a capability for the EOD technician to perform remote reconnaissance and neutralization at UXO and IED incident sites. The MTRS consists of a robotic vehicle and an operator control station (OCS) that is small enough to be transported by two people. There are 165 MK 1 systems currently fielded as of July 2006 with an additional 141 systems scheduled to delivered this year. There are 210 MK 2 systems currently fielded as of July 2006 with an additional 155 systems scheduled to be delivered this year. The MK 1 is manufactured by iRobot Corporation in Burlington, MA, and the MK 2 is manufactured by Foster-Miller, Inc. in Waltham, MA.

- **Mine Area Clearance Equipment (MACE)**
  For supporting mine clearing operations on expeditionary airfields, the Air Force employs the MACE flail system, which is rapidly lowered into position at the rear of the vehicle. The system can clear a mine path 3.5 m wide. The flail assembly consists of a rotating axle with 72 chains attached; the end of each of these is fitted with a hammer type head weighing 0.9 kg. The axle rotates at up to 700 rpm. There is 1 MACE currently fielded and 3 more expected by the end of FY2007. The overall goal is 10 fielded systems. The MACE is produced by the Hydrema Joint Stock Company of Stoevring, Denmark.

- **Multi-Function, Agile, Remote Controlled Robot (MARCbot)**
  MARCbot is a low cost IED investigative robot used by Army and Marine Corps personnel to provide a standoff investigation of suspected IED emplacements. MARCbot uses an articulating arm to maneuver a camera into position to confirm or deny a suspected IED, reducing the number of false alarm calls to EOD technicians and allowing the patrol or convoy to proceed with minimal exposure to hostile environments. There have been 500 systems fielded, with an additional 170 systems scheduled for delivery by the end of calendar year 2006. MARCbot is currently being produced by Exponent, Inc. in Phoenix, AZ. The U.S. Government has purchased an Engineering Drawing Package with Government Purpose Rights and currently, Applied Geo Technologies in Choctaw, MS, is working to prove their production capability as an additional source for procurement.

- **Omni-Directional Inspection System (ODIS)**
  ODIS is an approximately 40 lb prototype under vehicle inspection platform that is being developed and assessed for applications pertaining to sealed perimeter checkpoint security and includes newly improved and enhanced modular wheel designs providing the capability for field servicing without evacuation to the U.S. This effort will also evaluate the utility of potential single platform multi-mission rather than relying on multiple robot systems. There are currently approximately 15 ODIS prototypes employed in Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF) today. ODIS is produced by Kuchera Defense Systems of Windmer, PA.

- **Remote Ordnance Neutralization System (RONS)**
  The RONS is a fielded JS EOD robotic system for use by Army, Marine Corps, Navy and Air Force EOD technicians. The Navy is the single Service manager for EOD technology and training. RONS consists of a remote platform and an OCS, and is designed to complement or augment the EOD technician during reconnaissance, access, render safe, pick-up and carry away and disposal activities in extremely hazardous missions involving UXO and IEDs. Currently, 271 RONS are fielded to the four Services. The RONS is manufactured by REMOTEC, Inc. in Clinton, TN.

- **Robo-Trencher**
  The USAF Robo-Trencher is a fielded, converted Ditch Witch 7610 trencher used by Engineering Installation Squadrons (EIS) for communications installations. The trencher has been modified using previously developed modular, fielded ARTS robotic components. Robo-Trencher is able to provide a standoff capability to perform cable trenching and excavation mission in hazardous areas. There are 2 Robo-Trenchers currently fielded with no more planned.

- **Throwbot**
  Throwbot is a small, throwable robot designed for building clearing and short range reconnaissance missions. It has a daylight-only camera and is capable of righting itself upon deployment. Throwbot was designed at the University of Minnesota and is produced by Recon Robotics in Minneapolis, MN. There are 30 units procured and fielded for assessment.

- **Toughbot**
  Toughbot is a small, throwable robot designed for building clearing and short range reconnaissance missions. It contains one driving camera, one omni-directional (OD) camera, and an audio sensor. Toughbot is produced by Omnitech in Englewood, CO. There have been 51 units fielded.

(2) <u>A description of the manner in which the development of robotic and unmanned ground vehicle systems capabilities supports current major acquisition programs of DoD.</u>

The Army's Future Combat Systems (FCS) Brigade Combat Team (BCT) is the Army's Major Defense Acquisition Program (MDAP) to develop and field light, medium and heavy unmanned ground vehicles (UGVs). FCS (BCT) UGVs will support the mounted and dismounted force using the right UGV for the mission. The Armed Robotic Vehicle (ARV) is the heavier UGV that will support the Mounted Force with reconnaissance capabilities to target the enemy and weapon systems to engage and destroy the enemy. Modeling and Simulations for the FCS (BCT) and Training and Doctrine Command (TRADOC) System Manager (TSM) have demonstrated that ARVs supporting the Mounted Force have improved the survivability of manned ground vehicles (MGVs) and contributed significantly to the targeting of enemy forces. The Multi-function Utility/Logistics Equipment (MULE) vehicle is the medium size UGV to support the BCT when soldiers must dismount and engage the enemy. The MULE is lightweight and transportable by UH-60 and CH-47 and provides either firepower (ARV-Assault (Light) (ARV-A (L))) or the capacity to carry food, water and ammo to sustain the dismounted force (MULE-Transport (MULE-T)). The Small Unmanned Ground Vehicle (SUGV) weighs less than 30 lbs and will provide reconnaissance in urban environments including caves, sewers and tunnels. The value of the SUGV has been proven by the use of similar UGVs deployed in Afghanistan and Iraq. The SUGV will be light enough to be transported in the soldiers' packs without losing platform mobility or capabilities. This combination of UGVs in the System of Systems (SoS) concept networked via a Command, Control, Communications, and Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) architecture with sensors and battle command systems, will enable situational awareness and synchronized operations heretofore unachievable. FCS (BCT) tactical units empowered with UGVs will employ a new operational paradigm with unprecedented capabilities to enhance operational and tactical flexibility that will rapidly shape the battle space, improving reconnaissance of various terrains to gain and sustain information dominance enabling the FCS (BCT) to seize and control key terrain that will lead to closing with and destroying enemy forces.

The FCS UGV includes the SUGV, the MULE, and the ARV. There are three MULE variants: MULE-T, ARV-A (L), and MULE-Countermine (MULE-CM). There are two ARV variants: ARV-Assault (ARV-A) and ARV-RSTA (ARV-R). The Autonomous Navigation System (ANS) provides the capability to operate all UGVs in tele-operated mode, semi-autonomous leader-follower mode, and semi-autonomous route following mode. Taken together the UGVs envisioned for FCS are integral to the success of the Future Force BCT and are critical combat enablers on par with other manned FCS weapons and components:

- The SUGV is a lightweight, man transportable system capable of operating in urban terrain, tunnels, sewers and caves. It will weigh less than 30 lbs and carry up to 6 lbs of payload. Payloads will include a manipulator arm, fiber optic tether, electro-optic/infrared (EO/IR) sensor, laser rangefinder, laser target designator, urban unattended ground sensor (UGS) dispenser, and chemical/radiological/nuclear (CRN) detector.

- The MULE program has a 2.5 ton common chassis with three variants to support the Dismounted Soldier and enhance the clearing of anti-tank mines. The MULE-T will carry 1,900 to 2,400 lbs of equipment and rucksacks for dismounted infantry squads with mobility to follow the squad in complex terrain. The MULE-CM will provide the capability to detect, mark and neutralize antitank mines by integrating the FCS (BCT) Ground Standoff Mine Detection System (GSTAMIDS). The ARV-A(L) will have integrated weapons and a reconnaissance, surveillance, and target acquisition (RSTA) package to support dismounted infantry in locating and destroying enemy platforms and positions.

- The ARV is a 9.3 ton common robotic chassis with two specific mission configurations. The ARV-RSTA will support the mounted force providing reconnaissance and surveillance. The ARV-RSTAs using sophisticated on-board sensors will detect, recognize and identify targets with enough fidelity to support the use of line-of-sight (LOS), beyond line-of-sight (BLOS) and non line-of-sight (NLOS) assets to support cooperative engagements. The ARV-A will have an array of lethal armament consisting of medium caliber cannon, missile system and a machine gun system. When teamed with MGVs in the Combined Arms Battalion's (CAB) Infantry Company, the ARV-A enables the commander to extend the area of influence and significantly enhance situational awareness, lethality, survivability, and agility.

- The ANS is an open, modular state-of-the-art navigation subsystem applicable to all FCS (BCT) unmanned and manned ground platforms (except SUGV). ANS components are common across unmanned vehicles and include the following: core navigation sensors, i.e., global positioning system (GPS) and inertial navigation system (INS), perception sensors, autonomous navigation algorithms and software for obstacle detection and avoidance.

Army-sponsored Science and Technology (S&T) programs are critical to the successful fielding of FCS robotic capabilities. Components of the Research Development and Engineering Command (RDECOM) are investigating technologies such as perception, intelligent control, human-robot interface (HRI), advanced locomotion and manipulation. These technologies will provide FCS systems with increased capabilities in high speed mobility, safe operations, tactical behavior and manned/unmanned and unmanned/unmanned system collaboration.

The FCS MDAP contains the largest single program capability requirements for multiple UGVs to support the Army's future force; however, FCS will not be the first Program of Record (POR) to field UGVs to meet warfighter needs. Joint Ground Robotics Enterprise (JGRE) supported programs have enabled the fielding of the first generation of robotic UGVs providing a range of current force capabilities. These systems include the Air Force fielded MK-VI (1995) and All-Purpose Remote Transport System (ARTS) (1998), the Joint Explosive Ordnance Disposal (EOD)-fielded Remote Ordnance Neutralization System (RONS) (1999), the Air Force's MK-VI/F6A (2004), the Army's Robotic Combat Support System (RCSS) (2004), the Joint EOD-fielded Man-Transportable Robotic System (MTRS) (2006), as well as, the USMC's Assault Breacher Vehicle (ABV) (2006). In addition to the tremendous value of information provided from the assessment of COTS technology, each of these pioneering programs have provided key lessons learned to the Joint UGV community, served to validate and extend the state of the art in robotic technologies, contributed to programmatic and technical risk reduction for follow-on programs, and have directly paved the way for development of current PORs and prototype robotic SoS (the Army's Family of Integrated Rapid Response Equipment (FIRRE)) for other first generation UGVs, including the Army's Mobile Detection Assessment Response System (MDARS), and the U.S. Marine Corps' (USMC) Gladiator program, which are summarized below:

- **Assault Breacher Vehicle (ABV)**
  ABV, a USMC program, is a tracked, combat engineer vehicle designed to breach minefields and complex obstacles and provide in-stride breaching capability. ABV utilizes an M1A1 tank chassis as a platform. Equipment includes a Full-Width Mine Plow, two Mk 155 Linear Demolition Charge Systems, Light Vehicle Obscuration Smoke System, two Lane Marking Systems and a Remote Control Systems (RCS). The ABV can be operated manually by a live crew or remotely using the RCS. It is produced by Pearson Engineering, LTD., Newcastle-Upon-Tyne, UK. RS JPO is currently coordinating fielding requirements with Marine Corps Systems Command (MCSC), GTES Directorate, and Program Manager (PM) Engineer Systems.

- **Gladiator Tactical Unmanned Ground Vehicle (TUGV)**
  Gladiator, a USMC program, is an armed, armored combat robot to reduce risk and neutralize threats to the warfighter. The Gladiator carries a range of sensors and weapons including FLIR and day cameras, Shoulder-launched Multi-purpose Assault Weapons (SMAW), M240 or M249 machine guns, Light Vehicle Obscurant Smoke System (LVOSS), and Anti-personnel Obstacle Breaching System (APOBS). The system is teleoperated by a Marine up to 2-4 km from the vehicle. Gladiator is designed by Carnegie Mellon University in Pittsburgh, PA. Projected fielding quantity is 193 systems. The RS JPO is coordinating requirements with Marine Corps Combat Development Command, but the program is currently unfunded.

- **Mobile Detection and Response System (MDARS)**
  MDARS provides commanders with a robotic capability for conducting semi-autonomous random patrols and surveillance activities. MDARS enhances physical security, reduces personnel exposure in dangerous situations, provides continuous surveillance over unprotected high value inventory, reduces manpower requirements, and is an effective means of providing compensatory security in the event of security system malfunction. The MDARS Modernization Program includes detection on the move, increased sensor detection and assessment range, increase platform speed/mobility, and increased system reliability. The prime contractor for MDARS is General Dynamics Robotics Systems of Westminster, MD.

(3) <u>A description, including budget estimates, of all Department programs and activities on robotics and unmanned ground vehicle systems for FY2004-2012, including JRP and other programs and activities relating to RDT&E, procurement, and operations and maintenance.</u>

As technologies have matured, more systems have been fielded, and prototypes have made it into user hands for evaluation, there has been a steady increase in Research and Development (R&D) activities, Service requirements, Congressional interest, and overall investments over the last 16 years. Since 1990, the level of annual Joint Ground Robotics Enterprise (JGRE) appropriations has increased from approximately $20M to almost $50M in FY2006. As a result of U.S. commitment to the Global War on Terror (GWOT) and increasing numbers of Servicemen and women in harm's way, robotics capability needs to meet an increasing range of Joint and Service capability needs have increased dramatically, with Joint and Service robotics investments increasing at an accelerated rate. Current projections of total Department of Defense (DoD) investments over the period FY2006-2012 approach $1.7B. DoD plans for near-term robotics investments are focused to leverage rapidly maturing robotics technologies and to meet rising warfighter capability needs for better unmanned ground vehicles (UGVs).

Funding in the chart below is in $M and rounded to two decimal places. Funding projections below are based upon data in existing approved funding documentation.

Service	Program/Activity (STO name, Technology Project name/ Project type—S&T, RDT&E, Procurement, O&M)	Platform Missions or Program Objectives	# of Prototypes (BA 2-5)	Production Quantities (# of platforms in BA 5-7)	Funding Source	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12
ACTD	Chemical, Biological, Radiological, and Nuclear (CBRN) Unmanned Ground Reconnaissance (CUGR)	• Integrated CBRN sensors for UGV			RDT&E	$0.00	$16.75	$19.00	$9.15	$2.43	$0.00	$0.00	$0.00	$0.00
ACTD	Joint Unmanned Systems Common Control (JUSC2)	• Navy effort to develop software and C2 architecture to tie into legacy unmanned vehicle C2 systems to provide a common operational picture and management tool			RDT&E	$4.00	$8.10	$4.50	$4.25	$4.25	$0.00	$0.00	TBD	TBD
Air Force	AF EOD Enhanced Robot/HD-1	• EOD platform to increase operating distance, handling capability, and operations in ECM environment	3	140	RDT&E PROC	$0.00 $0.00	$0.00 $0.00	$0.20 $12.50	$0.00 $3.50	$0.00 $3.90	$0.00 $0.00	$0.00 $0.00	$0.00 $0.00	$0.00 $0.00
Air Force	All Purpose Remote Transport System (ARTS)	See Question 1 for ARTS mission description	5	74	RDT&E PROC	$1.70 $11.80	$1.90 $4.90	$0.70 $4.40	$0.40 $2.00	$0.00 $0.60	$0.00 $3.30	$0.00 $0.00	$0.00 $0.00	$0.00 $0.00

Service	Program/Activity (STO name, Technology Project name/ Project type—S&T, RDT&E, Procurement, O&M)	Platform Missions or Program Objectives	# of Prototypes (BA 2-5)	Production Quantities (# of platforms in BA 5-7)	Funding Source	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12
Air Force	Joint Architecture of Unmanned Systems (JAUS)	• Advanced JAUS interoperability development			RDT&E	$0.00	$0.31	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Air Force	Mine Area-Clearance Equipment (MACE)	See Question 1 for MACE mission description	3	10	RDT&E PROC	$0.00 $1.50	$0.00 $0.00	$0.30 $7.20	$3.00 $7.20	$3.00 TBD	$0.00 TBD	$0.00 $0.00	$0.00 $0.00	$0.00 $0.00
Air Force	MK-VI/F6A	• Small-size robot to deliver a suite of tools/attachments to attack and defeat small improvised explosive devices (IED) and submunitions.	3	146	RDT&E PROC	$0.00 $4.90	$0.00 $0.40	$0.00 $0.00	$0.00 $0.00	$9.00 $0.00	$0.00 $0.00	$0.00 $0.00	$0.00 $0.00	$0.00 $0.00
Air Force	Next-Generation EOD Remote-Controlled Vehicle (NGEODRCV)	• Provide modular “plug and play” robotic capabilities in multiple interagency mission areas, such as explosive ordnance disposal, search and rescue, swat, fire, and police			RDT&E PROC	$0.00 $0.00	$1.00 $0.00	$0.39 $0.00	$0.00 $0.00	$0.00 $0.00	$0.00 $13.39	$0.00 $6.90	$0.00 $7.08	$0.00 $0.00
Air Force	RC-30	• Remote capabilities to perform reconnaissance • Deployment of render safe devices • Removal of explosive hazards from work environments	1	3	RDT&E	$0.05	$0.10	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Air Force	RC-60	• Potential Air Force replacement for ARTS – lighter-weight candidate for airborne EOD mission	1	TBD	RDT&E PROC	$0.00 -	$0.00 -	$0.30 -	$0.10 TBD	$0.00 TBD	$0.00 TBD	$0.00 TBD	$0.00 TBD	$0.00 TBD
Air Force	Robotics for Agile Combat Support (RACS)	• Develops state-of-the-art robotic capabilities for counter-terrorism and force protection			RDT&E	$6.30	$1.80	$3.33	$4.00	$4.33	$4.43	$4.50	$4.58	$5.00
Army	Armed Robotic Vehicle (ARV)	See Question 2 for ARV mission description	12	708	RDT&E	$10.10	$20.70	$42.30	$40.70	$47.90	$54.10	$53.20	$35.20	$14.10
Army	Autonomous Navigation System (ANS)	See Question 2 for ANS mission description	72	7,300	RDT&E	$4.50	$18.90	$37.50	$28.10	$41.90	$44.30	$26.30	$22.20	$3.70
Army	Crew integration and Automation Testbed (CAT) ATD	• UGV-UAV control • Multi-mission crew station • Autonomous navigation for MGV • Embedded simulation system			RDT&E	$5.49	$4.00	$2.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Army	EyeBall R1	See Question 1 for EyeBall R1 mission description		6	RDT&E	$0.00	$0.00	$0.03	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Army	Mobile Detection Assessment Response System (MDARS)	See Question 2 for MDARS mission description	6	30	RDT&E	$1.00	$1.00	$1.50	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Army	Multi-function Utility Logistics Equipment (MULE)	See Question 2 for MULE mission description	16	1,578	RDT&E	$3.40	$17.30	$33.60	$30.20	$49.20	$43.30	$30.20	$38.40	$16.10

Service	Program/Activity (STO name, Technology Project name/ Project type—S&T, RDT&E, Procurement, O&M)	Platform Missions or Program Objectives	# of Prototypes (BA 2-5)	Production Quantities (# of platforms in BA 5-7)	Funding Source	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12
Army	Near Autonomous Unmanned Systems (NAUS) Advanced Technology Objective (ATO)	• Develop and demonstrate key robotics technologies on an ARV scale mobility platform to reduce risk			RDT&E	$0.00	$5.57	$23.27	$32.26	$23.96	$6.50	$0.00	$0.00	$0.00
Army	Remote Combat Support System (RCSS) (MV-4)	See Question 1 for MV-4 (RCSS) mission description		21	RDT&E PROC O&M	$0.00 $11.80 $0.00	$0.00 $1.52 $0.00	$0.00 $1.53 $0.00	$0.00 $0.00 $0.00	$0.00 $0.00 $0.00	$0.00 $0.00 $0.00	$0.00 $0.00 $0.00	$0.00 $0.00 $0.00	$0.00 $0.00 $0.00
Army	Robotic Co-Combatant Interaction Technology	• Demonstrate ability of UGV to operate in semi-auto mode in urban environment			RDT&E	$0.00	$0.00	$0.00	$0.00	$0.00	$2.87	$5.07	$5.07	TBD
Army	Robotic Follower (RF) ATD	• Provide mounted leader-follower capability to PM FCS (BCT) for integration into ARV, MULE and MGVs for resupply, rear security and NLOS/BLOS Fire mission			RDT&E	$7.10	$6.98	$3.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Army	Robotic Technology	• Efforts focused on advancing perception for autonomous ground mobility, intelligent vehicle control & behaviors, & human supervision of UGV			RDT&E	$0.00	$0.00	$0.00	$0.00	$0.00	$16.53	$16.08	$15.96	$0.00
Army	Robotics Collaboration ATO	• Develop tools, etc. to increase performance of mounted/ dismounted control and effectiveness			RDT&E	$0.00	$20.56	$20.32	$20.51	$22.10	$0.00	$0.00	$0.00	$0.00
Army	Robotics Collaborative Technology Alliance (CTA)	• Research in perception & intelligence for robotic behaviors • Understand interaction of soldiers with unmanned systems (UMS)			RDT&E	$0.00	$2.40	$2.41	$2.63	$2.68	$2.74	$2.79	$2.85	$0.00
Army	Small Unmanned Ground Vehicle (SUGV)	See Question 2 for SUGV mission description	6	1,245	RDT&E	$3.60	$8.10	$11.50	$8.70	$6.70	$4.90	$1.60	$1.80	$1.20
Army	Special Weapons Observation Remote Reconnaissance Direct Action System (SWORDS)	• Talon UGV with M240 machine gun • Remote lethal fires	3	TBD	RDT&E	$0.00	$2.47	$1.15	TBD	TBD	TBD	TBD	TBD	TBD
Army	Toughbot	See Question 1 for Toughbot mission description	51		RDT&E	$0.00	$0.12	$0.36	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Army	Unmanned Ground Systems Technology & Behaviors	• Develop and demonstrate UGV technologies			RDT&E	$0.00	$0.00	$0.00	$0.00	$0.00	$3.90	$6.42	$6.65	TBD
Army/ USMC	Multi-Function, Agile, Remote Controlled Robot (MARCbot)[a]	See Question 1 for MARCbot mission description		670	O&M[b]	$0.00	$0.00	$7.32	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Army/ USMC	Throwbot	See Question 1 for Throwbot mission description	30		RDT&E	$0.00	$0.06	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00

Service	Program/Activity (STO name, Technology Project name/ Project type—S&T, RDT&E, Procurement, O&M)	Platform Missions or Program Objectives	# of Prototypes (BA 2-5)	Production Quantities (# of platforms in BA 5-7)	Funding Source	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12
Joint	BomBot	See Question 1 for BomBot mission description	10	3,330	RDT&E PROC	$0.52 $0.00	$0.00 $10.00	$0.65 $0.00	$0.00 $6.40	$0.00 $0.00	$0.00 $0.00	$0.00 $0.00	$0.00 $0.00	$0.00 $0.00
Joint	Collaborative Engagement Experiment (CEE)	• Army, Navy, AF – Advanced interoperable collaborative UGV technologies			RDT&E (Navy) RDT&E (Army) RDT&E (AF)	$0.00 $0.50 $0.00	$2.80 $0.90 $0.90	$1.18 $0.39 $0.39	$0.00 $0.54 $0.00	$0.00 $0.70 $0.00	$0.00 $0.70 $0.00	$0.00 $0.50 $0.00	$0.00 $0.50 $0.00	$0.00 $0.50 $0.00
Joint	Joint Architecture of Unmanned Systems (JAUS)/AS-4	• Joint messaging architecture to enable interoperable “plug and fight” UGV			RDT&E	$1.40	$1.81	$1.00	$0.40	$0.40	$0.40	$0.40	$0.40	$0.00
Joint	Joint Robotic Repair Facility (JRRF)	• Supports and sustains unprogrammed and programmed robots in theater	N/A	N/A	O&M[b]	$2.50	$17.00	$89.00	$156.0	$0.00	$0.00	$0.00	$0.00	$0.00
Joint EOD	Man-Transportable Robotic System (MTRS)	See Question 1 for MTRS mission description	8	1,377	RDT&E PROC	$2.50 $0.00	$3.75 $47.70	$1.90 $76.20	$1.25 $73.80	$2.00 $16.00	$2.00 $0.00	$2.00 $0.00	$2.00 $0.00	$1.50 $0.00
Joint EOD	Next-Generation EOD Robotic System (NGEODRS)	• Analysis of Alternatives (AoA), Technology Demonstration, and POR to address needs identified in Initial Capabilities Document (ICD) for Joint EOD			RDT&E	$0.00	$0.00	$0.55	$1.50	$2.00	$2.00	$2.00	$2.00	$2.00
Joint EOD	Remote Ordnance Neutralization System (RONS)	See Question 1 for RONS mission description	4	271	RDT&E PROC	$0.50 $9.70	$0.50 $0.00	$0.25 $0.00	$0.25 $0.00	$0.25 $0.00	$0.25 $0.00	$0.25 $0.00	$0.00 $0.00	$0.00 $0.00
JGRE	Family of Integrated Rapid-Response Equipment (FIRRE)	• Ground protection under MANSCEN's 360 degree Hemispheric Fixed Site Protection Concept • Non-lethal and eventfully a lethal unmanned ground vehicle response capability to Project Eagle Eye			RDT&E[c]	$0.00	$12.55	$2.50	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
JGRE	Omni-Directional Inspection System (ODIS)	See Question 1 for ODIS mission description	15	TBD	RDT&E[c]	$0.80	$4.52	$2.12	$1.50	$1.50	$1.50	$1.50	$1.50	$0.00
JGRE	R-Gator	• Load hauling and patrol capabilities through tele-operation • Autonomous way-point navigation, push-pull, or manual operations		2	RDT&E[c]	$0.00	$1.00	$1.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Navy	Automatically Deployed Communication Relays (ADCR)	• Automatic deployment of high-bandwidth digital RF communication relays • Full stand-alone, “plug-and-playable” system designed to be carried by a UGV requiring NLOS operations			RDT&E	$0.15[d]	$0.32	$0.25	$0.54	$0.00	$0.00	$0.00	$0.00	$0.00

Service	Program/Activity (STO name, Technology Project name/ Project type—S&T, RDT&E, Procurement, O&M)	Platform Missions or Program Objectives	# of Prototypes (BA 2-5)	Production Quantities (# of platforms in BA 5-7)	Funding Source	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12
Navy	Man-Portable Robotic Systems (MPRS)	• Developing and transitioning realistic technologies to improve functionality and autonomy of small robots			RDT&E	$0.60	$0.90	$0.63	$1.00	$1.00	$1.00	$1.00	$1.00	$1.00
Navy	Robotics Systems Pool (RSP)	• Inventory of state-of-the-art robotic systems for loan to military users			RDT&E	$1.80	$0.50	$0.55	$0.64	$0.70	$0.75	$0.75	$0.75	$0.75
Navy	Robotics Technology Transfer (RTT)	• Expedites the fielding of robotic technologies to enhance the functionality and autonomy of robotic systems			RDT&E	$0.35	$0.60	$0.55	$1.00	$1.00	$1.00	$1.00	$1.00	$1.00
Navy	Unmanned Surface Vehicle (USV)	• Transitioning core technologies to enable an autonomous USV • Transition UGV navigation and obstacle detection/obstacle avoidance (ODOA)			RDT&E	$0.48	$0.58	$0.53	$1.13	$0.60	$0.30	$0.30	$0.30	$0.30
USMC	Assault Breacher Vehicle (ABV) Robotic Control System	See Question 2 for ABV mission description		33	RDT&E PROC O&M	$0.10 $0.00 $0.00	$1.40 $0.00 $0.00	$2.50 $0.00 $0.00	$0.92 $18.46 $0.00	$0.23 $4.55 $2.70	$0.11 $0.00 $5.30	$0.11 $0.00 $5.33	$0.12 $0.00 $5.41	$0.13 $0.00 $5.51
USMC	Dragon Runner	See Question 1 for Dragon Runner mission description	16		RDT&E	$1.50	$0.80	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
USMC	Gladiator Tactical Unmanned Ground Vehicle (TUGV)[e]	See Question 2 for Gladiator mission description	6	193	RDT&E	$3.40	$16.50	$3.80	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
					RDT&E Fiscal Year Totals[f]	**$61.8**	**$188.5**	**$228.4**	**$194.7**	**$227.8**	**$193.6**	**$156.0**	**$142.3**	**$47.3**
					PROC Fiscal Year Totals[f]	**$39.7**	**$64.5**	**$101.8**	**$111.4**	**$25.1**	**$16.7**	**$6.9**	**$7.1**	**$0.0**
					O&M Fiscal Year Totals[f]	**$2.5**	**$17.0**	**$96.3**	**$156.0**	**$2.7**	**$5.3**	**$5.3**	**$5.4**	**$5.5**
					Totals from FY2006-FY2012[f]			**$1.7B**						

[a] *This system is a COTS item which has been procured to support the war effort – no RDT&E has been expended.*
[b] *Global War on Terror (GWOT) funding.*
[c] *Congressionally added funding not included in Army programmed efforts. Service execution is monitored through oversight by JGRE.*
[d] *Initial RDT&E occurred in FY2003.*
[e] *This USMC capability remains a recognized requirement, but was zeroed from the USMC Program Objective Memorandum (POM) due to war support requirements.*
[f] *Totals were rounded to one decimal place.*

(4) <u>A description of the long term R&D strategy of the Department on technology for the development and integration of new robotics and unmanned ground vehicle systems capabilities in support of Department missions.</u>

Unmanned ground vehicle (UGV) technology is assuming increasing importance to military operations. Unmanned systems (UMS) now have the capabilities to perform missions that are dirty, dull, and dangerous. As the Global War on Terror (GWOT) enters its 5th year, it is apparent that UGVs have a growing role in future missions. UGV research is a Science and Technology (S&T) focus area for all Defense Advanced Research Projects Agency (DARPA) and all Services. Results from these research efforts will transition to support acquisition programs that will be integrated into the Army, Marines, Air Force, and Naval fleets. The Department of Defense (DoD) and the Service's long term strategy on the development and integration of technology into UGVs is described below.

The Joint Services Explosive Ordnance Disposal (EOD) UGV roadmap provides a coordinated plan for equipping Joint EOD technicians and consists of the Remote Ordnance Neutralization System (RONS), the Man-Transportable Robotic System (MTRS), and the BomBot. The next scheduled UGV for development is the Next Generation EOD Robotic System (NGEODRS). The need for the NGEODRS is called out in the Initial Capabilities Document (ICD) for Joint EOD (Navy document # 671-75-05), which is designated Joint Requirements Oversight Council (JROC) Interest. The development of the NGEODRS will be preceded by an Analysis of Alternatives (AoA) in FY2006-FY2007. The AoA will be an analytical comparison of the operational effectiveness, suitability, and life-cycle cost of the alternatives that satisfy JS EOD's need for a NGEODRS development. The AoA will explore numerous conceptual solutions with the goal of identifying the most promising options, thereby guiding the Concept Refinement Phase which will follow. The AoA will be conducted in accordance with current DoD guidance and will build upon prior analyses conducted as part of the Joint Capabilities Integration and Development System (JCIDS) that led to the ICD. The AoA will include the determination of alternatives and effectiveness measures. An effectiveness analysis and a cost analysis will be performed on each alternative to enable cost-effectiveness comparisons of the alternatives to be made.

The Navy's Space and Naval Warfare (SPAWAR) Systems Center (SSC) San Diego has performed supporting technology development and integration for all Services (particularly the U.S. Army and Marine Corps) for the past 25 years. Early robotic security work for Product Manager, Force Protection Systems (PM-FPS) on the Mobile Detection Assessment Response System (MDARS), currently installed at Hawthorne Army Depot (HWAD), is now being extended for force-protection applications in theater under the Family of Integrated Rapid Response Equipment (FIRRE) program. Similarly, SSC San Diego provided the initial tele-operated man-portable prototypes for the Army Chemical School and Engineers School at Fort Leonard Wood under the Man-Portable

Robotic System (MPRS) program, and then worked with iRobot and Foster Miller to develop a commercial off the shelf (COTS) industrial base. The MPRS program is now focused on developing autonomous navigation and collision-avoidance capabilities for small robots. Many of the autonomous navigation technologies developed under MPRS are being transitioned to the Navy under the Unmanned Surface Vehicle (USV) program to support the Littoral Combat Ship (LCS) USV Programs (Program Executive Office – Littoral Mine Warfare (PEO-LMW)). SSC San Diego's Robotics Technology Transfer (RTT) program seeks to identify, harvest, and optimize available supporting technology developed by industry, academia, or government to increase the autonomy and functionality of robotic systems being used in the field.

Important user feedback driving this effort is facilitated by RS JPO's Commercial Online Tracking System (providing part usage, meantime between failure reliability data, and other information), Warfighter Assessment Program, and the Robotics System Pool (RSP), which allows DoD organizations to check out representative hardware for hands-on experience and mission-specific evaluation. A comprehensive compilation of all known sources of available technology is maintained for the user and technical communities in the Mobile Robot Knowledge Base (MRKB). SSC San Diego is performing key development of collaborative-behavior and marsupial-delivery systems (air, land, sea) under the Automated Unmanned Mission System (AUMS) and Multi-robot Operator Control Unit (MOCU) projects. Extensive use of Joint Service reservists have added an important dimension to robotic readiness to deployed forces. The RS JPO will have activated and trained 60 reservists by the end of the calendar year to serve at the JRRFs and in Embedded Repair Teams (ERTs) providing critical sustainment and combat readiness of UGVs.

The Air Force Research Laboratory (AFRL), Tyndall AFB, FL, conducts UGV research and development through the Robotics for Agile Combat Support (RACS) program, as well as through ongoing All-Purpose Remote Transport System (ARTS) improvement efforts to develop a family of modular, scalable, Joint Architecture for Unmanned Systems (JAUS)-compatible robotic technologies to meet current threats and user requirements, as well as future capability needs. The RACS program incorporates rapid prototyping to develop and transition state-of-the-art robotic technologies and counter-terrorism and force protection solutions to the warfighter. Within RACS, the Advanced Robotics Systems program focuses on the development and integration of unmanned technologies in support of Agile Combat Support mission areas and platforms. The primary effort is to develop common architecture designs for autonomous vehicle technologies that focus on vehicle mobility, speed, and control, as well as multi-vehicle operations and marsupial control. This program seeks to develop and document these modular designs within the evolving JAUS/AS-4 standard. Upon program completion, mature technologies are transitioned to designated fielding project offices within the Air Force or DoD.

The Army's Future Combat Systems (FCS) Brigade Combat Team (BCT) is benefiting from the Army-Marine Ground Robotic Master Plan (GRMP), as well as the S&T being developed and demonstrated by a number of DoD agencies. The FCS UGV Integrated Product Team (IPT) is mitigating risks by observing and collecting data from tests and demonstrations being conducted by Army Research Laboratory (ARL), U.S. Army Tank-Automotive Armament Command (TACOM) Research, Development and Engineering Center (TARDEC) and DARPA. TARDEC has the Robotic Follower (RF) program, the Crew integration and Automation Testbed (CAT) program, and the combined ARL/TARDEC Near Autonomous Unmanned System (NAUS) Advanced Technology Objective (ATO). The UGV IPT has observed field testing by the DARPA (Unmanned Ground Combat Vehicle (UGCV) – Perception Integration (UPI) program with its platform (Crusher) and is initiating discussions to use DARPA technology. In addition, ARL, with its Collaborative Technology Alliance (CTA) partners, has and is continuing to develop required advanced sensor capabilities, unique capabilities for terrain classification, and is the source of the vehicle path planning infrastructure being used by FCS (BCT) Autonomous Navigation System (ANS). FCS (BCT) will continue to rely upon the S&T robotic community to improve mobility, survivability, tactical behaviors and increasing the speed and reaction to obstacles for UGVs. Finally, Army and Marine Corps ground robotic activities are being mapped in an annual GRMP utilizing the Technology Assessment and Transition Management (TATM) process developed by the Defense Acquisition University as a technology and capabilities decision support tool.

ARL maintains a balanced portfolio of research activities that supports the continuous development of advanced technology for future, more capable UGVs enabled through advancing levels of system intelligence and autonomy. These activities include basic and applied research being conducted by the Robotics CTA, a consortium of academic and industrial partners collaborating with ARL, focusing upon perception, intelligent control, and Soldier-robot interfaces. Advances in these technology areas, as well as anticipated results from additional applied research tasks that are part of the Army's Research Development and Engineering Command (RDECOM)-sponsored NAUS ATO, are having a direct impact upon FCS and UGV development for the Modular Force and will ultimately enable FCS to achieve its objective performance goals. For example, these programs have already successfully transitioned sensor technology, as well as perception and planning algorithms to the FCS ANS System Development and Demonstration (SDD) program.

The Army's TARDECs' main focus is on integrating and demonstrating sensor technologies, perception hardware and software, and robotic control technologies in relevant environments. This will enable UGV systems to maneuver on- and off-road at militarily significant speeds with minimal human intervention, thereby enabling the soldier to perform other mission tasks. The Unmanned Ground Systems Technology and Behaviors task, executed by TARDEC, will develop and demonstrate UGV technologies to reduce risk for the current and future modular force and increase the utility of UMS.

The Robotic Co-combatant Interaction Technologies task will demonstrate the ability for UGV to operate safely in a semi-autonomous mode in urban environments in the presence of soldiers, pedestrians, and other vehicles. The Robotics Collaboration ATO is expanding the tools, techniques, and autonomy to increase performance and increase effectiveness of Soldier-robot teams. The NAUS ATO develops and demonstrates key robotics technologies on an Armed Robotic Vehicle (ARV) scale mobility platform to reduce risk for PM FCS (BCT).

DARPA has current robotics technology development research ongoing in their Learning Applied to Ground Robotics (LAGR) program, which focuses on machine learning, vision, and image understanding, and in their UPI program, which seeks to enable autonomous operation by creating a vehicle with exceptional mobility. UPI provides a better understanding of the environment/terrain for UGV mobility. These technologies developed the Crusher vehicle, which will be available to the military in 2008.

Finally, the Director, Defense Research and Engineering (DDR&E) formed the Human-Robotic Interaction/Interface (HRII) Special Interest Group (SIG) to focus on critical Human Factors Engineering (HFE) aspects of UMS operation and control, and continues working with the JGRE and the Robotic CTA and their continued efforts, through IPTs, working groups (WG), and supporting Small Business Innovation Research (SBIR).

(5) A description of any planned demonstrations or experimentation activities of the Department that will support the development and deployment of robotics and unmanned ground vehicle systems by the Department.

The presence of the variety of robots in combat operations today have caused warfighters to embrace the idea that robots have a vital role on the battlefield. The ground robotics community is fortunate to be able to learn from the experiences in theater, not only with ground robots, but also through experiences with unmanned aerial vehicles (UAVs). Several areas of interest have emerged that the Department intends to explore with additional analytic rigor. These areas of interest include: frequency of allocation across the Services and robotic platforms, potential for common controllers across the Services and multiple platforms, the desirability of interchangeable payloads that can be carried on unmanned ground vehicles (UGVs) and UAVs to better facilitate increased capability to the Combatant Commanders (COCOM), and opportunities for collaborative engagements using unmanned systems (UMS) beyond that envisioned by Future Combat Systems (FCS). That these questions are being asked, with appropriate supporting experimentation to find answers, underscores an increasingly joint approach to robotics applications, as well as an emerging maturity of understanding of how to develop, field, and fight robotics systems at the Joint level.

Each Service conducts appropriate experimentation during all phases of research and development (R&D). Experimentation objectives are tailored to support the exit criteria of each phase of development and may focus upon a variety of program objectives, including investigating new technologies, verifying technology maturity, risk reduction, refining user requirements and tactics, techniques, and procedures (TTP), or validating prototype systems and concepts in relevant environments. Experimentation at the component or subsystem level is integral to Department of Defense (DoD) Research, Development, Test and Evaluation (RDT&E) activities and is included in program planning. Experimentation at the systems level or in integrated force applications is a focus of operational commands within the Services. Over the course of FY2006-2008, a number of Joint and Service UGV experiments are planned to advance enabling technologies, gain user feedback, refine capability needs and TTPs, and to reduce risk during System Development and Demonstration (SDD). A synopsis of upcoming experimentation efforts follows:

- **Air Force Experimentations**
  The Air Force, under its Robots for Agile Combat Support (RACS) program, will conduct three experiments in late 2006-2007 to assess enabling technology maturity. One experiment will feature an Automated Perimeter Security scenario in which multiple UGVs will collaborate with UAVs to complete security missions. Technology approaches for stand-off radar detection and assessment, command and control integration, and overall system effectiveness will be evaluated while gaining user feedback. In their Active Range Clearance Developments (ARCD) experiment,

the Air Force plans to advance the development of technologies needed to enhance the effectiveness of collaborative UGV-UAV operations to complete missions with both fixed wing and rotary wing UAV involvement. Finally, in August of 2006, the Air Force will participate in the Cargo Screening Advanced Concept Technology Demonstration (ACTD) and seek to demonstrate proof of a concept to combine automation of cargo inspection and material handling processes at aerial ports with use of robotics for removal of suspect items.

- **Army Experimentations**
  - The Army's Program Manager-Force Protection Systems (PM-FPS) is planning to conduct pre-fielding demonstrations at installations listed on the Mobile Detection Assessment Response System (MDARS) distribution list. Technology development experiments will be conducted at Hawthorne Army Depot (HWAD), NV, to evaluate candidate payload enhancements during the 2007-2008 timeframe. PM-FPS is coordinating with the Air Force Research Laboratory (AFRL) and the Physical Security Equipment Action Group (PSEAG) to develop and execute a FY2007 Joint Service Force Protection (JS FP)/physical security demonstration that emphasizes UMS and their applicability/interoperability in both fixed sites and tactical forward operating bases (FOBs). PM-FPS is also working with Maneuver Support Center (MANSCEN) to demonstrate the Family of Integrated Rapid Response Equipment (FIRRE) technologies, RDIM, and Integrated Commercial Intrusion Detection System (ICIDS) during the September 2006 Comprehensive Force Protection Initiative Demonstration at Yuma, Proving Ground, AZ. In addition, FIRRE will be a major component of the aforementioned FY2007 JS FP/physical security demonstration.

  - The Army's Tank-Automotive Armament Command (TACOM) Research, Development and Engineering Center (TARDEC) has ongoing Advanced Technology Demonstrations (ATDs) that continue to develop key technologies in support of the FCS program and UGV development. The Robotic Follower (RF) ATD will provide mounted leader-follower capability to PM FCS Brigade Combat Team (BCT) for integration into Armed Robotic Vehicle (ARV), Multi-function Utility/Logistics Equipment (MULE) vehicle and manned ground vehicles (MGVs) for resupply, rear security and Non-Line of Sight/Beyond Line of Sight (NLOS/BLOS) fire mission. In addition, it will provide dismounted leader-follower capability to Program Executive Officer (PEO), Soldier for integration into Land Warrior Advanced Capability for MULE application. Technologies included in the RF ATD are development of unique and extremely valuable terrain (object) registration techniques that permit precise autonomous following by a UGV and utilize Laser Radar (LADAR) sensor data, radar for vehicle following, pedometry for dismounted navigation, and obstacle map data sharing. Tactical mission opportunities exist for the RF as a ruck carrier, supply platoon, NLOS/BLOS fire and rear security, and support for manned combat, tactical and

support vehicles. This ATD will transition to FCS Autonomous Navigation System (ANS) in 2006. TARDEC additionally executes the Crew integration and Autonomous Testbed (CAT) ATD that has the objectives to demonstrate the crew machine interfaces, automation, and integration technologies required to operate and support FCS. Also included in the CAT ATD are crew driving and decision aids, advanced warfighter interfaces, UGV-UAV control, multi-mission crew station, autonomous navigation for MGVs, embedded simulation system, and advanced system architecture.

- The Army's PM FCS (BCT) UGV is scheduled to conduct risk reduction efforts and experiments in FY2007-2008 to mitigate risk and to test design concepts. Additional testing through FY2013 will provide additional benefits to the system effectiveness. This additional testing includes the following:

  - The ANS program has initiated the Robotic Convoy Experiment with two major events tentatively planned for June of 2007 and March of 2008 respectively. The experimental objectives include demonstrating robotic convoy operations, and evaluating soldier-UGV workload in a distributive collaborative environment of manned and unmanned vehicles. This will provide the first experimental ANS hardware and software that improves performance and reduces size and weight of hardware.

  - The Small Unmanned Ground Vehicle (SUGV) program will develop a prototype mobility chassis in FY2006 followed by testing tentatively in FY2007 to reduce platform weight while maintaining mobility.

  - The ARV and MULE platforms are building Engineering Evaluation Units (EEU) to provide early data to support development of prototype hardware to be delivered on or about 2010. In conjunction with the data derived from the EEUs, a robust Modeling and Simulation (M&S) program will further support the UGV prototype development.

  - In 2010 thru 2012, prototype vehicles from ARV, MULE and SUGV platforms will undergo Initial Qualification Testing (IQT) conducted jointly by Army and contractor test personnel. From 2011 thru 2013, a series of three Technical Field Tests (TFT) and Limited User Tests (LUT) will be conducted to collect system performance and Soldier input which will lead to the Initial Operational Test and Evaluation (IOT&E) tentatively scheduled for 2014.

- The Army Research Laboratory (ARL) conducts periodic experimentations to support its research program and to assess technology maturity. For example, in October 2006, ARL will conduct an experiment to examine the capability of a moving autonomous UGV detecting and avoiding moving vehicles and moving

human surrogates (mannequins). Plans for the experiment have been coordinated with the FCS program (UGV IPT) and will serve to help reduce known technical risks to the FCS program (i.e., Risk 213, Safe UGV Operations in FCS BCT).

- **Navy Experimentations**
  The Navy (Space and Naval Warfare (SPAWAR) Systems Center (SSC) San Diego, in conjunction with the Idaho National Laboratory (INL)) will conduct a series of three technology experiments from June 2006-June 2008 to investigate and enhance Intelligent Autonomy for UMS. Key technologies for evaluation will include: dynamic teaming, autonomous mapping, obstacle avoidance, and collaborative UAV-UGV behaviors. The experiments will be conducted in realistic environments in complex terrain (urban settings, engineered structures, forest canopy) and with realistic mission sets (Military Operations on Urban Terrain (MOUT) reconnaissance, IEDD) to assess component and systems performance using a multiple ground and air platforms. Assessments will be conducted of human performance metrics in the areas of workload and situational awareness from the control of multiple UMS.

(6) A statement of the Department organizations currently participating in the development of new robotics and unmanned ground vehicle systems capabilities, including the specific missions of each such organization in such efforts.

Throughout the Department, a large number of organizations are participating in the development of new robotics and unmanned ground vehicle (UGV) systems capabilities at an unprecedented level. The Joint Ground Robotics Enterprise (JGRE), as directed by the FY1990 Appropriations Bill, is providing oversight to these various efforts through a number of mechanisms as described elsewhere in this report. Through this enterprise management, the following organizations are working in a synchronized manner to develop these capabilities to meet user requirements:

- **Air Force Research Laboratory (AFRL), Robotics Research Group**
  Service – Air Force
  Mission – The Force Protection Branch of AFRL (AFRL/MLQF) at Tyndall AFB conducts robotics research, prototype development, and technology validation in response to existing and emerging Air Force requirements to enable the Robots for Agile Combat Support (RACS) concept and to support the Airborne Explosive Ordnance Disposal (EOD) Concept of Operations (CONOPS) to provide enhanced EOD capabilities to Air Force Rapid Engineers Deployable Heavy Operational Repair Squadron Engineer (REDHORSE) units for rapid occupation and unexploded ordnance (UXO) clearance of previously denied airfields. Through the RACS program and ongoing All-Purpose Remote Transport System (ARTS) improvements efforts, the Air Force is extending its research and development (R&D) programs by developing a family of modular, scalable, Joint Architecture for Unmanned Systems (JAUS)-compatible, robotic technologies to meet current threats and user requirements as well as future capability needs.

- **Defense Advanced Research Projects Agency (DARPA)**
  Service – Joint
  Mission – DARPA is a key player when it comes to delivering the right technologies and capabilities to the warfighter. DARPA has a wide variety of programs, one of which focuses on the networking of manned and unmanned systems (UMS). Its mission is to fill the battlespace with UMS that are networked with manned systems across a range of future air and ground vehicles. It's Science and Technology (S&T) program is a high-risk, high-payoff technology development effort.

- **Future Combat Systems (FCS), Brigade Combat Team (BCT), Unmanned Ground Vehicle (UGV) Integrated Product Team (IPT)**
  Service – Army
  Mission – The FCS (BCT) UGV IPT entered System Development and Demonstration (SDD) in May 2003. The UGV IPT is responsible for development

and fielding of UGVs for the FCS (BCT). There are four programs: ARV, consisting of two variants – ARV-R and ARV-A; Multi-function Utility/Logistics Equipment (MULE) vehicle, consisting of three variants – MULE-Transport (T,) MULE-Countermine (CM), and ARV-A-L; Small Unmanned Ground Vehicle (SUGV); and Autonomous Navigation System (ANS), which will be integrated on the ARV, MULE and manned ground vehicles (MGVs). The UGV program will develop the first prototypes for testing in 2010.

- **Product Manager, Force Protection Systems (PM-FPS)**
  Service – Army
  Mission – PM-FPS provides affordable, modular, scaleable, and tactical physical security capabilities for forward deployed forces while simultaneously providing state-of-the-art physical security equipment for Army installations worldwide. In the area of FP, PM-FPS is working with semi-autonomous robotics in Installation as cost savers and Forward Operating Bases (FOBs) as Combat Multipliers.

- **Product Manager, Robotic and Unmanned Sensors (PM-RUS)**
  Service – Army
  Mission – PM-RUS was chartered in FY2002 to bring together the development of common reconnaissance, surveillance, and target acquisition (RSTA) sensors to meet the growing needs of unmanned applications. Its mission is to develop, produce, field, and sustain world-class Army and Department of Defense (DoD) multi-purpose RSTA sensors and sensor systems for unmanned and unattended air/ground applications in support of the current and future forces.

- **Program Management Office for EOD / Counter Radio Controlled Improvised Explosive Device Electronic Warfare (CREW) PMS EOD/CREW)**
  Service – Navy
  Mission – PMS-EOD/CREW executes the development, production, fleet/field introduction and in-service engineering support for Joint Service (JS) EOD, Navy Underwater EOD, and Joint CREW programs. PMS-EOD provides full life cycle support for these areas. The Navy is the DoD Executive Agent for JS EOD and Joint CREW.

- **Robotic Systems Joint Project Office (RS JPO)**
  Service – Joint
  Mission – The RS JPO is the Army and Marine Corps life cycle manager for all ground robotic systems. As such, the RS JPO provides life cycle project management for the Army's Robotic Combat Support System (RCSS), and the U.S. Marine Corps' (USMC) Assault Breacher Vehicle (ABV) and Gladiator. The RS JPO also provides product management government oversight of the Army's UGVs of the FCS. The RS JPO is the transition manager for S&T programs to meet defined capability gaps, and

provides all logistics support for robotic systems employed in current operations through the Joint Robotic Repair Facility (JRRF).

- **Space and Naval Warfare (SPAWAR) Systems Center, San Diego (SSC San Diego)**
  Service – Navy
  Mission – The UMS branch of SSC San Diego provides network-integrated robotic and distributed sensing solutions for DoD and other federal and local agencies. The UMS branch performs work in nearly every domain of the battle space including air, land, sea, and subterranean.

- **U.S. Army Research, Development & Engineering Command (RDECOM)**
  Service – Army
  Mission – RDECOM's mission is to get the right integrated technologies into the hands of warfighters quicker. Its vision is to be recognized as the pre-eminent world leader in military research, development and engineering systems of systems, whose hallmark is transitioning the right technology in the shortest time to our Soldiers.

  - **Armament Research, Development and Engineering Center (ARDEC)**
    Service – Army
    Mission – ARDEC is the Army's principal researcher, developer and sustainer of current and future armament and munitions systems. ARDEC's overall mission is to improve already fielded items, develop new ones, maintain a strong armament technology base in Government, industry and academia, and provide technical support to the Soldier in the field. In this way, the Center achieves its vision of "providing America advanced armaments for peace and war."

  - **Army Research Laboratory (ARL)**
    Service – Army
    Mission – ARL conducts basic and applied research in core robotics technology required for the development of capable UMS for FCS, the modular force, and the future force. It conducts fundamental research, as well as technology assessment through modeling and simulation and field experimentation. It collaborates with other elements of the Army's RDECOM, the other Services, Government agencies, academia and industry. Its activities include basic and applied research being conducted by the laboratory and its partners in the Robotics Collaborative Technology Alliance (CTA) in perception, intelligent control, and human robot interface (HRI) technologies. ARL is focused upon the rapid transition of research to insure that the most capable technology is readily available to the soldier, as demonstrated by its recent transition of sensor, perception, and planning technology to the Army's FCS program.

- **Aviation and Missile Research, Development and Engineering Center (AMRDEC)**
  Service – Army
  Mission – The AMRDEC mission is to conduct R&D, integration, and assessment of technologies and concepts for UMS. AMRDEC leverages its experience with complex system integration, advanced software development, intelligent machine technologies, and aviation and weapon systems. AMRDEC focuses on unmanned aerial systems, lethality payload development and integration, software/computer assisted automation, software development, collaborative manned/UMS, UMS safety, and UMS standardization. Research projects incorporate independent Military User Assessments to ensure the technologies address capability gaps.

- **Communication-Electronics Research Development & Engineering Center (CERDEC)**
  Service – Army
  Mission – CERDEC's mission is to develop and integrate command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) technologies that enable information dominance and decisive lethality for the networked warfighter.

- **U.S. Army RDECOM Tank-Automotive Armament Command (TACOM) Research, Development and Engineering Center (TARDEC)**
  Service – Army
  Mission – TARDEC's mission is to conduct basic and applied research, systems integration, experimentation and transition technology in the areas of UMS and crew automation while leveraging advanced automotive technology to address current and future force capability gaps. TARDEC's research is focused on developing, maturing, and integrating ground robotic platform mobility, perception, planning, intelligence, and command and control technologies that span from the present day well into the next decade. On-going TARDEC Advanced Technology Objective (ATO) programs are a vital part of the Army S&T portfolio, helping to speed the maturation of advanced technologies needed to upgrade existing UMS and reduce technical risks associated with the UMS of the FCS (BCT). TARDEC's warfighter machine interface/crew stations and UGV test beds facilitate early user experimentation to explore concepts of operation and develop tactics, techniques and procedures (TTPs) with technology-driven operational issues.

(7) A description of the activities of the Department to collaborate with industry, academia, and the other government and nongovernmental organizations in the development of new capabilities in robotics and unmanned ground vehicle systems.

The Joint Ground Robotics Enterprise (JGRE) has pursued an active strategy of promoting synergistic collaboration jointly across the Services, with academia as well as industry. The JGRE continues to develop a range of strategic partnerships with government organizations and industry to leverage available funding, share technology advancements, accelerate research, develop and field solutions to our current forces, promote synergy across the Department of Defense (DoD) unmanned systems (UMS) community, and to promote interoperable systems. These collaborations take a number of forms and have included information and technical exchanges, collaborative programs across the Services, cooperation with other governmental agencies' developers, and experimentation with the user communities. Some of the JGRE strategic partners include the Defense Advanced Research Projects Agency (DARPA), the Army's Research, Development and Engineering (RDECOM)-sponsored Collaborative Technology Alliance (CTA), the interagency Technical Support Working Group (TSWG), the National Center for Defense Robotics (NCDR), national laboratories such as Idaho National Laboratory (INL), the National Institute for Standards and Technology (NIST), and others. Through collaborative partnerships and teaming initiatives, both Government and academia are able to focus their resources on conducting basic research into Science and Technology (S&T) areas that are most likely to produce robotics technology breakthroughs. The net result of effective partnering from a DoD perspective is to stretch available funding to gain additional programmatic efficiencies, and to accelerate the development and deployment of viable robotic solutions to Service capability requirements. A summary of ongoing collaborative efforts at both Joint and Service levels follows:

- **JGRE Synergy**
  JGRE Program Managers (PMs) and robotics community partners meet multiple times each year to exchange information and align program objectives. The JGRE typically has sponsored two JGRE Working Group (WG) meetings annually since the early-1990s to foster technical and programmatic information exchanges between government developers, operational users, and the requirements generation communities. Typical attendance and interest has remained high since their inception.

  Additionally, the JGRE initiated a standards based approach through the adoption of the Joint Architecture for Unmanned Systems (JAUS). Since 1998, the JGRE has sponsored a JAUS/AS-4 WG that has, through the active participation of Government, academia, and industry, effectively created a Joint standard robotics software architecture that will soon become an industry standard. The objective in pursuing the adoption of the JAUS architecture as the primary unmanned ground

vehicle (UGV) product line enabler has been to promote efficient development across the Services and to enable DoD-wide opportunities for interoperability (plug and fight), rapid technology insertion, and overall systems affordability at lower development costs. As the messaging architecture potentially supporting not only UGVs, but also unmanned underwater vehicles (UUVs), unmanned surface vehicles (USVs), and some unmanned aerial vehicles (UAVs), it has been a goal of the JGRE to sponsor the transition of JAUS toward becoming a commercial, international standard. To that end, the JGRE is partnering with the Society of Automotive Engineers' (SAE) Aerospace Council, who chartered an Unmanned Systems Committee in 2004 to transition JAUS into an Aerospace Standard. As more and more industrial and academic developers adopt the JAUS/AS-4 standard, the Department should realize significant long term benefits from its JAUS investment and in its partnering with SAE for expansion of the standard.

Taken together, these Joint forums and a Joint architectural approach have been highly instrumental in documenting a Joint development path going forward, stimulating capability needs documentation, in fostering better communications between users and developers, in communicating the status of ongoing development efforts, and in promoting greater understanding of current technology maturity and emerging requirements.

- **National Laboratories**
  The INL is working with several partners within DoD to advance the potential for intelligent unmanned vehicles to address critical national and homeland security missions. This collaboration has been functioning for the past two years through an inter-agency agreement with the JGRE and includes long-term technical collaborations with a number of DoD research institutions including Space and Naval Warfare (SPAWAR) Systems Center, Army Research Laboratory (ARL), Naval Research Laboratory, Tank-Automotive Armament Command (TACOM) Research, Development and Engineering Center (TARDEC), Simulation Training and Instrumentation Command, Maneuver Support Center at Ft. Leonard Wood, Night Vision Electronic Sensors Directorate at Ft. Belvoir, and the Robotic Systems Joint Program Office (RS JPO). A key goal of this project is to create and experimentally assess a common behavior architecture that provides "leap ahead" capabilities to both DoD and Department of Energy (DOE) unmanned assets. This work targets the use of collaborative UAVs and UGVs to perform critical security tasks especially in dynamic, highly complex terrain.

- **National Center for Defense Robotics (NCDR)**
  Beginning in 2002, NCDR, with the ongoing support, collaboration, and guidance of the OSD JGRE office, has established a nation-wide Agile Robotics Alliance numbering over 150 members, as well as helped form numerous partnerships among universities, small technology companies, and industry partners, including several

Mentor-Protégé agreements. NCDR's focus on the near-term transition and pragmatic application of UMS technologies for explosive ordnance disposal (EOD), surveillance, force protection (FP), and other missions is producing tangible results, including a project to develop a secure, digital, two-way controller for the BomBot, and a low-cost, expendable UGV, which is now being fielded.

- **Technical Support Working Group (TSWG)**
  A continuing JGRE partner is TSWG, an interagency research and development (R&D) organization managed by the DoD Assistant Secretary of Defense for Special Operations and Low-Intensity Conflict (ASD (SO/LIC)). TSWG identifies, prioritizes and coordinates interagency and international R&D requirements for combating terrorism. The JGRE works primarily with the Improvised Device Defeat (IDD) subgroup to align and coordinate applicable JGRE Joint and Service robotic development efforts and to foster rapid development of technologies and equipment to meet the high priority needs of the broader combating terrorism community. The JGRE participates in providing technical support to the development of the TSWG's Next Generation EOD Robotic Vehicle (NGEODRV) program, which is utilizing a common architecture based upon the JGRE-developed JAUS standard, and is transitioning resulting technology solutions to the JGRE and Joint EOD communities.

  Beginning in 2004, JGRE and TSWG have partnered to sponsor an annual Unmanned Systems Capabilities Conference (USCC) that serves as a forum to bring DoD, interagency, Federal, State, and local bomb squad users in direct contact with developers and industry representatives to share information on emerging capability needs, operational lessons learned, R&D activities, and Government and commercial robotic solutions. The JGRE-TSWG partnership is paying dividends by promoting efficiencies in both organizations programmatically and technically.

- **Explosive Ordnance Disposal/Low-Intensity Conflict (EOD/LIC)**
  The EOD/LIC program provides rapid prototyping and advanced technology development in response to the needs of military explosive ordnance disposal (EOD) and special operations forces (SOF) personnel. Managed by the DoD Assistant Secretary of Defense for Special Operations and Low-Intensity Conflict (ASD (SO/LIC)), EOD/LIC technology developments are focused primarily on detection, access, identification, and neutralization of conventional as well as improvised explosive hazards across a broad spectrum of threat environments.

  EOD/LIC is continuing development of an Advanced Robotic Vehicle program with two primary objectives: 1) the development of an e-commerce solution to support advanced robotic vehicle manufacturing and 2) the development and manufacturing of Advanced Robotic Vehicle technologies. The e-commerce manufacturing capability in the robotics area will provide a semi-automated Internet-based tool to support a flexible high technology workforce. The intent of the Advanced Robotic Vehicle

Manufacturing Program is to develop business methods that will allow limited-quantity production run items to be made in a cost-effective manner. The scope of this effort is to develop an e-commerce solution that works in conjunction with rapid prototyping techniques – a solution that provides a seamless transition from R&D to manufacturing – and also to test the solution utilizing state-of-the-art robotics technologies.

- **Joint Industry Collaboration – Association for Unmanned Vehicle Systems International (AUVSI)**
  The JGRE has promoted the advancement of Intelligent Ground Vehicles through the support of the AUVSI Intelligent Ground Vehicle Competition (IGVC). IGVC has influenced up to 35 universities per year, annually, over the last 15 years to design, develop, and demonstrate in an outdoor environment successive levels of autonomous mobility performance. Over the years, the JGRE has supported the IGVC, both with funding and manpower for officiating. This year was especially notable, as the JGRE endorsed the first ever integration of JAUS. This evolutionary standard is the driving force bringing this broad industry, Government, and academic community together through an interchangeable/interoperable message format tailored to UMS. This JGRE IGVC effort advanced the capabilities and competence of student and faculty researchers in 11 universities, including 3 international schools. In addition, the JGRE-supported IGVC has enhanced the competitiveness for universities to compete successfully in high visibility DoD programs, such as the 2007 DARPA Urban Challenge.

- **Air Force Collaborations**
  The Air Force is working closely with universities in Wyoming, Florida, and Tennessee, as well as with the Office of the Secretary of Defense (OSD), the Army Corps of Engineers, and Radiance Corp. Such collaboration is intended to advance the technology base for advanced systems, encourage small corporations with innovative technologies to develop a contractual relationship with DoD, and to advance technologies supporting intelligent navigation systems, unexploded ordnance (UXO) response technologies, development of a library of robotic manipulators, and automated mine clearing vehicles. The Air Force Research Laboratory (AFRL) has worked closely with the University of Florida on several programs, including the NaviGATOR vehicle for the DARPA Grand Challenge in FY2005.

- **Navy Collaborations**
  The Navy is collaborating with the JGRE to address prioritized needs identified through warfighter feedback and assessments, to identify promising technologies, to assess Technology Readiness Levels (TRL) for platforms, and to transition systems to acquisition programs. The Navy has entered into a Memorandum of Agreement (MOA) with the INL to assist in the coordinated development, evaluation, and sharing of robotics technology. There are also existing contracts/grants between the Navy and

the Center for Commercialization of Advanced Technology (CCAT) and Hawaii Technology Development Venture (HTDV) to seek mature robotic technologies in the areas of power, communications, mission planning, human robot interface (HRI), and sensors. The Robotics Systems Pool (RSP) has Memorandums of Understanding (MOU) with the Navy to provide a resource of commercial off the shelf (COTS) platforms for loan, to support warfighter assessments and feedback to enhance the spiral development process, and to expedite the integration of technologies into effective, supportable, fielded solutions.

- **Army Collaborations**

  The Army collaborates with a wide array of academic and industrial organizations, as well as other Government agencies, such as the National Aeronautics and Space Administration (NASA) Marshall Spaceflight Center, DOE, and the Department of Commerce. ARL has made a concerted effort to collaborate with industry, academia, and other Government agencies to advance robotics technology. Under the banner of the Robotics CTA, ARL has for the past five years entered into a cooperative agreement with a consortium of ten academic and industrial partners, augmented by additional researchers, that has focused upon rapidly advancing perception, intelligence, and HRI technology to enable near-autonomous mobility for UGVs and a seamless incorporation of these vehicles into a mixed force of manned and unmanned assets. These efforts directly support the Army's Future Combat Systems (FCS) Brigade Combat Team (BCT) program and have already resulted in the direct transfer of technology that will enable PM FCS (BCT) to meet its threshold goals.

  Additional collaborative efforts being pursued by FCS (BCT) include:

  - The Autonomous Navigation System (ANS) program has a contract with Auburn University on precision Leader Follower (LF) Concepts Analysis and Verification to develop, analyze, and verify through integrated hardware/software on-vehicle testing, concepts that will accomplish precision LF relative position knowledge to sub-meter accuracy required, and sub-5 centimeter accuracy goal, using integrated Global Positioning System/Inertial Navigation System (GPS/INS) hardware similar to FCS (BCT) GPS/INS configuration.

  - The Armed Robotic Vehicle (ARV) program is closely aligned with the ARL/TARDEC Near Autonomous Unmanned Systems (NAUS) Advanced Technology Objective (ATO) that will mitigate risk for autonomous tactical behaviors, increase situational awareness, and provide safer operations of UGVs around dismounted soldiers and higher speed mobility for UGVs. The ARV and Multi-function Utility/Logistics Equipment (MULE) programs are tracking the DARPA Unmanned Ground Combat Vehicle – Perception Integration (UPI) program. The DARPA platform, Crusher, designed and built by Carnegie Mellon

National Robotics Engineering Center is a leader in platforms for extreme mobility and autonomy for off-road navigation.

- The FCS UGV Integrated Product Team (IPT) mitigates program risk by tracking the progress and improvements made by ARL, TARDEC, DARPA and other collaborative efforts as they are identified.

Since 2002, the DoD JGRE, the U.S. Army Medical Research and Materiel Command (MRMC) Telemedicine and Advanced Technology Center (TATRC), TARDEC, the Army Research Office's Small Business Innovation Research (SBIR) program, and NCDR have jointly invested and worked together to design and develop JAUS-compliant, multi-purpose, mobile UGVs that can support a variety of modular combat and combat support payloads to include casualty extraction and evacuation modules, modular weapons platforms, and removable and interchangeable cargo compartments. MRMC TATRC has also collaborated with the Edgewood Chemical and Biological Center (ECBC) Military Applications in Reconnaissance and Surveillance (MARS) for CB Defense program to equip its experimental medical surveillance and casualty extraction robot teams with sensor suites for CBR detection. MARS is a technology feeder program for the Chemical, Biological, Radiological and Nuclear (CBRN) Unmanned Ground Reconnaissance (CUGR) Advanced Concept Technology Demonstration (ACTD).

Finally, the results of collaboration for the Department's ground fighting forces, the Army and the Marine Corps, are captured in an annual Ground Robotic Master Plan (GRMP). As discussed previously, the GRMP utilizes the TATM, system engineering process to analyze, map, manage and leverage R&D and S&T, thereby providing opportunities to further improve the effectiveness of collaboration among industry, academia, and other government and non-government organizations in the development of new capabilities.

(8) <u>An assessment of the short-term and long-term abilities of the industrial base of the United States to support the production of robotics and unmanned ground vehicle systems to meet Department requirements.</u>

Challenging robotics technology, such as the autonomous navigation systems, mission sensors, batteries, etc., induce significant technical and production risk meriting Government oversight of production planning and capability. In assessing the short-term abilities of the Industrial Base, it is noteworthy that companies such as iRobot, Foster-Miller, and Remotec provide UGV platforms to support troops in Afghanistan and Iraq primarily for improvised explosive device (IED) detection and disposition. While iRobot's role in the Future Combat Systems (FCS) program calls for the development of a portable, reconnaissance and tactical robot, their PackBot is a militarized commercial off the shelf (COTS) utility vehicle using an iRobot-developed autonomous guidance, navigation, and control capability. Remotec, iRobot and Foster-Miller have demonstrated capable production lines and post-production support systems for the small unmanned ground vehicles (UGVs) they have provided to Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF). These companies are currently producing approximately 30 systems per month but have the capability to increase production to 80 systems per month or higher given the demand.

The Department also assists in smooth transitions to the Industrial Base through the appropriate use of rapid prototyping capabilities providing a means of transitioning mature technical data packages to industry for accelerated production. For example, the Air Force Research Laboratory (AFRL) possesses the capability of in-house rapid prototyping with strong transition strategies to provide industry with technical data packages, thereby providing a government option to streamline production processes and contribute to fostering industrial base efficiency. Two recent examples of the use of rapid prototyping and technical data package transition to industry are the successful transitions of the urgent warfighter request for the BomBot through the Naval Explosive Ordnance Disposal Technology Division (NAVEODTECHDIV) to Innovative Response Technologies and the Robo-Trencher to Applied Research Associates, Inc., Vertek Division to support forces in Afghanistan and Iraq. Additionally, the Army Aviation Missile RDEC also possesses a rapid prototyping capability and was recently successfully utilized to integrate the FIDO explosive detection sensor to iRobot Packbots that were deployed to OIF. And finally, EOD/LIC has collaborated with industry to modify BomBot to improve Special Forces missions in Afghanistan and Iraq.

In looking at longer term UGV industrial base capabilities, an Industrial Capabilities Assessment (ICA) was completed by the FCS Brigade Combat Team (BCT) Operations and Production Planning (OPP) ICA team to summarize the status of the UGV industrial base and its ability to sustain robotic system prototype development and rate production. Supporting information was gathered from subcontractor questionnaires, site visits, program reviews, and contributions from PM FCS (BCT), Tank-automotive Armament

Command (TACOM), and U.S. Army Materiel Systems Analysis Activity (AMSAA). The assessment evaluated the industrial base on criteria related to emerging technologies, critical processes, financial health, and subtier supplier capabilities. The ICA found that subcontractors supplying UGVs for FCS (BCT) have extensive expertise in designing, developing, modeling, and testing robotic vehicles and integrating advanced sensors and mission payloads. There are no identified industrial base capability risks at this time; however, there are many issues related to production of hardware and software, and these issues are being formally tracked to ensure that they do not result in unmanageable risk. Future ICAs will better characterize the available technology, manufacturing practices, and capabilities of the industrial base. Overall, the ICA found that the industrial base demonstrated the ability to provide unmanned ground systems for System Development and Demonstration (SDD) and is satisfactorily planning for initial production and full-rate production in support of the FCS (BCT) program.

Because of the proliferation of demand for military ground robotics for applications, a growing number of companies and organizations are supporting development and production of UGVs. These include but are not limited to Lockheed Martin, Northrop Grumman, General Dynamics, Stanford University, Virginia Tech, Carnegie Mellon University, and Applied Research Associates, Inc. Components for UGVs come from a vast array of suppliers. In addition, an initial assessment of the UGV industrial base was conducted by the PM FCS (BCT) to provide a look at the ability of the supply chain to sustain robotic system prototype development and rate production.

For additional information, see: D786-11072-6 *Future Combat Systems, System Development and Demonstration Phase, Industrial Capability Assessment, Annex E: Unmanned Systems; Revision B November 07, 2005.*

(9) <u>An assessment of the progress being made to achieve the goal established by section 220(a) (2) of the Floyd D. Spence National. Def. Auth. Act for FY2001 (as enacted into law by Pub. Law 106-398; 114 Stat 1654A-38) that by 2015, one third of operational ground combat vehicles be unmanned.</u>

With the fielding of the first Future Combat Systems (FCS) Brigade Combat Team (BCT) in 2014, the Department will be well underway towards meeting the goal established by the Floyd D. Spence National Defense Act for 2001. The real world events during the past two years have set the stage by enhancing awareness of the potential applications for unmanned systems (UMS) in support of our national security interests. Systems are effectively used in counter improvised explosive device (IED) operations, explosive ordnance disposal (EOD), force protection (FP), route clearance, countermine operations, and other engineering operations. With the continuing requests for robotic systems to satisfy needs in the theater, short-term efforts as well as Programs of Record (PORs), the intent of Congress that warfighters benefit from the presence of ground robotics on the battlefield will no doubt be realized.

Defense transformation, especially highlighted by the FCS (BCT) program, provides significant capability for the future force through the employment of unmanned ground combat vehicles (UGCV). The FCS (BCT) Combined Arms Battalion (CAB) consists of 88 manned ground vehicles (MGVs) and a number of High Mobility Multi-Wheeled Vehicles (HMMWVs) and Heavy Expanded Mobility Tactical Trucks (HEMTTs). The CAB will deploy 6 Armed Robotic Vehicles-Assault (ARV-A) and 9 ARV-Reconnaissance (ARV-R) to support the mounted forces in the Recon Troops, Infantry and Mounted Combat System (MCS) companies. Each platoon in these companies will deploy either an ARV-A or ARV-R platform. In addition, the CAB Headquarter and Headquarters Company will maintain 6 ARV-A Light (L) and 18 Multi-function Utility/Logistics Equipment -Transport (MULE-T) platforms to support the CAB when it deploys units as dismounted forces. The CAB will have 27 Small Unmanned Ground Vehicles (SUGVs) to support the infantry and recon troops for reconnaissance in urban environments, caves, and tunnels when necessary. This will provide one SUGV for each squad in the Infantry and Recon squads. To maintain mobility when encountering minefields, each CAB will deploy 10 MULE-Countermine (CM) platforms to detect and neutralize anti-tank mines. Each MGV in the CAB will be equipped with Autonomous Navigation System (ANS), enabling each MGV to function in an unmanned mode based on the commander's discretion. The ANS on MGVs is envisioned to allow the crew to automate certain driving functions to ease stress and workload on the crew and provide for autonomous operation while not engaged in direct engagement with enemy forces. The FCS (BCT) has focused on having the right UMS to accomplish the mission in support of the soldier when both mounted and dismounted.

In summary, UGVs today are clearly proving their effectiveness in current operations, saving lives while also supporting operational force tempo requirements. These

unmanned capabilities will continue to expand both in quantities deployed and in mission areas supported across the services, including combat, combat service, and service support. The Department's direction with respect to leveraging the potential of robotics is very much aligned with Congressional direction.

(10) <u>An assessment of international research, technology, and military capabilities in robotics and unmanned ground vehicle systems.</u>

A number of U.S. allies currently conduct research and development (R&D) activities directed towards developing military capabilities for robotics and unmanned ground vehicles (UGVs). Canada conducts research in the areas of autonomous systems with a focus on sensors and integration for robotic systems, control systems for robotic applications, data communications systems, robotic vehicle platforms, artificial intelligence for robotic systems, and the ergonomic aspects of man-machine interface. Germany has sponsored Science and Technology (S&T) efforts directed towards the development of critical technologies for UGVs including perception, intelligent control, autonomous robotic vehicle platforms, as well as human interface and planning. Recently, it has begun to focus on the development of small (i.e., man packable) robots. Australia is concentrating on the areas of platform-related technologies systems and weapons, man-unmanned systems, control theory and control systems.

France is focusing on the areas of system collaboration, weapons, level of autonomy, and night vision and electronic sensors to include countermine and de-mining technologies. The United Kingdom is primarily working on navigation, mobility, communication, and ground vehicle integration. Israel is conducting work on tank systems dealing with laser range-finders, design and fabrication of tank systems. South Korea recently initiated research focused on development of a Multi-function Utility/Logistics Equipment (MULE)-like platform, as well as real time tracking and Human Robotic Interface (HRI) efforts which they hope will ultimately result in a vehicle that can be used to monitor the Demilitarization Zone. Other international efforts include HRI by Switzerland and systems for mine clearing and mobility by Denmark. In summary, the aforementioned countries are concentrating on capabilities for urban operation and combat application, as opposed to Japan, where defense applications for robotic technologies are their primary goal.

In general, U.S. capabilities, research, and technologies are leading the way for the international efforts. However, Japan's effort with HRI is comparable, while the humanoid-like robotic technology may be somewhat ahead of those in the U.S. at present. South Korea began investing heavily in HRI and may partner with the U.S. in the future. Canada is increasing their investing efforts with platforms and may be considered comparable to U.S. platform technology.

(11) <u>A description of the role and placement of the JRP in the Department.</u>

On pages 70-71 of the Robotics subparagraph of the Conference Report to the DoD Appropriations Act, 1989 (Public Law 100-463), H. Rpt. 100-1002, the conferees noted that the Services' robotics programs lacked coordination, and expressed the intent that "The Deputy Secretary of Defense for Tactical Warfare Programs should assume the role of focusing these technology efforts"... and should submit a master plan by May 1, 1989 addressing Department initiatives to advance joint robotics programs. On page 96 of the Conference Report to the DoD Appropriations Act, 1990 (Public Law 101-165), H. Rpt. 101-345, under Title IV-Research, Development, Test and Evaluation, subparagraph Robotics, the conferees directed the "consolidation of DOD-related robotics funding into one program under the control of the Office of the Secretary of Defense (OSD)", and directed "funding of $21,599,000 in the RDT&E, Defense Agencies account for the new joint program." The OSD response was to create the Joint Robotics Program (JRP), now known as the Joint Ground Robotics Enterprise (JGRE).

OSD's role has remained to provide JGRE policy and direction to: (1) oversee a consolidation of efforts; (2) concentrate on establishing definitive robotics operational capabilities; and (3) pursue critical technologies to satisfy capability needs. The JGRE has implemented Congressional direction by building strong, cohesive, user-oriented research and development (R&D) and acquisition efforts. It has created opportunities for effective exchange and coordination through regular working group (WG) meetings, establishing robust, shared technical databases, and by forming Working Integrated Product Teams (WIPTs) to manage the program and resolve issues. The JGRE has set priorities to reduce duplicative efforts and use scarce resources more efficiently. Meanwhile, the Services have responded to requests from the field and JGRE/other DoD UGV successes with increasing capability needs documentation and financial commitment in the form of budgeted procurement funds for the most mature technologies.

During FY2006, the JRP expanded its scope to remain ahead of the changing conditions brought about by greater warfighter understanding of how to employ robotics in operational environments and significant advances in robotic technology maturity. To reflect this increased scope, the JRP transformed into the JGRE. While the fundamental mission described above remains the same, the approach has matured to one of enterprise oversight. This approach involves additional direction and prioritization, taking into account near-term emerging requirements and Global War on Terror (GWOT) needs, mid-term and long-term technology maturation, and greater collaboration between war fighters, laboratories, and program managers to link doctrine, technology and capability needs.

The Enterprise Director, Joint Ground Robotics (JGR), oversees the DoD's JGRE and reports to the Deputy Director, Land Warfare and Munitions (LW&M), Portfolio Systems

Acquisition, Office of the Under Secretary of Defense, Acquisition, Technology and Logistics (OUSD (AT&L)). This organizational structure enables JGRE to synchronize and coordinate with air and naval unmanned systems (UMS) counterparts, which also belong to Portfolio Systems Acquisition. As part of the new vector for JGRE, the Enterprise Director is working to develop the ground portion of the Department's Integrated UMS Roadmap. The intent of the UMS Roadmap is to lay out a deliberate strategy to guide the future development of UMS and technologies in a manner that enables leveraging across all UMS, while also being responsive to the warfighter's needs given the different environmental domains (e.g. air, ground, sea). This integrated roadmap will serve as the plan against which future prioritization, funding decisions, and direction will be executed, thus ensuring effective returns on investments into unmanned technologies and system developments.

(12) <u>A description of the mechanisms of the Department for coordinating pre-systems development and demonstration funding for robotics and unmanned ground vehicle systems.</u>

The Joint Ground Robotics Enterprise (JGRE) funding and oversight processes are designed to complement and dovetail with Joint and Service funding and prioritization processes. Investment decisions are informed by documented user capability requirements from Initial Capabilities Documents (ICDs), Operational Need Statements (ONS), Joint urgent ONS, and urgent universal need statements, as well as other sources such as User Roadmaps, and Industry Surveys. JGRE funding prioritization is also informed by investments made in budget activities (BA) outside those for JGRE (BA 4 and BA 5) in an effort to maintain enterprise momentum, to reduce unnecessary duplication and sustain the flow of a continuum of evolving technologies from basic technology development through to system development (System Development and Demonstration (SDD) and procurement). Prototype solutions are produced and evaluated by the user for proof of concept. Once a concept is validated, the Services budget (POM) for out-year funding and a program is transitioned to a System Program Office (SPO) for establishment of a formal acquisition Program of Record (POR).

As part of the enterprise oversight strategy for JGRE, five thrust areas have been established for shaping future investment and maximizing the Department's return on investment:

- Technology Development – BA 3 efforts that will provide technology base development means for the advanced technology development of subsystems and components, as well as efforts to integrate subsystems and components into unmanned ground vehicle (UGV) system prototypes for field experiments, early user trials and/or tests in a simulated environment.
- Technology Enablers – BA 4 and BA 5 efforts that mature technologies needed to enable broad robotic applications, such as UGV range extension, extended robotics communications, etc.
- Unmanned Systems (UMS) Product Line Enablers – efforts that are required for effective robotics technology application but are not technologies themselves (the Joint Architecture for Unmanned Systems (JAUS) standard architecture for example, is not a technology, but enables efficient technology maturation and interoperability across the enterprise product line).
- Concept Demonstration/Warfighter Experimentation – allows promising, but still developing technologies to be provided to warfighters for early assessment so that users can develop or refine realistic requirements underpinned by sound operational concepts.
- Robotics Risk Reduction Enablers – provides the funding to allow technologies to be matured for a specific system while the Services are finalizing capability requirements and establishing funding for formal program initiation (helps overcome the

technology transfer challenges , often referred to within the DoD community as the "'valley of death.").

To execute approved JGRE efforts, the Enterprise Director, JGR, has established an effective management structure that meets to share information, provide coordinating program execution direction, and to establish priorities and work plans. Through their strategic planning process, the JGRE Managers have identified and are executing the following fundamental core processes required to ensure efficient management of scarce resources and to enable effective oversight for the JGRE:

- Plan, program, and budget for JGRE initiatives
- Effectively communicate knowledge of robotics and JGRE priorities
- Identify and transfer robotic technology to the appropriate organization/agency
- Manage assigned programs in accordance with acquisition directives and guidelines
- Develop architectures and establish frameworks to achieve interoperability

Appendix

Acronyms

ABV	Assault Breacher Vehicle
ACTD	Advanced Concept Technology Demonstration
ADCR	Automatically Deployed Communications Relays
AFRL	Air Force Research Laboratory
AFRL\MLQF	AFRL, Material and Manufacturing Directorate, Aerospace Expeditionary Force Division, Force Protection Branch
AMC	Army Material Command
AMRDEC	U.S. Army Aviation and Missile Research, Development, and Engineering Center
AMSAA	U.S. Army Materiel Systems Analysis Activity
ANS	Autonomous Navigation System
AoA	Analysis of Alternatives
AP	Anti Personnel
ARDEC	Armament Research, Development and Engineering Center
ARL	Army Research Laboratory
ARTS	All-Purpose Remote Transport System
ARV	Armed Robotic Vehicle
ARV-A	Armed Robotic Vehicle - Assault
ARV-A(L)	Armed Robotic Vehicle – Assault(Light)
ARV-RSTA	Armed Robotic Vehicle - Reconnaissance, Surveillance, and Target Acquisition
ASD (SO/LIC)	Assistant Secretary of Defense for Special Operations and Low-Intensity Conflict
AT&L	Acquisition, Technology, and Logistics
ATD	Advanced Technology Demonstration
ATO	Advanced Technology Objective
AUMS	Autonomous UAV Mission System
AUVSI	Association for Unmanned Vehicle Systems International
BA	Budget Activity
BCT	Brigade Combat Team

BLOS	Beyond Line-Of-Sight
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance
CAB	Combined Arms Battalion
CAT	Crew integration and Automation Testbed
CBRN	Chemical, Biological, Radiological, and Nuclear
CCAT	Center for Commercialization of Advanced Technology
CEE	Collaborative Engagement Experiment
CENTCOM	U.S. Central Command
CERDEC	Communication-Electronics Research Development and Engineering Center
CMU	Carnegie Mellon University
COCOM	Combatant Command/Commander
CONOPS	Concept of Operations
COTS	Commercial Off-the-Shelf
CREW	Counter Radio Controlled IED Electronic Warfare
CRN	Chemical/Radiological/Nuclear
CTA	Collaborative Technology Alliance
CUGR	CBRN Unmanned Ground Reconnaissance
DARPA	Defense Advanced Research Projects Agency
DDR&E	Director, Defense Research and Engineering
DGC	DARPA Grand Challenge
DoD	Department of Defense
DOE	Department of Energy
ECBC	Edgewood Chemical & Biological Center
EEU	Engineering Evaluation Units
EIS	Engineering Installation Squadron
EO/IR	Electro-Optical/Infrared
EOD	Explosive Ordnance Disposal
EUCOM	European Command
FCS	Future Combat Systems
FIRRE	Family of Integrated Rapid Response Equipment

FOB	Forward Operating Base
FP	Force Protection
FRA	Forward Repair Activity
FY	Fiscal Year
GOTS	Government Off-the-Shelf
GPS	Global Positioning System
GSTAMIDS	Ground Standoff Mine Detection System
GWOT	Global War on Terror
HFE	Human Factors Engineering
HRI	Human Robot Interface
HRII	Human Robot Interaction/Interface
HTDV	Hawaii Technology Development Venture
HWAD	Hawthorne Army Depot
IALR	Institute for Advanced Learning and Research
ICA	Industrial Capabilities Assessment
ICD	Initial Capabilities Document
ICIDS	Integrated Commercial Intrusion Detection System
IDD	Improvised Device Defeat
IED	Improvised Explosive Device
IEDD	Improvised Explosive Device Defeat
IGVC	Intelligent Ground Vehicle Competition
INL	Idaho National Engineering and Environmental Laboratory
INS	Inertial Navigation System
IOT&E	Initial Operational Test and Evaluation
IPT	Integrated Product Team
IQT	Initial Qualification Testing
JAUS	Joint Architecture for Unmanned Systems
JBC2S	Joint Battlespace Command and Control System
JCIDS	Joint Capabilities Integration and Development System
JGR	Joint Ground Robotics
JGRE	Joint Ground Robotics Enterprise
JROC	Joint Requirements Oversight Council

JRP	Joint Robotics Program
JRRF	Joint Robotic Repair Facility
JS	Joint Service
JUSC2	Joint Unmanned Systems Common Control
LADAR	Laser Radar
LAGR	Learning Applied to Ground Robots
LCS	Littoral Combat Ship
LF	Leader Follower
LOS	Line of Sight
LUT	Limited User Test
LW&M	Land Warfare and Munitions
M&S	Modeling and Simulation
MACE	Mine Area Clearance Equipment
MAPMCS	Mechanical Anti Personnel Mine Clearing System
MARCbot	Multi-Function, Agile, Remote Controlled Robot
MARS	Military Applications in Reconnaissance and Surveillance
MCS	Mounted Combat System
MDAP	Major Defense Acquisition Program
MDARS	Mobile Detection Assessment Response System
MGV	Manned Ground Vehicle
MOA	Memorandum of Agreement
MOCU	Multiple-Robot Operator Control Unit
MOU	Memorandum of Understanding
MOUT	Military Operations on Urban Terrain
MPRS	Man-Portable Robotic Systems
MRKB	Mobile Robot Knowledge Base
MRMC	U.S. Army Medical Research and Materiel Command
MTRS	Man-Transportable Robotic System
MULE	Multi-function Utility/Logistics Equipment Vehicle
MULE-CM	MULE-Countermine
MULE-T	MULE-Transport
NASA	National Aeronautics and Space Administration

NAUS	Near Autonomous Unmanned Systems
NAVEODTECHDIV	Naval EOD Technology Division
NCDR	National Center for Defense Robotics
NDI	Non-Developmental Item
NGEODRS	Next Generation EOD Robotic System
NGEODRCV	Next-Generation EOD Remote Controlled Vehicle
NIST	National Institute of Standards and Technology
NLOS	Non Line of Sight
O&M	Operations and Maintenance
OCS	Operator Control Station
OD	Omni-Directional
ODIS	Omni-Directional Inspection System
ODOA	Obstacle Detection/Obstacle Avoidance
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
ODOA	Obstacle Detection and Obstacle Avoidance
ONS	Operational Need Statement
OPP	Operations and Production Planning
ORD	Operational Requirements Document
OSD	Office of the Secretary of Defense
OUSD	Office of the Under Secretary of Defense
OUSD (AT&L)	Office of the Under Secretary of Defense, Acquisition, Technology and Logistics
PEO-LMW	Program Executive Office – Littoral Mine Warfare
PM	Product/Project/Program Manager
PM-FPS	Product Manager, Force Protection Systems
PM-RUS	Product Manager-Robotic and Unmanned Sensors
POM	Program Objective Memorandum
POR	Program of Record
PSEAG	Physical Security Equipment Advisory Group
R&D	Research and Development
RACS	Robotics for Agile Combat Support

RCS	Remote Control System
RCSS	Robotic Combat Support System
RDEC	Research, Development, and Engineering Center
RDECOM	Research, Development and Engineering Command
RDT&E	Research, Development, Testing & Evaluation
REDHORSE	Rapid Engineers Deployable Heavy Operational Repair Squadron Engineer
RF	Robotic Follower
RONS	Remote Ordnance Neutralization System
RS JPO	Robotic Systems Joint Project Office
RSP	Robotics Systems Pool
RSTA	Reconnaissance, Surveillance, and Target Acquisition
RTT	Robotics Technology Transfer
S&T	Science and Technology
SAE	Society of Automotive Engineers
SBIR	Small Business Innovation Research
SDD	System Development and Demonstration
SID	Special Interest Group
SoS	System of Systems
SPAWAR	Space and Naval Warfare Systems Center
SPO	System Program Office
SSC- San Diego	SPAWAR Systems Center - San Diego
STO	Science and Technology Objective
STTC	Simulations & Training Technology Center
SUGV	Small Unmanned Ground Vehicle
SWORDS	Special Weapons Observation Remote Reconnaissance Direct Action System
TACOM	Tank-automotive Armament Command
TARDEC	U.S. Army TACOM Research, Development and Engineering Center
TATRC	Telemedicine and Advanced Technology Center
TBD	To Be Determined
TFT	Technical Field Test

TMR	Tactical Mobile Robots
TPE	Theater Provided Equipment
TRADOC	Training and Doctrine Command
TRL	Technology Readiness Level
TSM	TRADOC System Manager
TSWG	Technical Support Working Group
TTP	Tactics, Techniques, and Procedures
TUGV	Tactical Unmanned Ground Vehicle
UAV	Unmanned Aerial Vehicle(s)
UGCV	Unmanned Ground Combat Vehicle
UGS	Unattended Ground Sensor
UGV	Unmanned Ground Vehicle(s)
UMS	Unmanned System
UPI	UGCV – Perception Integration
USAF	United States Air Force
USCC	Unmanned Systems Capabilities Conference
USMC	United States Marine Corps
USV	Unmanned Surface Vehicle
UUV	Unmanned Underwater Vehicle(s)
UXO	Unexploded Ordnance
VIR	Virginia International Raceway
WG	Working Group
WIPT	Working Integrated Product Team