UNMANNED GROUND VEHICLE MASTER PLAN

July 1991

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GLOSSARY

BTI	Balanced Technology Initiative
COEE	Concept of Employment Evaluation
DARPA	Defense Advanced Research Projects Agency
DDDRE	Deputy Director of Defense, Research, and Engineering
DEMVAL	demonstration-validation
DoD	Department of Defense
DoE	Department of Energy
DT&E	development test and evaluation
EMD	engineering and manufacturing development
EOD	explosive ordnance disposal
EUT&E	Early User Test and Evaluation
FLIR	forward looking infrared
FPA	focal plane array
FO	fiber optic
FOV	field of view
FY	fiscal year
GPS	Global Positioning System
HMMWV	high mobility multipurpose wheeled vehicle
hp	horsepower
IOT&E	Initial Operational Test and Evaluation
JPO	Joint Project Office
LWIR	long wavelength infrared
MBU	Mobile Base Unit
MIT	Massachusetts Institute of Technology
MOA	Memorandum of Agreement
mph	miles per hour
NBC	nuclear, biological, and chemical
NIST	National Institute of Standards and Technology
NLOS	non-line of sight
OCU	operator control unit
ORD	Operational Requirement Document
OSD	Office of the Secretary of Defense

P3I	preplanned product improvement
PE	program element
R&D	research and development
RCS	real-time control system
RECORM	Remote Control Reconnaissance Monitor
RF	radio frequency
ROND	Remote Ordnance Neutralization Device
RRR	Rapid Runway Repair
RSTA	reconnaissance, surveillance, and target acquisition
SIMNET	Simulation Network
STV	surrogate teleoperated vehicle
STV(I)	surrogate teleoperated vehicle (integrated)
T&E	test and evaluation
TMAP	Teleoperated Mobile All-Purpose Platform
TUGV	Tactical Unmanned Ground Vehicle
TWP	Tactical Warfare Programs
UAV	unmanned aerial vehicle
UGV	unmanned ground vehicle
UGVMP	Unmanned Ground Vehicle Master Plan
UGVTEE	UGV Technology Enhancement and Exploitation

I. SUMMARY

A. BACKGROUND

In recent years Congress "has been concerned about the direction and composition of the many diverse robotics projects undertaken by the armed services and defense agencies."[1] Although the Senate Appropriations Committee recognized the effort and progress embodied in the 1989 robotics master plan, it requested consolidation of all ground vehicle robotics projects "under OSD policy and program direction."

In January 1990, in response to this request, previously separate ground vehicle-related robotics projects were consolidated in a single program element (PE 0603709D). Since then, the Tactical Warfare Programs (TWP) office of OSD has been responsible for this program element (PE), providing program direction, allocating appropriated funds to projects within this PE, and carefully monitoring the progress of these projects. The Services and the Defense Advanced Research Projects Agency (DARPA) are responsible for the conduct and daily management of the projects.

Following the consolidation of funding, in order to decide on the projects that would be conducted under this PE, a number of planning activities took place in DoD and between OSD and the Services. The overall rationale for the robotics program was developed, based on analysis of existing and emerging requirements. The various projects underway or proposed by the Services were reviewed. Several were terminated and those that were selected were restructured to produce "a more focused and cost-effective robotics program." The results of this process were reported in last year's Unmanned Ground Vehicle Master Plan (UGVMP).[2,3]

This year's UGVMP is the first to cover a full year under direct OSD responsibility. It represents an update, expansion, and adjustment of last year's UGVMP. Both the

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1 Report 101-132 from the Senate Committee on Appropriations on the Department of Defense Appropriations Bill, 1990. Quotations in this section are from Report 101-132.

2 Unmanned Ground Vehicle Master Plan, Department of Defense, April 1990

3 Here and hereafter, the term UGV is used in a general sense to include a range of applications. The term Tactical Unmanned Ground Vehicle (TUGV) will refer to a specific project, described below, which is developing one class of UGVs.

individual projects and their interrelationships within the overall program have been better defined.

B. PURPOSE AND SCOPE

The purpose of this UGVMP is to provide a single, integrated DoD document that lays out the strategy for introducing supervised robotic vehicles into our forces and the plan for development and acquisition of unmanned ground vehicle systems. The UGVMP describes the conceptual and management framework within which robotics projects are being pursued, the details of these projects, and the relationships among them. OSD is using the UGVMP as a management tool in fulfilling its responsibilities for oversight of the robotics program.

The primary emphasis of the efforts described in this report is on teleoperated and supervised unmanned ground vehicles, i.e., unmanned systems that move over the ground (referred to simply as UGVs in this report). A variety of potential applications of UGV systems are mentioned in the report, but detailed discussion is limited to those applications that are being pursued.

Although unmanned air vehicles (UAVs) are not included within the plan, UGV/UAV interoperability of remote command and control stations and commonality of architectures are being pursued. Technologies, such as artificial intelligence, that other programs are developing are being used for UGV systems. Similarly, the technology base projects within the UGV program apply to other programs such as the physical security program.

C. BASIS FOR UGV SYSTEMS PLANNING

The potential payoffs of UGVs include the following:

- Reduced risk to human life and increased operational flexibility in combat or other hazardous environments
- Economy of manpower or reduced costs in operations done repetitively (e.g., logistics) where manpower savings more than offset investments in equipment
- Reduced training costs and increased training realism
- Improved performance where automated systems either perform better than humans or eliminate the system compromises required by human physiological limits (creature comfort, fear, fatigue, vibration, etc.)
- Force multiplication where operators with UGVs bring substantially more capability to bear than would be possible by individual troops without UGVs.

There are strong reasons for believing that the structure and operations of future land forces will depend heavily on robotic systems:

- There are a variety of potential applications of robotics to land operations that can increase efficiency and safety. These include reconnaissance, target engagement, logistics, runway repair, minefield detection and neutralization, explosive ordnance disposal, physical security, and operations in contaminated environments. (The threat of encountering chemical and biological weapons in Third World conflicts is growing rapidly.)
- Force size will be substantially smaller (e.g., forward-deployed forces in Europe) but without corresponding reductions in areas of responsibility.
- The hardware that is necessary for many of these applications is developing rapidly. Modern sensors, computers, and communication links can acquire, process, and transmit data far beyond the capabilities of individuals restricted to manual operations.
- Robots and robot-like devices continue to grow in importance with commercial applications that range from cruise control of automobiles to complex autopilots and from manufacturing to medicine.

In a number of ways, Desert Storm reenforces the view that future land forces will depend on robotic systems:

- For the first time, UAVs were widely used in combat.
- Land forces confronted the immediate threat of chemical weapons.
- A hurried request for remotely operated, mine-clearing tanks, and shallow water craft was made.
- High technology weapons demonstrated the effectiveness of autonomous guidance.
- Desert Storm revealed the political significance of individual weapon systems in regional conflicts, SCUD/PATRIOT being the most dramatic example.
- Desert Storm set a standard of minimal friendly casualties against which the results of future conflicts will be measured.

Although the potential applications and payoffs of UGV systems are apparent and although today's sensors and computers, coupled interactively with humans, can meet the requirements for many of these applications, for many other applications the software that is required to approximate human capability to integrate data and exercise control authority does not exist. Developing such software is the major challenge for future autonomous systems. Non-line-of-sight (NLOS) teleoperation avoids the severe software challenges of autonomous operation but involves significant communications, man-machine interface, and human factors issues. Nevertheless, teleoperation is feasible today; except for a few highly structured applications, autonomous operation is not.

Given the status of robotics technology and user requirements, current DoD planning for UGV systems stresses two types of system development. The first type involves UGVs that must operate on the battlefield with other land combat systems and forces. The Tactical Unmanned Ground Vehicle (TUGV) development is the near-term thrust of the UGV program in this category. The second type involves relatively narrow, but cost-effective, applications other than land combat that have limited and achievable requirements for automating human control functions. These narrower projects develop specific robotics techniques and also support the goal of gaining user acceptance of robotic systems.

The UGV program strategy is based on a coordinated evolution of demonstrated capabilities and user requirements. In the near term, teleoperation and teleassistance are emphasized, together with extensive user opportunities to gain experience with prototypes. In the mid-term, supervised robotics will be demonstrated and introduced for navigation and/or reconnaissance, surveillance, and target acquisition (RSTA) functions. In the far term, highly autonomous robotic systems based on artificial intelligence will be developed. Far term robotics research is being conducted by DARPA.

The UGV plan described in this report has been structured to maximize future use across the Services, to focus limited resources on existing and emerging requirements, and to preclude duplicative activities. Technology programs have been focused on the system applications that were selected. Specific programmatic plans, described below, have been developed to ensure that appropriate technology is demonstrated and that demonstrated technology is integrated into system development.

As described in Section II.F, considerable attention has been given to fostering organizational relationships (among DoD components and between them and other agencies, universities, and industry) that will assure technology transfer and maximize the productivity of the funds expended under the Joint Robotics Program:

- Development of the TUGV under a memorandum of agreement (MOA) between the Army and Marine Corps
- Collaboration among the advanced system development and technology projects for demonstration and integration of technology prior to Engineering and Manufacturing Development (EMD)

- Development of robotic UGV navigation technology under an MOA between DARPA and TWP that incorporates technology transfer from academia to industry and Government
- Pursuit of joint DoD and DoE development opportunities
- Colocation of the TUGV and UAV joint project offices (JPOs) to facilitate cooperation in the development of employment concepts and common control architectures.

D. PROGRAM SUMMARY

The following three programs that were supported last year are no longer part of the Joint Robotics Program:

- Remote Control Reconnaissance Monitor (RECORM)--This is a light-weight, two-man transportable UGV system designed to provide explosive ordnance disposal (EOD) personnel the means to visually search for, identify, and determine the condition of unexploded ordnance from a remote, safe location. This project is now in EMD and is being funded by the Services.
- Semiautonomous Mission Modules--As stated in last year's UGVMP, a one-time allocation of $1.3 million was provided in FY1990 to maintain program continuity with the stipulation that this project would not be included in subsequent year's UGVMPs.
- Training Wheels--This was a specialized project to partially automate the opposing forces at the National Training Center in order to save personnel costs and to increase training realism. This project, which was cooperatively funded with the Army, has been dropped because of threat changes and affordability considerations. Leader-follower technology will be evaluated as part of the technology maturation program.

These projects are not discussed further in this plan.

Chapter II describes in detail the UGV acquisition program strategy. The following three 6.3B projects are being pursued:

- Tactical Unmanned Ground Vehicle (TUGV)--This is a joint Army/Marine Corps program to develop, produce, and procure UGVs for battlefield deployment. Initially, this project will develop a teleoperated/teleassisted system in which the operator is capable of performing remotely the functions of reconnaissance, surveillance, and target acquisition (RSTA), nuclear, biological and chemical (NBC) detection and laser designation. The near-term program includes extensive user familiarization with surrogate teleoperated vehicles (STVs) in order to assess operational benefits and liabilities and to assist in refining requirements before entering EMD.

- Rapid Runway Repair (RRR)--A specialized[4] application to develop a teleassisted repair system capable of driving to a damage site, finding craters, mapping damage, removing debris, breaking and removing upheaved pavement, backfilling, and compacting and grading backfill materials. Its purpose is to remove personnel from a hazardous environment. This project is cooperatively funded with the Air Force.
- Remote Ordnance Neutralization Device (ROND)--A teleoperated/teleassisted system to provide EOD personnel safe separation from hazardous accident/incident sites where explosive, chemical, or radiation risks are present. This project is developing a remotely operated mobile platform with closed circuit TV, a six-degrees-of-freedom manipulator, and a suite of EOD-unique tools with automated tool exchange.

Although RRR and ROND have relatively narrow applications, each will make a contribution to the development of UGVs. Both programs involve the integration of sensor and effector technology and both programs have potential civil applications.

The TUGV is the principal effort of the current UGV advanced development program. The TUGV program is being planned and managed with an awareness that it represents an initial step in the evolution and fielding of UGVs for combat applications and that its success or failure may have far-reaching consequences. The program concept has been restructured by OSD in accordance with the principles of Directives 5000.1 and 5000.2. Figure 1 shows the restructured program concept and the role of ongoing technology maturation efforts. The left column of figure 1 represents the TUGV program. This column is further divided horizontally to show the successive phases of the acquisition program. The right column shows the role of technology maturation programs in preparing for EMD and for subsequent preplanned product improvements (P3I) and second generation UGV systems. Important features of the program concept include the following:

- The development and use of a STV to foster integration of user, technology, and developer perspectives.
- Concepts of employment and user requirements trade-offs based on extensive experience with the STV.
- Technology maturation programs, both near term and longer term, focused heavily on TUGV applications.

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4 Much less specialized if potential civilian applications are considered.

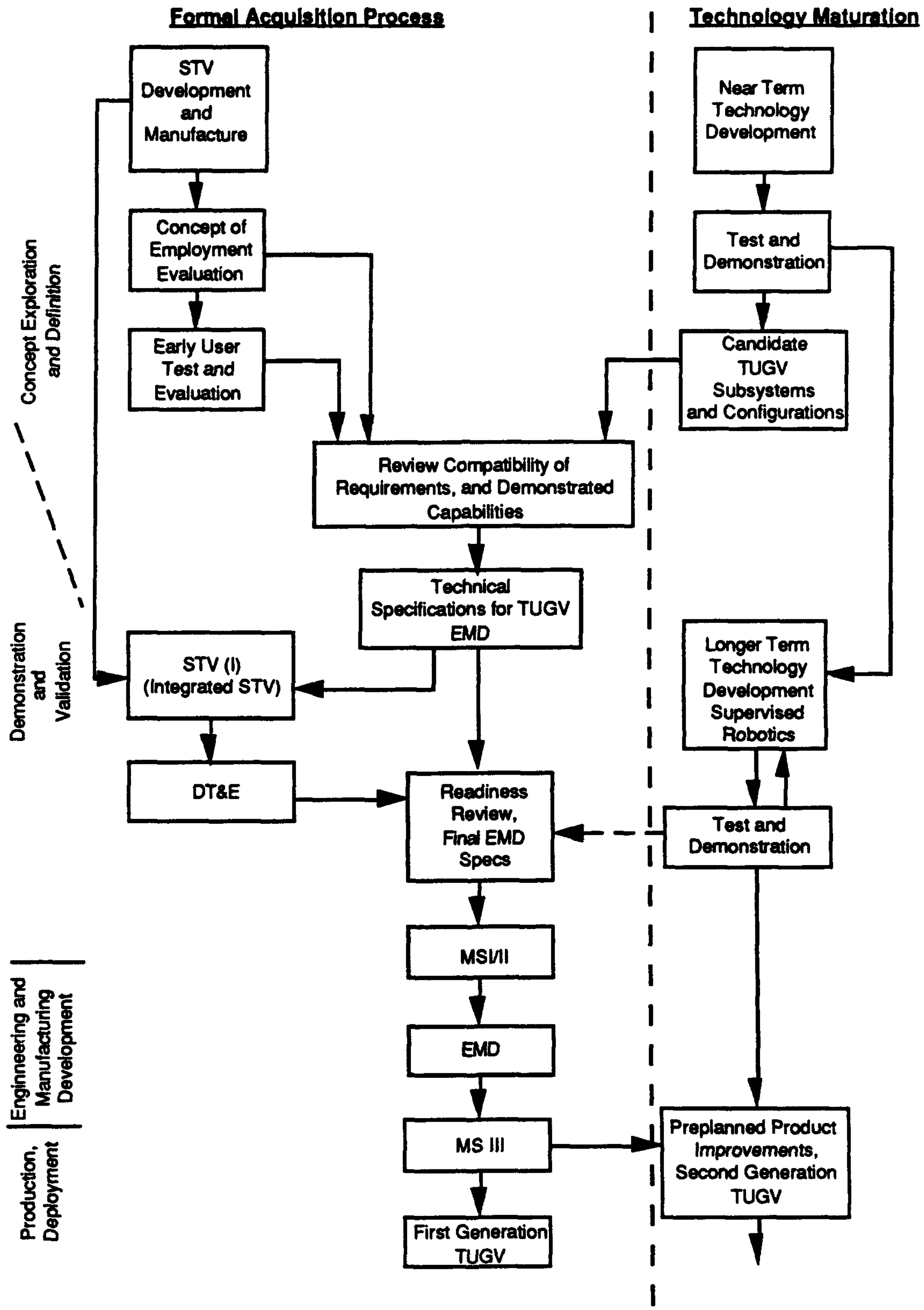

Figure 1. TUGV Program Concept

- Integration of demonstrated technology into the STV. The resulting configuration, designated as STV(I), will provide a high fidelity representation of the system to be developed and will ensure that this system has strong user support. It will include a basic sensor suite for driving and RSTA, fiber optic cable and RF communication links, remote operator control, and subsystem algorithms and software.
- Emphasis on event-oriented schedules that reduce risk and generate program support.

The longer term goals of the TUGV programs are as follows:

- Realization of mature technology for a supervised UGV by the year 2000
- Fielding of highly autonomous UGV systems by the year 2010.

II. UGV PROGRAM STRATEGY AND MANAGEMENT

Chapter I described the broad rationale for the UGV program. This chapter continues the discussion of rationale by focusing on each of the major components of the program and the role of individual projects within those components. Management aspects of the program are highlighted.

A. OVERVIEW

As stated in Chapter I, the following three projects are in advanced system development and are being funded under PE0603709D:

- Tactical Unmanned Ground Vehicle (TUGV)
- Rapid Runway Repair (RRR)
- Remote Ordnance Neutralization Device (ROND)

These (and future) projects are supported by UGV Technology Enhancement and Exploitation (UGVTEE) tasks that are addressing technologies critical to the timely development of UGV systems. Two extensive series of technology maturations and demonstrations are underway. These efforts are referred to as Demo I and Demo II and are discussed in Section E below. They directly support the various UGV functional needs, planned demonstrations, and future product improvements.

The RRR project has less demanding requirements for navigation and communications than the TUGV. Because of the structured setting in which it will operate, RRR navigation can incorporate more robotic features. The guided robotic positioning and operation of heavy equipment represents a unique set of requirements that bring effector technology for civil engineering into the overall robotics program. Potential civilian applications of this technology, especially for work in hazardous environments, are being explored with DoE.

Table 1 shows the overall funding structure of the UGV program. Based on DoD budget guidance, the plan assumes a constant level of annual funding of about $21 million. The majority of this amount is planned for 6.3B development programs; a breakdown of this funding among TUGV, RRR, and ROND is shown in Table 2.

Table 1. Planned Funding for PE0603709D ($M)

	FY90	FY91	FY92	FY93	FY94
Development Programs	10.90	10.35	11.80	11.20	11.00
Technology Base	9.70	10.08	8.30	8.80	9.00
Study, Taxes	0.22	0.57	0.64	0.66	0.63
Total	20.82	21.00*	20.74	20.66	20.63

* The original FY1991 budget of $22.0 million was reduced by $1.0 million due to reprogramming.

Table 2. Planned Funding for 6.3B Development Programs ($M)

	FY90	FY91	FY92	FY93	FY94	Total
TUGV	6.70	7.65	8.10	8.10	3.00	33.90
RRR*	0.75	2.00	2.00	1.50	0.50	7.75
ROND	0.80	0.70	1.70	1.60	1.50	7.60

* In addition to the amounts shown, the Air Force has budgeted $0.25 million in FY1990, $0.375 million in FY1991, $0.325 million in FY1992, $0.30 million in FY1994.

Table 2 displays the funding planned for TUGV, RRR, and ROND up to EMD. Coincidentally, EMD is planned to occur in FY1994 for each of these programs. The Services are responsible for EMD funding. Next year's UGVMP will describe the FY1994 plan in detail.

B. TUGV

1. Overview

In the third quarter of FY1990, an MOA established the Joint Army/Marine Corps TUGV program with the Army as lead service and the Marine Corps providing the project manager. The need for the TUGV arises from the convergence of two major trends. First, the lethality of the modern battlefield has increased dramatically. Proliferation of modern precision-guided munitions and chemical and biological weapons and developments in directed-energy weapons necessitate commensurate improvements in technology to extend the survivability of individual soldiers and marines. Second, reductions in force structure require materiel advances that are force multipliers. The overall purpose of the TUGV program is to increase the effectiveness and survivability of combined arms forces by extending the control radius of human presence on the battlefield.

The long term objective of the TUGV program is to extend the operational capability to perform RSTA-related missions, without introducing limitations that are not present in alternative manned systems. This can only be accomplished through increased automation. Future TUGVs will allow an operator to control multiple vehicles and oversee several missions. A program to develop this capability has been initiated (see section E3 below). Other TUGV characteristics such as mobility, deployability, and endurance should match or exceed those of comparable manned systems.

The first generation TUGV will be a teleoperated, lightweight, helicopter transportable, mobile system. Under the control of a safely positioned remote operator, it can be navigated to its position and perform forward observation over prolonged time periods. In achieving forward presence, this system will significantly lessen the exposure of combat soldiers and marines to hazardous and lethal environments. Potential TUGV missions include RSTA with laser designation and weapon targeting; NBC detection and surveillance; and obstacle detection and breaching.

Figure 2 presents an overview of the pre-EMD phase of the TUGV program. This phase involves parallel, interacting sequences of system hardware and software development, tests, demonstrations, and supporting studies. Initial design concepts are based on user requirements, previous UGV programs, trade-off studies, and technology demonstrations. Final TUGV specifications for EMD will be based on performance assessments of the basic STV, STV(I), and the technology maturation demonstrations, complemented by a few focused studies in support of system development.

As stated in Chapter I, the STV will be used to formulate and evaluate concepts of employment and to engage the user in early test and evaluation. A parallel program of technology maturity demonstrations provides important data on technological capabilities as well as operational and human factors. Based on the results of ongoing technology maturation demonstrations (Demo I), the performance of the basic STV, and updated user requirements, the most promising technological capabilities will be integrated into the STV and tested. The STV(I) phase will reduce risk and provide a sound basis for EMD. The technology demonstration program will continue beyond Demo I, in parallel with EMD, to lay the basis for both P3I of the first generation TUGV and for a possible second generation TUGV.

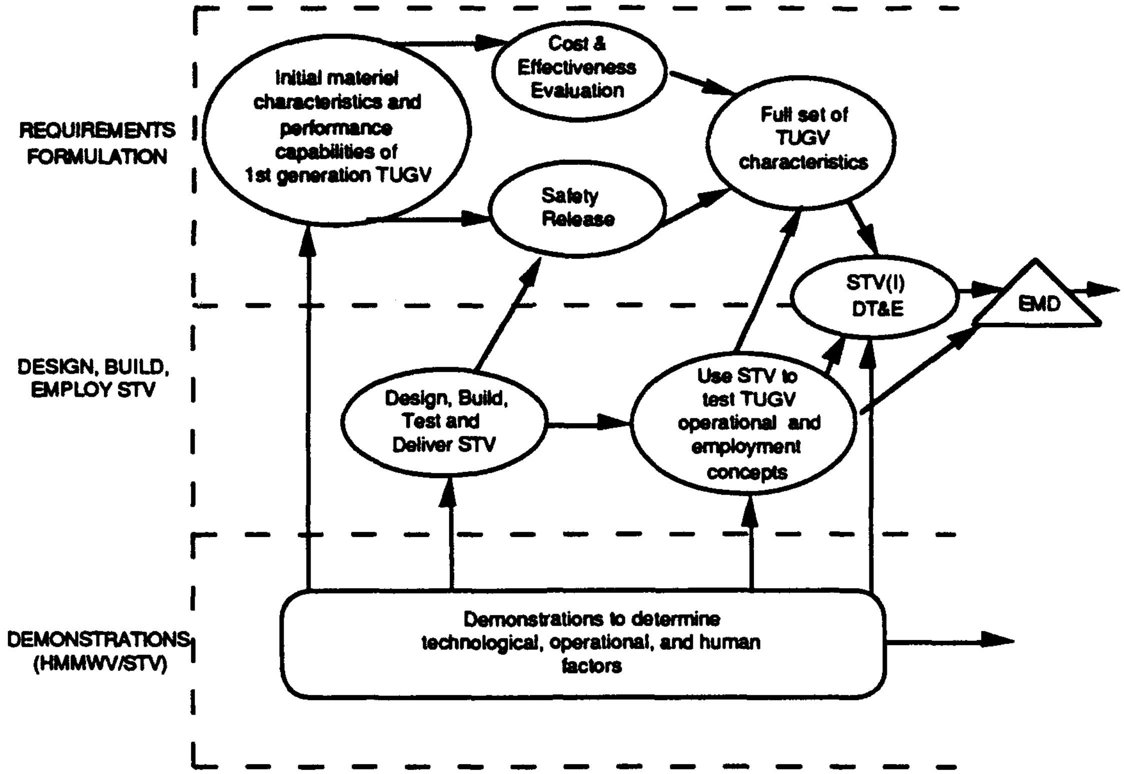

Figure 2. Pre-EMD TUGV Program Overview

2. Program Logic

This section provides a detailed description of the TUGV program plan up to the EMD decision in first quarter FY1994. The major prerequisites for the EMD milestone decision are an Operational Requirement Document (ORD), an approved Test and Evaluation Master Plan, an independent cost estimate, and a readiness review. Accomplishment of these prerequisites depends on a number of interrelated activities which are discussed under three headings: studies and analyses, technology transition efforts, and advanced system development using the STV platform.

a. Studies and Analyses

Concept design studies were initiated in September 1990. These will be followed by a study to evaluate and select the best technical approach and the system characteristics and performance capabilities. By the fourth quarter of FY1992, this process will have selected a candidate system concept and evaluated its cost and effectiveness in order to support the EMD system specifications.

In addition to the above studies, efforts are underway to utilize the DARPA-developed Simulation Network (SIMNET) as a valuable tool in the TUGV development process. During the coming year, a detailed analysis of the appropriate role for SIMNET will be completed.

b. Technology Transition

The TUGV project will use the UGVTEE program and other non-UGV programs to provide component technology options. The heart of the technology transition efforts are two technology maturity demonstrations, Demo I and Demo II. The first uses teleoperated high mobility multipurpose wheeled vehicles (HMMWVs) and is oriented primarily toward subsystem development. The second is oriented primarily toward subsequent P3I and second generation capabilities. Demo I will be completed during the third quarter of FY1992. It examines a number of operational, technological, and man-machine interface factors.

c. Advanced System Development

OSD has directed the TUGV Joint Project Office (JPO) to manage the risk of advanced system development through two steps: development of the basic STV followed by a second phase in which selected demonstrated technologies for teleassistance are integrated into the basic STV and tested.

As pictured in Figure 3, the STV is a small, lightweight, modular, teleoperated UGV. It can be transported internally by a HMMWV, towed by smaller vehicles, or driven either by an onboard driver or under remote command and control. It also can be air-transported by rotary- and fixed-wing aircarft.

Structurally, the basic STV is composed of four major components: (1) a Mobile Base Unit (MBU), (2) an Operator Control Unit (OCU), (3) a RSTA module and/or other modular mission payloads, and (4) a data communications link. Descriptions of each of these components follow:

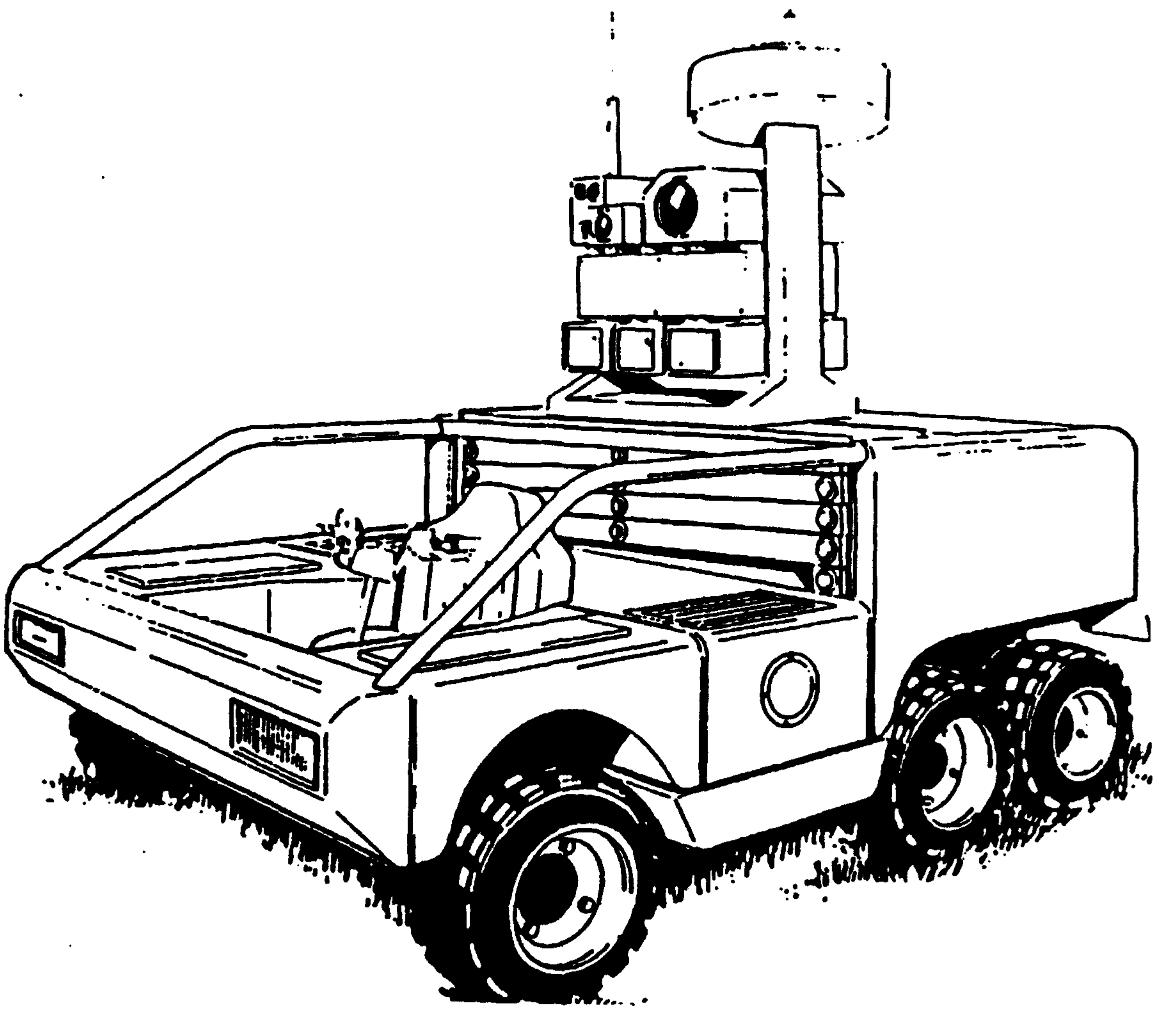

Figure 3. STV

- The MBU is a six-wheel-drive, fully amphibious platform. It contains all automotive and navigational components, including sensors and controls for teleoperated driving under day, night, and adverse environmental conditions. The platform is powered by a hybrid 25 horsepower (hp) diesel engine and a 3 hp electric motor system. The latter provides quiet locomotion whenever required. Automotively, the STV will be able to traverse roads at 35 miles per hour (mph) and travel off-road at 25 mph. Its remote driving speeds will depend on the skill of the operator and on the sophistication of the software that controls the driving. The STV's functional architecture is hierarchical with information processing done at a number of levels. The processor allows incorporation of increased levels of machine autonomy as appropriate software matures. The navigator relies on a differential Global Positioning System (GPS), with a conventional measurement system as backup, to provide location and direction of travel. The STV also contains a sensor and antenna platform that can be elevated to about 5 meters above ground level. The platform is designed for quick interchange of modular mission payloads.

- The OCU is a man-portable monitor and control console equipped with appropriate control interfaces, power supply, processor, and communication links to control the MBU and mission modules. The operator receives video, audio, and vehicle status information from the STV location.
- The STV has two complementary data communication links to transmit information and commands between the remote operator and the STV. They are an umbilical cord fiber optic (FO) link and a wireless radio frequency (RF) link. The FO bandwidth allows secure and covert NLOS transmission of high resolution video data. It cannot be jammed, interrupted, or monitored and allows numerous vehicles to operate in the same area without mutual interference. The main disadvantage of FO links is that they restrict operational mobility of UGVs. The tactical RF data link provides two-way wireless communication in situations where the remote operator has to move from location to location or where the FO link is severed or not desired.
- The STV RSTA mission module consists of a suite of sensors used for both driving and RSTA. The sensor suite includes day and night sight, forward-looking infrared (FLIR), laser range finder and designator, and acoustic sensors. The sensors are able to acquire targets out to at least 2 km with 360-degree coverage. Incorporation of an NBC detection system is also planned. The STV equipped with a RSTA module is adaptable to physical security applications.

3. Program Schedule and Funding

Figure 4 provides an overall program schedule and highlights the role of the STV in preparing for TUGV EMD. The STV contract, awarded in December 1990, calls for the delivery of 14 STVs. Two of these will be used for safety and technical tests. The remaining 12 vehicles will be used initially in a series of developmental and operational test and evaluation (DT&E and OT&E) efforts. A Concept of Employment Evaluation (COEE) will test and refine operational and organizational concepts for both the Army and Marine Corps. Additional user evaluations will be conducted at various military facilities (Fort Sill, Fort Knox, JTF6, and Fort McClellan). The COEE will include STV employment under controlled conditions and in field exercises that simulate operational scenarios. The COEE will be followed by a joint Early User Test and Evaluation (EUT&E). Hands-on user experience will clarify the operational role, value, and requirements of TUGV. The results will be used to develop the ORD and to assess the combat value of the TUGV.

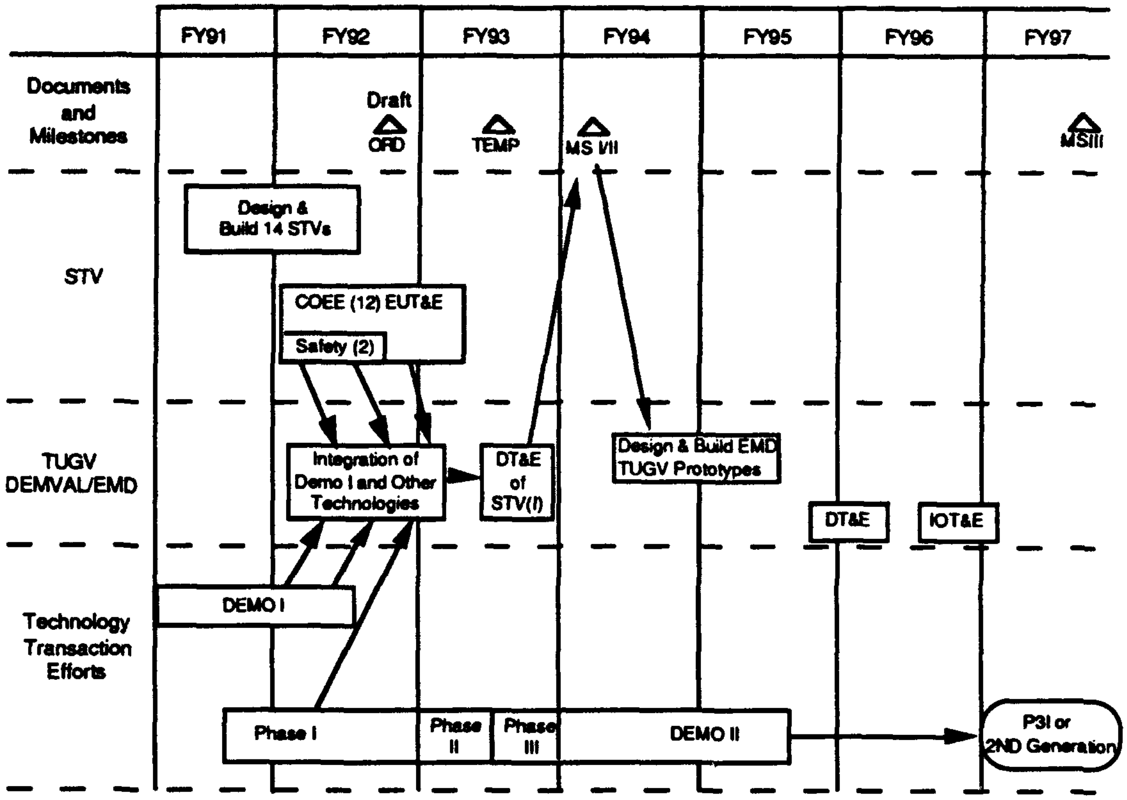

Figure 4. TUGV Program Schedule

Based on the results of the COEE, EUT&E, and Demo I, selected technologies will be integrated into the STV and tested. The STV(I) DT&E results will help determine whether the TUGV is ready for EMD.

d. Engineering Manufacturing Development

In the EMD phase, the selected system contractor(s) will be responsible for fabricating a production-ready TUGV. The Government will conduct DT&E and Initial Operational Test and Evaluation (IOT&E) of the contractor-provided TUGV prototypes. These tests will determine readiness for production of a first generation TUGV. Milestone III is planned for the end of FY1997.

Figure 5 summarizes the TUGV schedule and also shows the funding for TUGV by fiscal year (FY1990-FY1997).

		FY90	FY91	FY92	FY93	FY94	FY95	FY96	FY97
Schedule	Milestone I/II					△ 1/94			
	DT&E				▭			▭	
	OT&E			COEE EUT&E				IOT&E	
	Milestone III								8/97 △
Funding ($K)	Required	6700	7650	8100	8100	21600	28400	24500	106600
	OSD	6700	7650	8100	8100	3000			
	Army*					11.9	25.4	22.2	8.0
	USMC*					5.0	5.8	5.1	2.5

* Service amounts show planned funding. The USMC has budgeted $5.0 million in FY1994, $1.4 million in FY1995, $2.0 million in FY1996, and $2.5 million in FY1997

Figure 5. TUGV Program Schedule and Funding

4. Technology Maturation

The TUGV program rests on a number of earlier UGV technology base programs, such as the Army's Teleoperated Mobile All-Purpose Platform (TMAP) and the Marine Corp's Teleoperated Vehicle. Nevertheless, the TUGV is a pioneering program in the sense that no UGV to perform the RSTA mission has ever been fielded. Hence, there is little operational experience with such a system. The COEE and EUT&E are designed to help fill this gap.

In addition to operational issues, there are significant technological limitations on the performance of certain TUGV functions. The first generation system will be constrained by current technology limitations with respect to:

- Software algorithms for autonomous navigation, target acquisition, and other functions
- Availability of suitable RF communication alternatives.

The results of ongoing and future technology efforts will eliminate or reduce some of these limitations, but the near-term goal is to arrive at a practical first generation design within the constraints of current technology.

5. TUGV Summary

In summary, the TUGV program is one of the major near-term thrusts of the UGV program. During the past year, a detailed program plan has been developed and is being executed. This plan:

- Recognizes and addresses both technological limitations and the absence of previous operational experience
- Is based on an event-driven schedule that reduces risk
- Requires solid confirmation of the technological readiness and combat value of the first generation TUGV before entering the EMD phase.

C. RAPID RUNWAY REPAIR (RRR)

1. Overview

To safely perform sustained offensive and defensive air operations, it is essential that the runways from which the planes take off and land remain intact. Restoration of operational capability following enemy attack of airfields is a USAF requirement. Airbases should be reopened and available for flight operations within 4 hours of attack. However, dangerous post-attack conditions complicate and inhibit runway repair: subsequent attacks may occur; the enemy may scatter mines during initial or follow-on attacks; and the threat of lethal chemical and biological agents is increasing. These hazardous conditions not only inhibit manned runway repair operations but also require additional manpower and equipment for backup support.

The Rapid Runway Repair UGV provides a telerobotic means of executing runway repair and recovery and alleviates some of the safety and manpower issues associated with RRR. The repair vehicle can perform under post-attack conditions while the remote operators and other airbase personnel remain at a safe distance. Based on preliminary performance tests of a brassboard design, it is estimated that these remotely operated RRR machines working alone will decrease crater repair time by 35 percent compared to manually operated systems.

2. Program Plan

In preparation for EMD, the RRR program embodies work with two vehicles: (1) an existing John Deere semiautomatic excavator (see Figure 6) used for initial capability demonstration and (2) a new excavator vehicle. Drawing on technological and operational concepts generated, in part, from testing the John Deere excavator system, efforts toward producing a mature RRR vehicle for EMD concentrate on three key areas: (a) communications (b) navigation and guidance, and (c) technology integration in the prototype vehicle.

A draft Statement of Work for procurement of the excavator platform has been completed. The Test and Evaluation Master Plan is being developed. As part of the risk management, a series of demonstrations will be conducted in each of the three key areas: (1) communications demonstration in July 1992, (2) navigation/guidance demonstration in August 1993, and (3) total system demonstration in the last quarter of 1994.

- Communication--Using a fixed operator control station and the existing RRR multipurpose excavator, communications links will be tested to evaluate their performance in transmitting/receiving the data required for the RRR mission. The demonstration will cover communications for both teleoperation and autonomous operation. (Multiple vehicle communications will be included in the total system demonstration.)
- Navigation/Guidance--A series of navigation subsystem demonstrations will be conducted separately over a 12-month period. These will cover autonomous path planning, driving based on GPS and inertial navigation, and ultrasonic obstacle avoidance. In August 1993, the integrated navigation system will be demonstrated. This includes driving the test vehicle, under remote operator supervision, over runway sections to a repair site at a speed of 10 mph, while avoiding known and unexpected obstacles.
- System--In 1994, the total system (as well as multiple vehicle command, control and communication) will be demonstrated. Communication and navigation systems will function in the context of a complete mission. A crater will be blown in the test runway and completely repaired by the semiautonomous crater repair vehicle. The process will involve navigating to the crater, inspecting the crater, determining the repair sequence, and executing the complete repair sequence.

Thorough coordination is maintained with the UGV advanced technology development community and the TUGV JPO for potential spinoff technology applications. One such effort, an Army-developed communication protocol, has already been adapted to a remote control system for the John Deere excavator. A National Institute of Standards and Technology (NIST) real-time control architecture and a modular architecture developed by Sandia National Laboratories are currently being evaluated for possible application to the vehicle architecture and design.

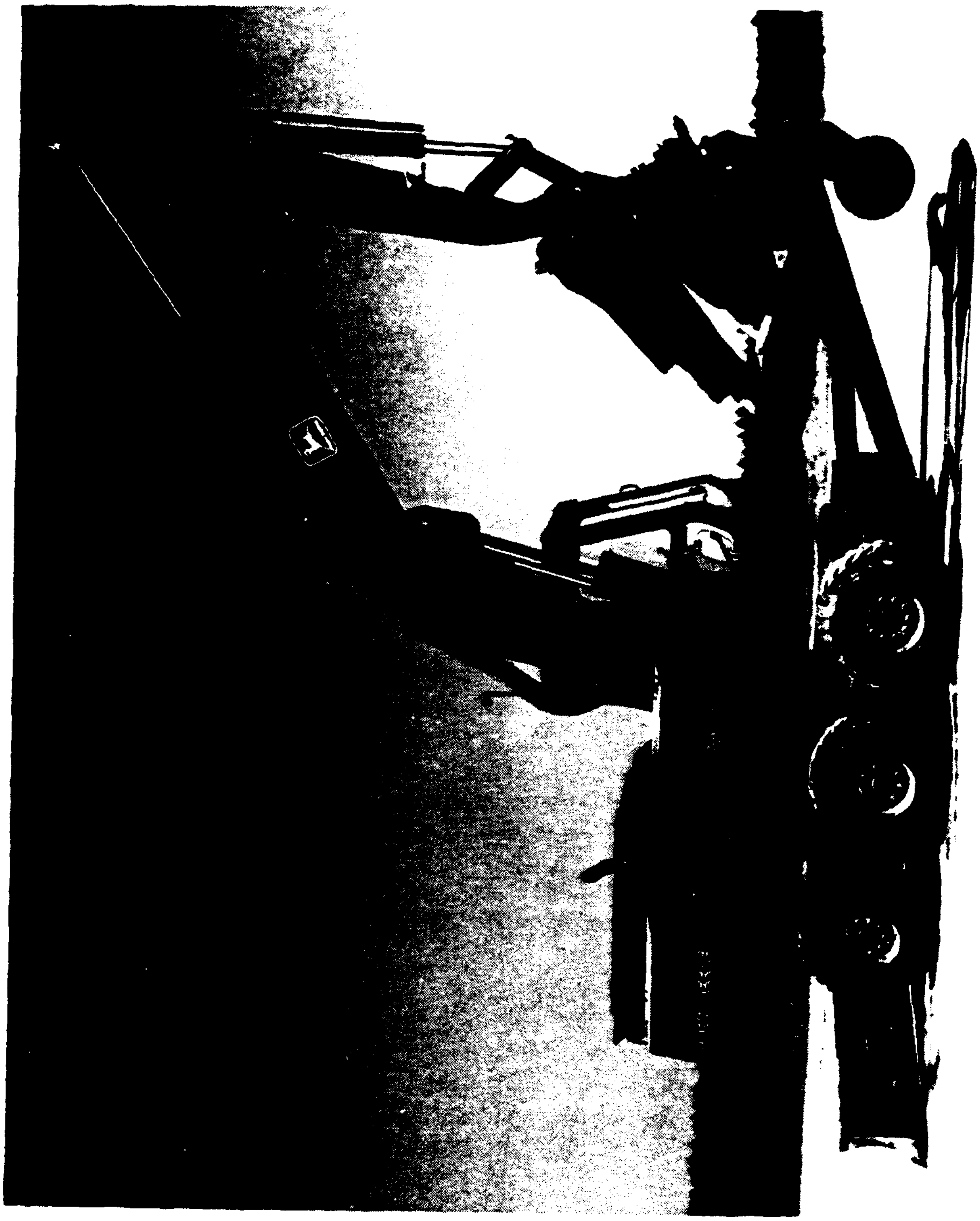

Figure 6. RRR Demonstration Unit

Using the existing John Deere RRR robotic excavator, a smart joystick project to enhance remote control operability was completed in 1987. By 1988, the John Deere vehicle was preprogrammed to perform the following functions automatically: digging, level scraping, compacting, impact hammering, and automated tool changing. A remote control system for the vehicle has been procured. Its installation and integration with onboard systems is currently underway.

Current plans call for use of the John Deere excavator not only to demonstrate required repair capability but also for exploring buried waste retrieval for DoE. A joint proposal with Sandia (DoE) for development of a new telerobot for waste site remediation is being discussed. Such a project would combine the technological and operational concepts developed for RRR with DoE expertise. If approved, an MOA between DoD and DoE will be concluded in FY1991.

The RRR program is progressing in all three of the areas described above. For communications, an evaluation of a packet radio communication link is currently underway. For the technology integration, vehicle design specifications have been completed. A contract was awarded in April 1991.

3. Program Schedule and Funding

Figure 7 shows the schedule and funding for RRR by fiscal year (FY1990-FY1997).

		FY90	FY91	FY92	FY93	FY94	FY95	FY96	FY97
Schedule	Initiation	3/90							
	Milestone II					7/94			
	DT&E			6/92	6/93, 10/93	1/94		6/96, 7/96	
	OT&E							9/96	2/97
	Milestone III								6/97
Funding ($K)	Required	1000	2375	2325	1800	800	600	3400	2900
	OSD	750	2000	2000	1500	500			
	Service	250	375	325	300	300	600	3400	2900

Figure 7. RRR Program Schedule and Funding

D. REMOTE ORDNANCE NEUTRALIZATION DEVICE (ROND)

1. Mission Description

ROND is being developed in accordance with the Joint Service EOD Operational Requirement for ROND of 26 February 1990. It will provide EOD personnel the means to secure unexploded ordnance, attach a render safe procedure device/tool, withdraw to a safe area, and fire/function the tool. The ROND platform will separate the EOD operator safely from hazardous accident/incident sites where explosive, chemical, and radiation hazards are present.

2. System Description

The ROND consists of an operator control console, a mobile platform shown in Figure 8, a closed-circuit color television system, an RF link, a tethered link, a self-supporting power source, and a manipulator consisting of an arm and end effector with common tools. The control console includes an RF transmitter, fiber-optic transceiver, video receiver, television display monitor, power converter, and associated electronics for mobile platform control and telemetry. The mobile platform is equipped with a removable closed-circuit television camera (with ability for both color or low-light black and white) with zoom lens, removable video lighting, fiber-optic and RF communication links, and associated electronics. The fiber-optic tether enables system commands and sensor data to be passed between the mobile platform and control console when RF communication is not possible or not desired. For security and safety reasons, RF communication should be encrypted. In addition, all control and data/video/audio links should be digital for direct digital data storage and processing. A hybrid lightweight diesel/electric battery system will supply power for operational functions. The ROND is operable in all expected weather conditions including rain, snow, sleet, sand, and dust. The platform is designed for low velocity driving in a wide spectrum of operational environments.

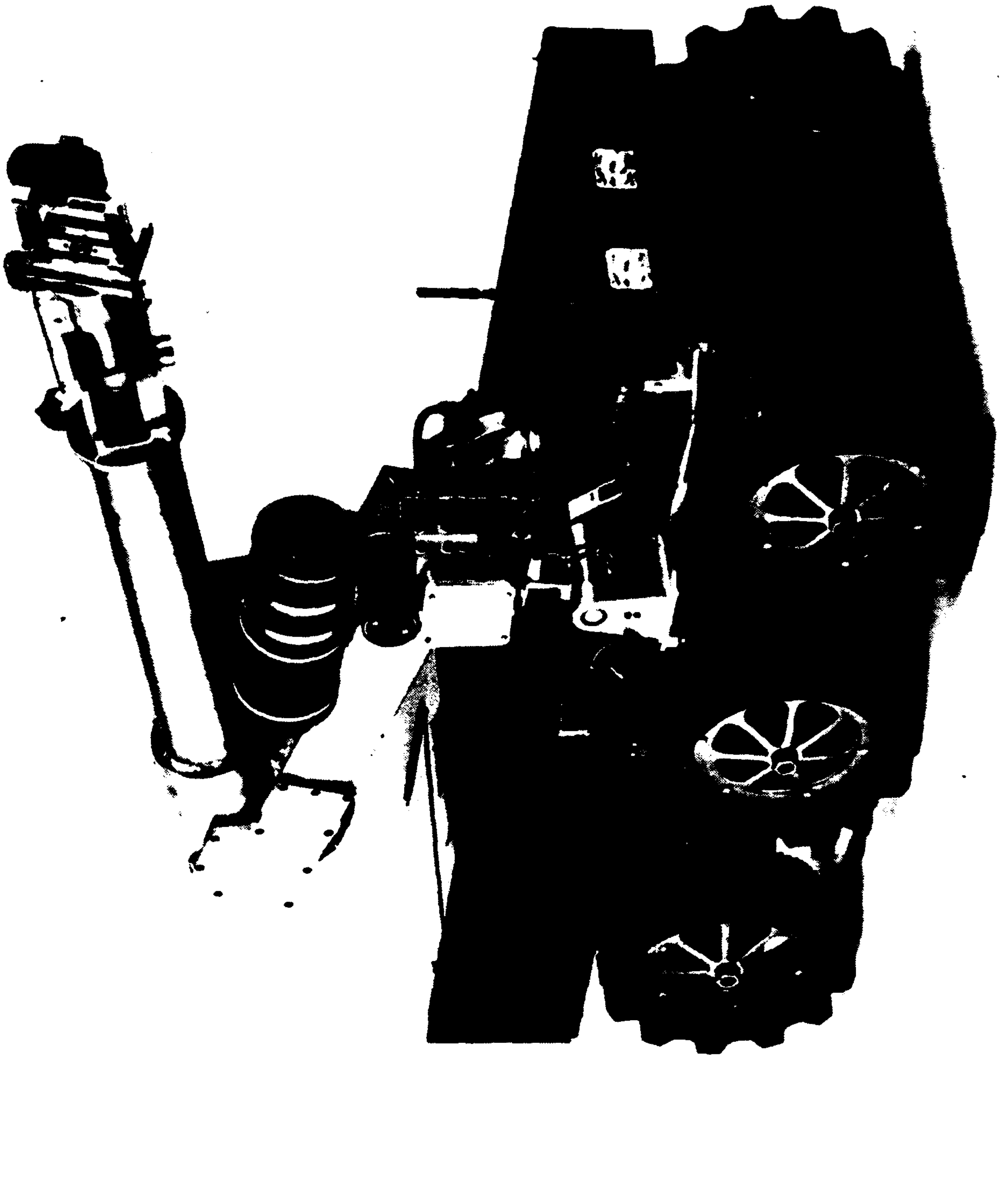

Figure 8. ROND Exploratory Development Prototype

The ROND UGV will have a highly versatile seven-function manipulator exhibiting six degrees of freedom, including a three-axis wrist assembly with position control. The manipulator will have an operational envelope of 6 feet above the ground and 3 feet from all edges of the platform, and 2 feet below ground level at 3 feet from all edges. A quick tool change capability will be accomplished telerobotically via the master control. Using changeable grippers, the manipulators will be able to grasp a variety of shapes, e.g., rectangular, cylindrical, spherical, and conical, corresponding to typical ordnance/explosive device configurations. Tools will be both man and machine emplaceable and stored on the platform in a secure holster until needed by the arm or released by the operator for man emplacement. Tool requirements include the .50 caliber dearmer, rocket wrench, mechanical impact wrench, and various common hand tools. The .50 caliber dearmer will be capable of being positioned and fired from the manipulator arm.

3. Development Status, Schedule, and Funding

The ROND program was initiated in March 1990 and is currently in Advanced Development (DEMVAL Phase). Two efforts have been initiated: (1) a design/development contract to meet all the parameters stated in the operational requirement, and (2) a nondevelopmental approach to identify the commercially available item that meets most of the stated requirements. The Milestone II decision, scheduled for March 1994, will include the determination of which approach will be continued in EMD.

Technical evaluation is scheduled to start in April 1996 and operational evaluation in July 1997. The Milestone III procurement decision is scheduled for December 1997.

Figure 9 shows the schedule and funding by fiscal year (FY1990-FY1998).

		FY90	FY91	FY92	FY93	FY94	FY95	FY96	FY97	FY98
Schedule	Initiation	▲ 3/90								
	Milestone II					△ 8/94				
	DT&E				8/93 – 12/93		5/95 – 9/95	5/96 – 1/97 Techeval		
	OT&E								6/97 – 7/97 Opeval	
	Milestone III									△ 4/98
Funding ($K)	Required	800	700	1700	1600	1500	1100	1100	1100	1000
	OSD	800	700	1700	1600	1500	0	0	0	0
	Service						1100	1100	1100	1000

Figure 9. ROND Program Schedule and Funding

E. UGV TECHNOLOGY ENHANCEMENT AND EXPLOITATION (UGVTEE)

1. Overview

Current and future UGV projects are supported by a technology base program that is directed to exploit robotics advances and mature those technologies that are critical to the robotization of UGV systems. The near- and mid-term focus of this program is on providing the mission capabilities and technological enhancement required for the TUGV and for the relatively narrow applications of other UGVs. This part of the program (DEMO I) will conclude in FY1992. The long term focus is on technologies that will enhance operational capability and survivability. This part of the program (DEMO II) has been initiated. Its main emphasis is on autonomous navigation under battlefield conditions. This includes RSTA functions while the UGV is moving, automated communication with other vehicles, and workload partitioning between vehicles to accomplish mission objectives.

Table 3 shows planned funding for Demo I and Demo II by fiscal year (FY1990 - FY1995). Demo I and Demo II will advance critical UGV component technologies along a path that progresses from teleoperation to robotics. A study is underway to look beyond DEMO II to a wide spectrum of technologies that extend from intelligent autonomy for general, adaptive battlefield employment to rote autonomy for specific, nonadaptive land warfare use. The first capability leads to UGVs that, in general, will be expensive and nonexpendable; rote autonomy is directed toward special purpose, inexpensive, and expendable UGVs.

Table 3. UGVTEE Program Funding ($K)

	FY90	FY91	FY92	FY93	FY94	FY95
Demo I	9700	6080	3300	800		
Demo II		4000	5000	8000	8000	6000
New Initiative					1000	3000
Total	9700	10080	8300	8800	9000	9000

2. Demo I--Technology for First Generation UGVs

The principal purpose of Demo I is to mature critical system component technologies for first generation UGVs and demonstrate their readiness for acquisition programs. Based on the results of Demo I, selected technologies will be integrated into the basic STV for the development of a full-up TUGV prototype. The emphasis is on reducing operator workload while enhancing performance of the RSTA mission. Demo I includes products resulting from non-UGV program activities in order to maximize technology transfer to the UGV program. The majority of the hardware and software for Demo I has already been developed and is operational.

The T&E portion of Demo I is being conducted at Aberdeen Proving Ground, Maryland, using U.S. Army Test and Evaluation Command facilities specially developed for UGV DT&E. The Aberdeen test courses vary from flat, oval terrain to densely wooded winding trails with slopes exceeding 45 degrees. Five HMMWVs will be used as the demonstration vehicles, employing separate mission modules for RSTA and NBC detection. It should be noted that, although the demonstration itself will occur during a week-long period in the third quarter of FY1992, data collection from Demo I is already underway and will continue beyond the formal demonstration. Major Government participants in the Demo I program include the Army Materiel Command, TUGV JPO, Naval Ocean Systems Center, DARPA, DoE, and NIST.

As described below, Demo I emphasizes integrated testing and technology maturation demonstration in the five critical technology areas:

- Human Factors/Man-Machine Interface--Operator workload and performance for the teleoperated and supervisory modes of operation.
- Communication--The relative utility of various wide-band communications and low data-rate communication alternatives.
- Navigation--The effects of high and low data rate operations on full-time teleoperated and supervisory control for day and night mobility operations. Automated mobility modes such as retrotraverse, and obstacle detection/avoidance.
- RSTA Mission Package--Mission package performance while the vehicle is stationary.
- Computer Control Architecture--New options for UGV control through integration of teleoperated and limited robotic control modes.

Figure 10 gives a breakout of the FY91 Demo I Funds by these technology areas, with system integration and testing added. The percentages reflect Demo I emphasis on teleassistance and technology maturation for the TUGV. (Demo II will emphasize supervised robotics; hence navigation and system integration are expected to account for about 75 percent of the investment.)

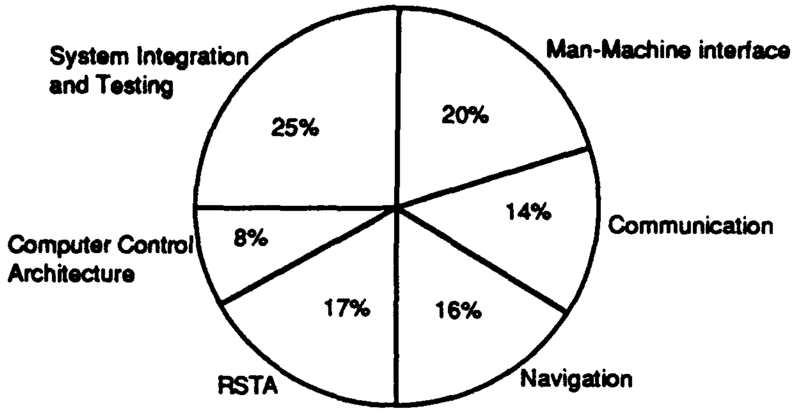

Figure 10. UGVTEE Technology and Distribution

a. Human Factors/Man-Machine Interface

Limited experience with earlier UGV programs shows evidence of operator sensitivity to sensor type, number, mounting configuration and size of the display, and control layouts. These areas must be studied in more detail in order for the system developer to select appropriate design parameters. Assessments are underway or will be conducted for the design parameters listed below.

Camera Placement Tradeoffs--How does camera placement affect operator vision/perception of the driving path and driving performance? It is essential to optimize camera placement before assessing other parameters of the vision system.

Field of View (FOV)--What FOV for the vision optics is the best compromise for operator performance under tactical UGV development? Do we need zoomatic FOV capability?

Low Data Rate Communications--What is the minimum amount of video data required for compression/restoration algorithms that permits acceptable performance by the remote operator?

Monoscopic versus Stereoscopic Vision--How does stereo vision compare with monoscopic regarding the remote operator's perceptions and judgments of distance for remote driving?

Monochrome versus Color Displays--Given that color video will triple bandwidth requirements and increase system cost, to what extent does color video enhance operator driving performance?

Dynamic Range Technique Tradeoffs--What system responses to dynamic lighting changes minimize adverse effects on operator use of sensor information? To what extent should we compensate computationally for these dynamic range variations to ease the strain on the operator?

Night Operations--What systems or procedures will enable the operator to perform remote driving and target acquisition at night? What are the limits of our current night vision sensors?

Operator Control Station Configurations--What are the essential tasks for teleoperated systems that must be supported by the operator station? How can this station best be configured using minimal display and control elements? How should user performance, cost constraints, and technical capabilities be balanced?

Demo I will also include evaluations in which the operator can take full control of any aspect of UGV operation or can exercise control options that allow him to step outside the full-time teleoperation mode by invoking a limited degree of automatic control. Operator workload and performance using these control options and their comparison to full-time teleoperation is a major focus of Demo I.

b. Two-way Communications Between Operator and Vehicle

The effect of communications technology on UGV operations involves a complex series of interactions among data-rate, line-of-sight limitations, frequency allocation, man-machine interface, and level of onboard UGV autonomy. At present, fiber optic communication links provide the baseline communication medium for UGVs. They have many attractive features. However, the users generally require radio frequency links as a backup to the fiber or as the primary link in certain scenarios, for survivability and mobility reasons.

Studies are being performed to determine the data rates necessary for operators to drive and use specific UGV mission packages. Demo I vehicles will be equipped with wide-band radio communications links, an onboard video compression subsystem, and a 1.8 GHz tactical data link (packet radio). These capabilities will permit communications with data rates that vary from multiple color video links to a single, compressed, black and white channel using tactical radio communications. During the early part of Demo I, potential data compression algorithms were evaluated. This resulted in a collaborative effort with Oak Ridge National Laboratory to integrate an in-house-developed composite compression algorithm with Massachusetts Institute of Technology's (MIT's) prediction image compression algorithm. The use of low data-rate links for RSTA sensor outputs and associated algorithms to present data to the remote operator will be evaluated. For stationary RSTA platforms, this includes a long duration data transfer cycle (order of seconds or even minutes) to establish a panoramic view of a surveillance area that is retained in a remote command and control processor. Subsequently, short bursts of update information are transmitted when changes are detected by the UGV processor. These changes are then superimposed on the original view for operator assessment. As a result of these evaluations, candidate radios for command/status and video transmission for Demo II and the TUGV system will be identified.

Performance enhancements for fiber-optic cable durability will also be addressed; these improvements will be applied directly to the STVs and demonstrated in FY1992.

c. Navigation

UGVs rely on sensors and processors to maneuver the vehicle. The system must sense terrain, plan its path, determine its current location and path, recognize and avoid obstacles, and arrive at its mission site. For teleoperated systems, high fidelity sensory data are of primary importance. For supervised systems, reduction of operator workload is of greater importance. This effort examines full-time teleoperated control under high and low data rate conditions for day and night operations. Supervisory control modes--those in which the TUGV accomplishes portions of the workload (e.g., route planning, obstacle detection, and path following)--are also evaluated. The teleassisted navigation techniques to be evaluated in Demo I exploit knowledge of the environmental structure. They include retracing a previously driven path (retrotraverse); operator designation of specific waypoints (spline driving); autonomous road following; and limited obstacle avoidance. The primary purpose is to investigate whether it is possible to mitigate some of the performance demands on the operator in a control modality that emphasizes teleoperation. (Demo II, which addresses supervised robotics, has as its target the simultaneous control of multiple robotic vehicles operating in unstructured environments.)

d. RSTA Mission

The basic hardware and software for the RSTA mission were developed outside of the UGV program. These were adapted for UGV use and were integrated into the RSTA mission module. This module will be used to investigate the remote performance of basic military tasks such as sensor emplacement and determination of observer location and orientation, and detection, tracking, and classification of multiple objects. Two subsystems have been developed to explore partial automation of target detection, cueing, and tracking functions. They provide an interface to a single operator who can control multiple stationary vehicles equipped with RSTA modules. The target cueing software will be compatible with the STV hardware and operating system. In Demo I, RSTA performance will be evaluated while the mission module is stationary. In Demo II, the RSTA and navigation functions will be integrated and the vehicle may be stationary or moving during mission performance.

A separate mission module to remotely detect NBC events is being assembled to evaluate the UGV utility in this role.

e. Computer Control Architecture for UGVs

Demo I has adopted a computer control architecture known as the real-time control system (RCS). NIST developed the RCS and it has been successfully employed in a number of military robotics technology demonstrators, e.g., the TMAP. RCS is a hierarchical architecture, which permits the operator to interact with the UGV at a variety of levels supporting both teleoperation and supervisory control. At low levels, control loop times are measured in milliseconds and exert direct control of individual vehicle actuators. At high levels, control times are measured in minutes and represent planning functions. The RCS provides the operator with the ability to move from level to level within the system, always maintaining his operational orientation by providing the contextual information necessary at that level. The STV contractor's selection of the RCS architecture and common computing hardware for the STV provides an excellent conduit for technology transfer from Demo I into the STV. The RCS architecture may become the standard for UGVs, if further testing shows that it satisfies the spectrum of UGV requirements.

3. Demo II--Supervised Autonomous Navigation for UGVs

The purpose of Demo II is to develop and mature those navigation technologies that are critical to evolving UGVs from labor intensive teleoperation to supervised autonomy. These technologies will enable TUGVs to operate in a limited bandwidth, tactical communications environment, by incorporating a cost-effective, semiautonomous navigation system, which removes the requirement for the UGV operator to maintain continuous control of driving and RSTA functions. Program emphasis is on exploiting emerging hardware and software advances in passive and active sensing, autonomous navigation, and high performance computing and in demonstrating their maturity for acquisition programs of second generation UGVs by 1995. To assess comparative performance with the first generation TUGV, DEMO II will integrate these technologies on the STV.

a. Passive and Active Sensing

Passive sensing is increasingly important to reduce battlefield detectability. TUGV navigation and RSTA require three-dimensional sensing of the path to be driven under day/night/all weather conditions. This can be achieved through stereovision and integration of multiple types of sensors or multiple wavelength bands. The DEMO II passive vision system will be dual band and comprise two pairs of imaging sensors--a pair of charge-coupled video detectors and a pair of scanning, long wavelength, infrared, focal plane array (LWIRFPA) sensors. The LWIR-band corresponds to the 7 to 12 micron atmospheric transmission window and provides night vision, adverse weather, and countermeasure resistance. Second generation imaging LWIR detectors that are becoming available have the required vertical and horizontal resolution and photon flux sensitivity for stereo vision application.

In stereo vision, images from the two non-colocated sensors are correlated to extract depth and establish a three-dimensional FOV map. Program focus is on resolving hardware issues related to:

- FOV spatial resolution, and sensor sensitivity for obstacle detection and classification (e.g., protrusions vs. holes) and path charcterization (e.g., hard, bare ground vs. grass)
- Calibration, alignment, and stabilization of optics and sensors
- Image acquisition rate as a function of driving speed.

The geographic/environmental map obtained from the passive sight system will be complemented with active sensing by adapting off-the-shelf or developmental interferometric equipment (e.g., an IR ladar or a millimeter wave radar) for TUGV application.

b. Autonomous Navigation

Figure 11 shows a flow diagram of the autonomous navigation functions being sought in second generation UGVs. The figure omits the supervisory role of the operator, who can monitor navigation performance and can intervene at any time either on his own initiative or as requested by the system. The left column refers to pre-mission navigation functions. The right column refers to en route navigation and driving functions.

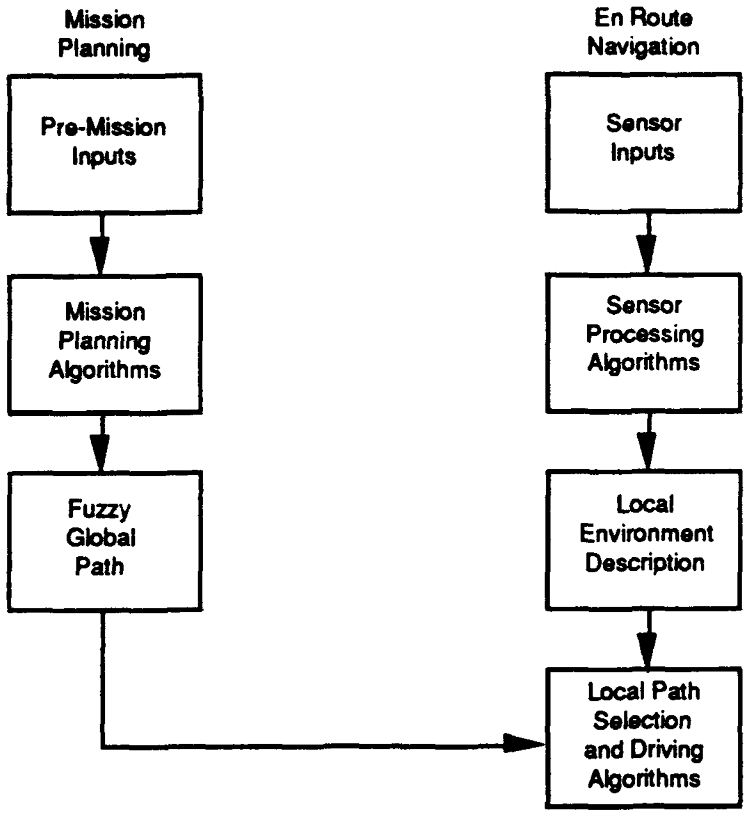

Figure 11. Autonomous Navigation Functions

The navigation portion of mission planning translates military mission, associated cartographic data, information on the location of friends and foes, and military control measures and constraints into an approximate, drivable path for one or multiple TUGVs. In addition to a fuzzy outline of the path on a digital terrain map, the navigation plan includes essential actions and objectives; decision strategies for anticipated situations; contingency actions (e.g., cueing supervisor's attention) for unplanned events; and level of interaction between cooperative UGVs. The plan should take advantage of terrain and vegetation to mask UGV movement. The navigation planning algorithms are intended for iterative use with the initial plan being revised and supplemented by the human operator interacting with the algorithms.

Once the UGV begins to traverse the planned path, autonomous navigation functions depend on sensor inputs and algorithms for processing these inputs in order to ascertain and characterize the local environment. This includes local three-dimensional map generation from stereo vision and/or interferometry images; model-based environment characterization with object and scene identification and tracking; landmark recognition; and global and local map merging to upgrade the terrain map and determine vehicle location and orientation.

Local path planning uses the terrain map, the sensed environment, vehicle position, and planning constraints. Driving algorithms include:

- Neural network and feature based road following, allowing the vehicle to travel on paths ranging from multilane paved highways to gravel roads to jeep trails, traverse intersections, and recognize road branches
- Road and cross-country navigation based on "fuzzy routes or spline driving" instructions with position provided by GPS receivers, inertial measurement systems, odometry, and vision activated landmark position estimates
- Vision-guided obstacle avoidance
- Execution of local path plan timed to the global mission plan and appropriately adjusted to terrain, visibility, path surface condition, automotive and dynamic constraints, and limitations on concurent processing of the large amount of data required for the vehicle navigation and RSTA functions.

c. High Performance Computing

DoD has an ongoing research and development (R&D) program to develop a succession of prototypes of scalable parallel and distributed heterogeneous high performance computing systems and associated software and algorithms for military applications. These systems are developed with progressively larger scale, more advanced components, more dense packaging, and more advanced architecture. DEMO II will use the most current prototype that is suited for TUGV applications. Under consideration are the Intel iWarp and an Image Understanding Architecture Processor developed jointly by the University of Massachusetts and Hughes.

d. RSTA While Driving

RSTA is an essential and pervasive function of military units operating in a battlefield environment. If UGVs are to conduct this vital activity autonomously, the human must be replaced by machine intelligence, which automates both the extraction of the relevant information from sensors signals and the decision-making process. DoD R&D has been investing heavily in signal image processing and automated target recognition--e.g., the Balanced Technology Initiative's (BTI's) multisensor-aided targeting project is developing aided/automated RSTA to assist and reduced the workload of ground vehicle operators. As a result, the consistency and trustworthiness of the extracted information and of the decisions that locate and identify potential threats in a highly complex and hostile environment are increasing steadily. The computer algorithms to realize this capability encompass artificial neural networks, image separation, feature detection/extraction, pattern recognition of static and dynamic objects, and adaptive multi-dimensional processing.

DEMO II will adapt those algorithms that are most suited for TUGV application and mesh the RSTA and the navigation functions to provide RSTA while on the move. This coupling allows coordinated processing of signals from the optical sensors, and adaptive partitioning of the processing workload between navigation and RSTA functions based on the local situation. Accomplishing this difficult task depends on the configuration, capacity, and throughput of the computer system that will become available through DARPA's high performance computing program.

e. Communication Link

DEMO II will exploit the RF communication hardware and software developed in DEMO I to link the TUGVs with each other and with the remote supervisor. These links may be direct or indirect depending on the environmental and operational situation. For example, to route the line-of-sight signal path around terrain obstacles, the TUGVs partaking in the deployment will form a communication relay chain. The architecture and software algorithms for low signature, secure communications will be embedded in the onboard processor. They will be demonstrated either with the communication equipment used in Demo I or, if available, with an off-the-shelf, autotracking, narrow beam system.

f. Program Funding, Schedule, and Execution

Program funding and schedule detailing the four phases of DEMO II are contained in the MOA between the Deputy Director of Defense Research and Engineering (Tactical Warfare Programs) [DDDRE(TWP)] and DARPA (Appendix A). The program milestones are summarized in Figure 12.

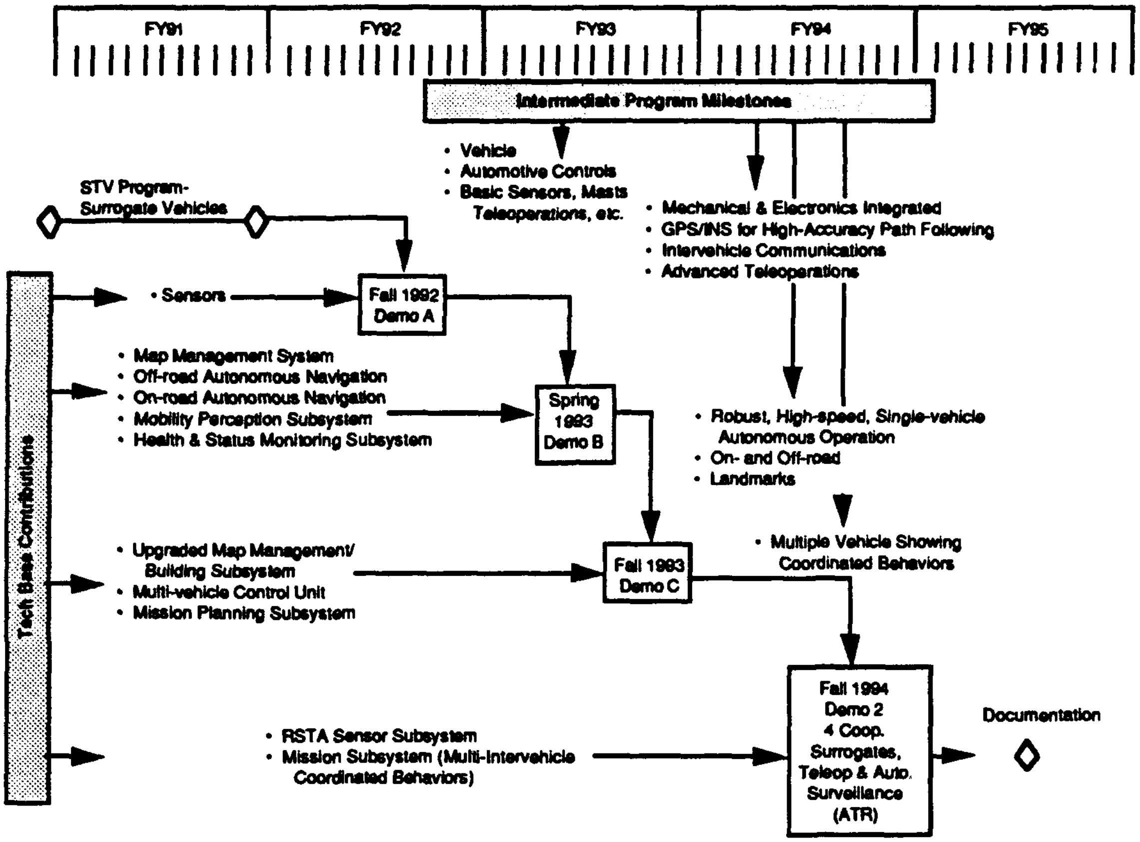

Figure 12. DEMO II Program Milestones

F. MANAGEMENT RESPONSIBILITIES

1. Overview

In response to Congressional direction, UGV projects were consolidated under PE 0603709D. The DDDRE (TWP) assumed responsibility for the management of this PE and for integrating all UGV-related robotic projects within a single plan. The TWP management staff for UGVs provides specific program direction, allocates funds to projects, coordinates the different projects, and carefully monitors progress.

To assist in fulfilling these responsibilities, a UGV working group was formed. Chaired by TWP, the working group includes representatives of the Services, DARPA, and other elements of the OSD. Working group members provide the information required for UGV program management. The working group provides a forum for discussing and resolving issues and for transmitting program direction and decisions. In general, UGV projects are funded under the consolidated PE up to the start of EMD. The Services are responsible for EMD and procurement funding.

UGV projects include land combat applications and other applications. The TUGV JPO is performing the detailed planning, management, and execution of acquisition projects for UGV land combat systems. This office represents the Service proponent for the introduction of UGVs into land warfare forces. Currently, the TUGV JPO's main responsibility is the development and fielding of an affordable tactical TUGV for the RSTA mission for the Army and Marine Corps. The TUGV JPO and the Army UAV office are both located at Missile Command to enhance coordination, commonality, standardization, and interoperability between the UGV and UAV acquisition programs.

The TUGV JPO does not have responsibility for the UGV projects that are not focused on land combat. The Air Force project office for RRR is at Tyndall AFB, Florida. The teleoperated RECORM, already in EMD, and ROND are unique to EOD and are being continued by the Joint Service EOD program. OSD oversees these projects, and they are integrated in overall UGV program plans.

Four essential areas have been identified: telerobotic navigation, communications links for supervised UGV control, man-machine interface, and mission subsystems for the individual UGVs. To avoid duplication and to ensure an integrated, focused program, one individual oversees each of these technical areas. This person serves as a focal point within DoD, is a member of the UGV working group, has responsibility for technical coordination within DoD, and maintains cognizance of national and international efforts in his area of responsibility.

2. Army/Marine Corps Coordination

The joint Army/Marine Corps TUGV program was established in FY1990. A joint project office was set up at Missile Command and staffed for the pre-EMD phase of development, with the Marine Corps providing the project manager.

A near-term objective of the TUGV program is to develop TUGV employment concepts and to foster user proponency for TUGV acquisition. These activities using STVs are being conducted on a joint basis. This will aid in the design finalization and enhance the cost-effectiveness of the TUGV by integrating and reconciling the perspectives and requirements of both Services early in the program.

3. DARPA/TWP Coordination

Realization of the full potential of land combat UGVs will depend on the availability of robotic navigation with supervisory control by the operator. This capability will allow the operator to control multiple vehicles. Building on its extensive artificial intelligence program, DARPA has made considerable progress in developing autonomous navigation.

To accelerate the progress and maturation of autonomous navigation and to establish an industrial R&D base for this technology, DARPA and TWP have concluded an MOA. A copy of this MOA is contained in Appendix A. The goal of this part of the program is to provide the technological basis for advanced development of UGVs that use supervised autonomous navigation and, therefore, permit multiple vehicle control.

4. Joint EOD Program

For explosive ordnance disposal, DoD has established a joint EOD program. The Navy is the lead Service and is responsible for developing EOD systems that meet the needs of all Services. Hence, EOD systems that use UGVs are automatically joint programs.

5. UGV/UAV Coordination

Overall program coordination between the UGV and UAV programs is done within TWP, which oversees both programs. In addition, the colocation of the JPO TUGV and the UAV project office enhances coordination of their acquisition projects and provides the required technology support through the same research, development, and acquisition center. TUGV employment concepts are being developed in conjunction with UAVs.

6. UGV Program/Physical Security Program Coordination

The DoD Physical Security program contains the requirement to develop UGVs for interior and exterior security surveillance and enforcement at military sites. The technology needs for the exterior constituent coincide to a large degree with those for the TUGV. The demonstration and validation phase of the first generation exterior physical security UGV is planned to start in FY1992. Program funding is provided by PE0603228D (Physical Security Equipment) at $1.5M per year. Technical coordination is ongoing to take advantage of the robotics technology base, the hardware and software being developed by the TUGV project, and the work on physical security done by the Defense Nuclear Agency and Sandia National Laboratories.

7. Government/Academia/Industry Interrelationships for Demo II

A major program objective is to transition the UGV-related machine intelligence and robotics technologies that are developed by universities to the principal DoD agencies responsible for acquisition of UGVs and to industry to establish an R&D base. To achieve this, each phase of DEMO II is executed in two steps: First, the technologies to be demonstrated are integrated by the participating universities in a bread board design on a HMMWV. Carnegie Mellon University serves as the focal point for this step. After these technologies have been validated, they are transferred to industry for system integration on the STV.

Figure 13 illustrates the technology transfer process. As part of this process, workshops are held quarterly to bring together all program constituents, review work done, discuss and resolve problems, coordinate future work, and adjust programs.

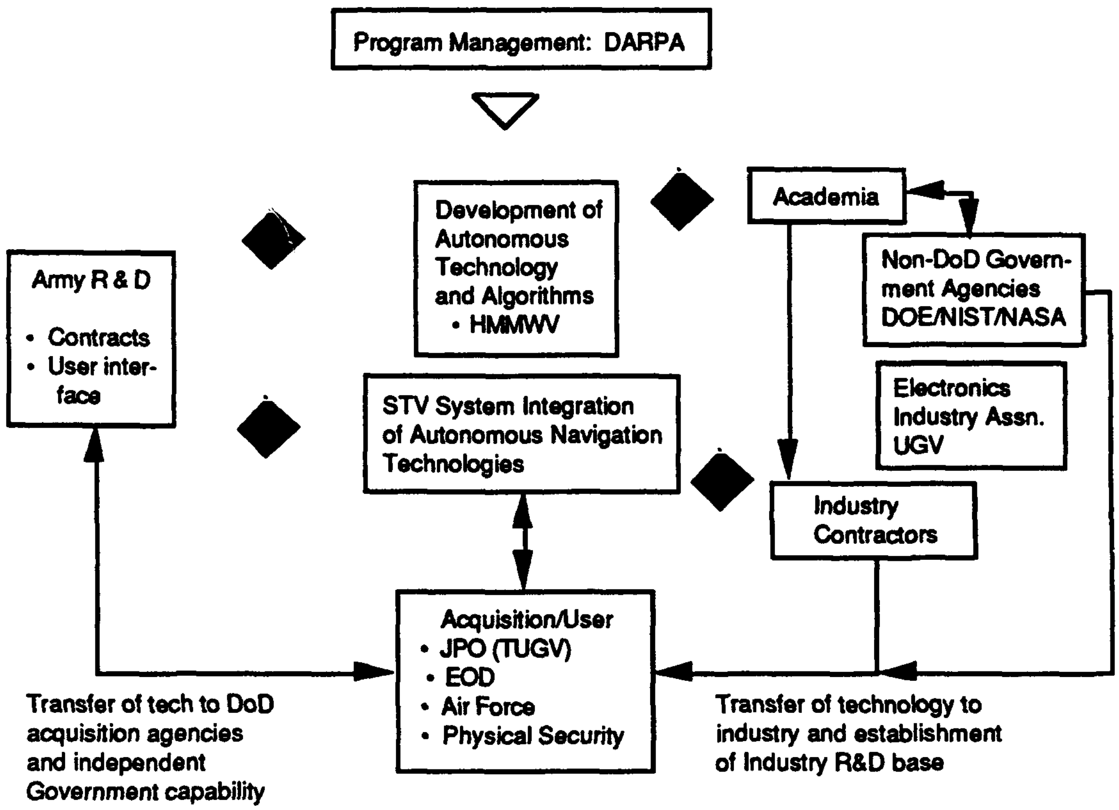

Figure 13. DEMO II Program--Interrelationship Between Academia, Industry, and Government

APPENDIX A

DDDR&E/DARPA MEMORANDUM OF AGREEMENT

Appendix A
MEMORANDUM OF AGREEMENT
BETWEEN
DEPUTY DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING (TWP)
AND
DIRECTOR, DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

Subject: SUPERVISED AUTONOMOUS NAVIGATION FOR UNMANNED GROUND VEHICLE

General:

This Memorandum of Agreement (MOA) and associated implementation instructions prescribe an agreement between the office of the Deputy Director for Defense Research and Engineering, Tactical Warfare Programs (TWP) and the Defense Research Projects Agency (DARPA) to develop and mature supervised autonomous navigation technologies for advanced system development of unmanned ground vehicles (UGVs) by 1995.

Background:

All Services ground vehicle robotics projects have been consolidated in FY1990 under OSD policy and program direction as requested by Congress. A UGV master plan has been established that focuses the resources on a few acquisition objectives that are attainable in the near future. Available systems do not capture the full potential of technology for UGVs which must operate with the maneuver forces and enhance their operational capability and sustainability. Autonomous navigation has been identified as the most critical technology that must be advanced to make UGVs the envisioned force multiplier. Over the last decade DARPA has considerably advanced artificial intelligence (AI) technologies that relate to autonomous navigation. This progress indicates that supervised autonomous navigation could be available by 1995 for advanced system development applications, if the program is properly focused on this objective.

Concept:

The program's objective is to develop and mature those navigation technologies that are critical to move UGV capability from the labor intensive teleoperations to supervised autonomy. The agreement establishes a five year program, combining TWP and DARPA resources.

Program Date:

The program will begin in FY1991 and continue for five years.

Program Resources:

Precluding adverse guidance by OSD or Congress, the two parties entering into this agreement will provide the following funds to support this program:

	FY91	FY92	FY93	FY94	FY95	Totals
TWP	3.0M	5.0M	8.0M	8.0M	6.0M	30.0M
DARPA	-	4.0M	4.0M	4.0M	4.0M	16.0M
Totals	3.0M	9.0M	12.0M	12.0M	10.0M	46.0M

In addition to these resources assigned to the MOA, DARPA is developing related technologies under the Machine Vision and Artificial Intelligence Science and Technology programs that will feed into or substantially contribute to the successful execution of this MOA. Specific leverage is obtained from the Machine Vision and Automated Planning and Knowledge Base programs as follows:

	FY91	FY92	FY93	FY94	FY95
Machine Vision	9.9M	8.7M	7.6M	4.3M	TBD
Planning	9.2M	8.1M	6.0M	3.0M	TBD
Totals	19.1M	16.8M	13.6M	7.3M	TBD

Program Oversight:

Program will be conducted under DARPA directed technical management with DDDR&E(TWP) oversight.

Program Termination Provision:

This MOA will cease to exist upon notification by either party that the MOA no longer suits the respective organizational goals and/or resources. Funding commitments by either party, however, will extend one fiscal year beyond the fiscal year in which the MOA is terminated to assure program continuity and funding stability.

Program Implementation Instruction:

TAB A specifies and defines the scope of program including deliverables and participating organizations.

IMPLEMENTATION INSTRUCTIONS FOR THE MEMORANDUM OF AGREEMENT FOR THE PROGRAM "SUPERVISED AUTONOMOUS NAVIGATION FOR UNMANNED GROUND VEHICLES"

PURPOSE:

These implementation instructions provide guidance for the working relationship between the Defense Advanced Research Projects Agency (DARPA) and the Office of the Deputy Director of Defense Research and Engineering, Tactical Warfare Programs (TWP) and define the scope of work.

OBJECTIVE:

The program's objective is to develop and mature within five years those navigation technologies which are critical for the system development of supervised autonomous unmanned ground vehicles to meet the needs of the ground forces of the future. Program focus is on exploiting the artificial intelligence advances made by DARPA's science and technology program. The developed navigational technologies will be transitioned to the principal DoD agencies which are responsible for and support the acquisition of unmanned ground vehicles and to industry to establish an R&D base that will support their development.

DESCRIPTION OF PROGRAM:

This program addresses only those unmanned ground vehicle components which are common to a broad spectrum of possible battlefield use. It does not address mission related subsystems. The program's focus is on the navigation and mobility aspects of tactical unmanned ground vehicles. This includes necessary reconnaissance and surveillance during driving and the architecture for interfacing potential mission modules. Man-machine interface is limited to supervisory oversight. Navigation will rely on "fuzzy" route planning, i.e., vague outline of path, and on-vehicle processing to fuse map and sensor data in order to find and drive an obstacle free traversible path.

To enable a comparative performance assessment with the first generation tactical unmanned ground vehicles, this program will integrate and demonstrate the developed supervised autonomous navigational technologies on the surrogate teleoperated vehicle. This MOA authorizes the acquisition of up to six surrogate teleoperated vehicles. This vehicle is currently being developed by the Joint Project Office for the Tactical Unmanned Ground Vehicle.

The program will be conducted through a four phase, demonstration directed approach with a high degree of industry interaction to facilitate the adoption of autonomous navigational technologies. The four phases leading to an unmanned ground vehicle demonstration (Demo II) include:

Phase I - 1991 through October 1992

Phase I will culminate in Demo A, to be conducted in September 1992. Phase I will integrate basic mechanical and electrical components, automotive controls, basic color and infrared visual sensors, GPS/INS and odometry, and intervehicle communications required to support the foundation of autonomous navigation on four surrogate teleoperated vehicles, to be purchased from funds made available under this MOA. Demo A will demonstrate autonomous inertial path following and autonomous visual path following based on spectral and neural net approaches.

Phase II - October 1992 through May 1993

Phase II will culminate in Demo B, to be conducted in May 1993. Phase II will integrate basic map management functions including single vehicle mission planning, off-road semi-autonomous navigation, on-road semi-autonomous navigation, robust high speed capability, landmark detection and identification. Demo B will demonstrate, in relatively benign terrain such as Range III at MICOM, map based planning and robust integrated navigation capabilities derived from the integration of the technical components in Phase II.

Phase III - May 1993 through October 1993

Phase III will culminate in Demo C, to be conducted in October 1993. Phase III will integrate multiple vehicle control from a man-portable operator control unit, utilizing an updated map management and map building subsystem, which will rely on map information from overhead visual imagery, such as obtained from an unmanned aerial vehicle. Additionally, this phase will integrate the results of research in multiple agent interactions. Demo C will demonstrate two semi-autonomous vehicles executing coordinated navigation, including use of the multiple vehicle control unit, while simultaneously conducting a trade-off analysis of two processor types, the Intel iWarp, and the UMass/Hughes Image Understanding Architecture.

Phase IV - October 1993 through June 1995

Phase IV will culminate in OSD Joint Unmanned Ground Vehicle Demonstration II, to be conducted in October 1994. Phase IV will integrate a reconnaissance, surveillance and target acquisition subsystem, potentially in conjunction with BTI efforts, with a multiple vehicle mission subsystem, resulting in the capability to robustly navigate a team of four vehicles as a screening force in support of manned vehicles. Following the demonstration, post-demonstration activities will include the preparation of design and documentation packages sufficiently detailed to facilitate seamless transition of development technologies to the Services and the Joint Project Office for the Tactical Unmanned Ground Vehicle.

Program Management

Program will be conducted under DARPA directed technical management with DDDRE&E (TWP) oversight. TWP and DARPA staff personnel will jointly provide program guidance, semiannual assessment of program progress, and assure compliance with program implementation instructions. To ensure the transfer of autonomous navigational technologies, DARPA will closely work with the Services.