Advanced C2 Vehicle Crewstation for Control of Unmanned Ground Vehicles

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1.0 INTRODUCTION

1.1 Rationale

Future military operational requirements may utilize unmanned or unattended assets for certain military missions that currently place military personnel in harms way for performing jobs and tasks that can be accomplished with robotic assets. To answer these needs, the US Army established two advanced technology demonstration (ATD) programs, the Crew integration & Automation Testbed (CAT) and the Robotic Follower (RF), for the development, integration and demonstration of technologies for reduced crew operations and unmanned vehicle control. The Tank Automotive Research, Development and Engineering Center (TARDEC) of the U.S. Army Tank-automotive and Armaments Command (TACOM) is executing these programs together in an effort entitled Vetronics Technology Integration (VTI). VTI comprises a number of different commercial, and government participants working research issues for near and far term vehicular electronics and robotic challenges.

1.2 Context

The use of robotics in the near term will be through soldier-robot teams. A great deal of research is being conducted into developing semi-autonomous robotic systems and our research and development efforts are focused on defining new interfaces to empower the warfighter to employ these autonomous systems while conducting their existing mission (Dahn and Gacy, 2002). The range of human tasks for robotic control may range from manual control (telepresence control) to supervisory autonomy requiring varying levels of man-in-the-loop operations. These varying conditions define a mixed-initiative environment for control of heterogeneous unmanned vehicles.

1.3 Overview

This paper addresses research and development being conducted for the Human-Machine Interface (HMI) technical area within the VTI program to address the human interactions and control mechanisms for

Paper presented at the RTO SCI Symposium on "Critical Design Issues for the Human-Machine Interface", held in Prague, Czech Republic, 19-21 May 2003, and published in RTO-MP-112.

soldier-robot teams controlling both a manned vehicle and unmanned ground (UGV) vehicles in a one operator to many (1:N) UGV ratio. Robotic and telepresence control in multiple asset environments is characterized by high attentional demand. Accordingly, research into multi-modal control systems and new display concepts are being investigated to help mitigate simultaneous demands imposed on the controllers.

We present an analysis and HMI development approach in use to develop an interface for an integrated crew station in a direct fire combat vehicle with control of multiple direct fire unmanned ground vehicles. Specifically, for the crew station we have developed interface standards for the variety of displays presented to the soldier. These standards address such factors as: consistency among displays, increased operator situation awareness of the current state of the displays, operation in a moving vehicle using protective gear, and presentation of the material in a useful and appropriate manner. We are developing the interface with attention paid to the unique requirements of the system while following both military and other human factors specifications. The use of consistent and well-accepted design principles will also provide for easier integration into both legacy and future systems at any level of robotic control. Results from this work are intended to transition to those responsible for developing execution concepts and plans for operational (e.g., command & control, scout, reconnaissance) and specialty (e.g., combat engineering) missions.

In section 2 we define the operational drivers including mission payloads and system capabilities that defined the design-space for the crewstations and supporting interfaces. Section 3 defines the human-centered design approach used to build the interfaces and summarizes a couple of the principles used throughout the design. In section 4 we discuss a three-phased training / experimental approach to achieve full crew proficiency, subjectively measure workload of the crew under loaded conditions, and provide crewstation interface design feedback from the warfighters. Section 5 discusses some of the conclusions reached from the limited scope experimentation. Section 6 summarizes and provides conclusions.

2.0 OPERATIONAL MISSION CONTEXT

As noted above, there are numerous different operational missions that could be performed using robotic assets. These missions depend on the specific platform capabilities such as whether the system is airborne, ground-based, water-based (surface or subsurface), whether it can deploy subsystems, expendability of the system (cost), and a myriad of other parameters and mixed requirements. For our purposes, the VTI program started with ground-based wheeled robotic platforms capable of autonomous navigation and will progress into control of micro air vehicles (MAVs) and unattended ground sensors (UGS) over the next three years.

2.1 Mission Requirements

The mission defined for the program was to develop and utilize CAT and RF ATD assets in two separate configurations. In one configuration, the CAT served as a command vehicle that controlled two armed reconnaissance vehicles (ARV) that would be used in direct fire combat engagements. In the second configuration, the CAT was a reduced-crew armored combat vehicle capable of conducting fight, scout, and carrier missions as well as having embedded robotic control capabilities. The missions for each of the configurations were different. These mission differences required different mission payload modules (MPMs) to meet mission objectives and were significant drivers in the design process. There existed a set of warfighter tasks that were common to the different mission requirements and supporting system configurations. We start this section with the description of the system in broad terms and then work into the differences required by the different mission objectives.

2.2 System Capabilities and Description – General

To effectively describe the system capabilities needed to support both the UCD and the armored combat vehicle configurations within the VTI program, we found it essential to define an *objective system* which would encompass all the requirements.

As depicted in Figure 1, the ***objective*** system consists of a control vehicle with two crewstations which could be configured to act as interchangeable control stations for commanding, driving, or controlling multiple remote ARVs. The objective ARVs are armed with four Javelin missiles and an Objective Crew Served Weapon (OCSW). Each ARV was modeled with an acoustic sensor to detect incoming fires and contained a mast mounted, deployable, fixed-image Reconnaissance, Surveillance and Target Acquisition (RSTA) capability.

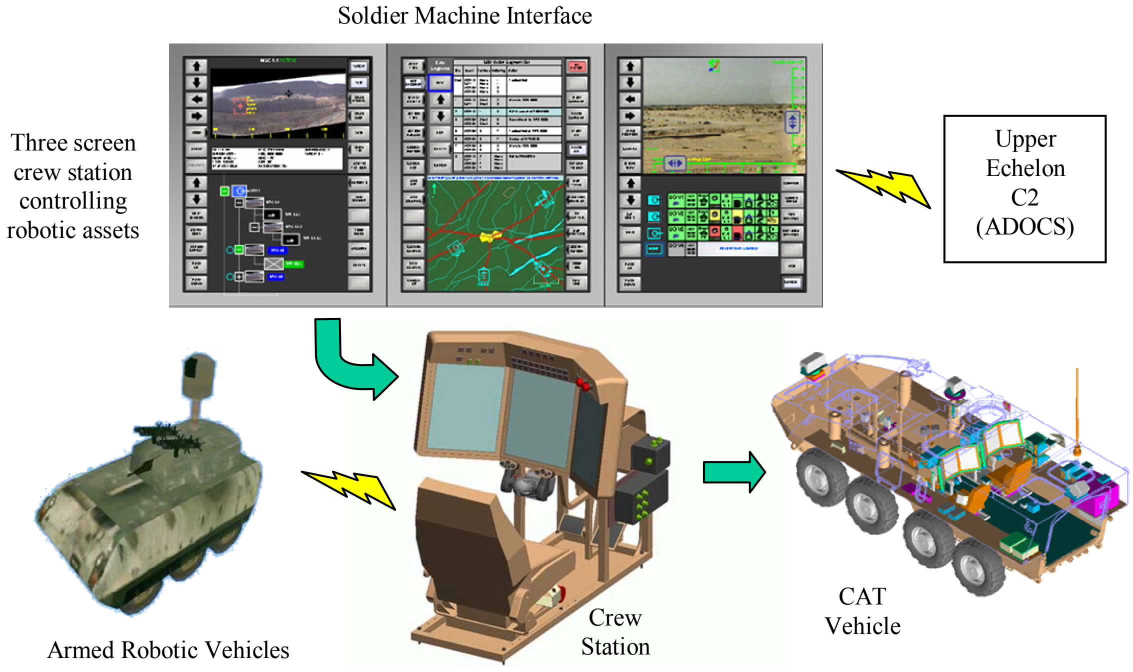


Figure 1: UCD Objective System.

The physical assets used to represent the VTI system in all configurations consists of the following subsystems:

1) the crew-integration and automation testbed command vehicle (CAT)
   a) with two identical crewstations
   b) and the Embedded Simulation System (ESS)
2) the robotic follower (RF)
   a) with the COUGAR turret (UCD only, see below)
3) the experimental unmanned vehicle (XUV)
   a) with and without the mounted RSTA platform
4) the remotely located ADOCS base-station

Short descriptions of these systems are provided to establish the technologies that were used or simulated in the CAT simulation integration laboratory (SIL) for the *virtual* experimentation and demonstration.

2.2.1 The Crew integration and Automation Testbed-Control Vehicle (CAT)

The CAT is based upon the Stryker chassis. The Stryker is a family of eight-wheel drive combat vehicles, transportable in a C-130 aircraft, being built for the US Army by GM GDLS, a joint venture set up by General Motors Defense of Canada and General Dynamics Land Systems Division of USA. The Stryker is based on the GM LAV III 8 x 8 light-armoured vehicle, in service since early 2001. The VTI program modified the Stryker to include drive-by-wire and other automation features. Navigation and obstacle avoidance sensors were installed on the exterior of the vehicle to permit semi-autonomous land navigation. A communications system interacts with geographically separated robotic vehicles by receiving and transmitting position information and commands. The CAT is capable of controlling ARVs using remote teleoperation, semi-autonomous operation, and robotic following. The CAT crew can also control the CAT vehicle itself using drive-by-wire (indirect driving through camera views), semi-autonomous operation, and high speed road following. The seats in the troop compartment have been removed and replaced with two crew workstations and the ESS system. Each workstation has a seat for an operator, and a console containing a Soldier Machine Interface (SMI) that has multi-function displays (MFD) and controls to enable the operator to control one or more of the unmanned ground vehicle (UGV) robotic assets.

Figure 2: CAT Vehicle.

The CAT capabilities include:

Advanced Crewstation Soldier Machine Interface	Improve soldier effectiveness with multi-function displays
Drive by Wire	Remote driving ability with displays and switchable driver control between crewstations
Indirect Vision Displays	Improve survivability by seating driver under armor
Autonomous Mobility	Advanced electronics and sensor systems to release constant attentional demand of driving
Unmanned Vehicle Planning and Control	Force Multiplier and improved survivability for the *warfighter*
Speech Recognition	Improve soldier efficiency by reducing time to input commands
Embedded Simulation	Improve war fighting ability through virtual training, battlefield visualization, and mission rehearsal

2.2.2 Crewstation Capabilities

The CAT crewstation Soldier Machine Interface (SMI) was adapted from the Crewman's Associate (CA) ATD which developed a design for a two-man crew operating a future main battle tank and the Vetronics Technology Testbed (VTT) which implemented a physical realization of the Crewman's Associate design. The VTI used lessons learned from the VTT and integrated own-vehicle control of an armored combat vehicle and unmanned vehicle planning and control into a single interface.

The interface provides capabilities for Move, Look, Shoot, and Communicate of both the CAT vehicle and its unmanned ARVs and focuses on "on-the-move" command and control.

The SMI provides crew interface for:

- Advanced Situational Awareness
- Target Acquisition and Engagement
  - RSTA (Intelligence, Surveillance, Reconnaissance)
  - OCSW
  - Javelin Missile
  - Battle Damage Assessment
- Maneuver
  - Autonomous Mobility
  - Teleoperation
- System Control and Status
- Command, Control, and Communications (C3)
  - Digital Reporting

- Digital Map and Route Planning
- Battlefield Visualization
- Embedded Training and Mission Rehearsal

As shown in Figure 3, the crewstation consists of three large touch screens, some hard buttons for display selection and crewstation control, a yoke to control driving and target acquisition, and a gas pedal and brake.

Figure 3: CAT Crewstation.

Each multifunction screen can hold up to two different information displays based on different functions. RSTA, mission planning, and the map display can be double sized, utilizing the full screen display. Touch buttons are oversized to accommodate operations on the move. Video from remote sensors are displayed on any of the top three display areas.

The SMI provides the operators with many displays, which can be selected in whatever combination is required for the operator to complete his mission. Each of the available displays in the SMI is described in the following section.

Setup

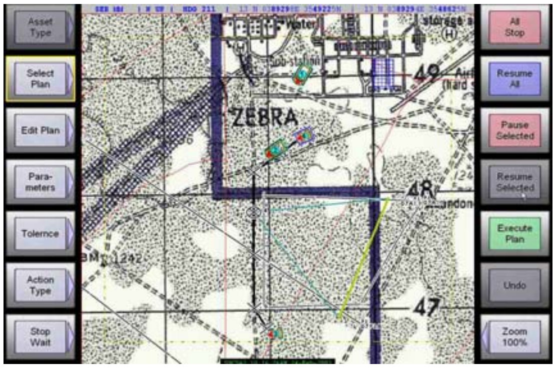
The Setup display is the first display used after the crewstation is powered on. It is used to select the state of the system, whether it is operational combat (real environment) or training combat (virtual environment). Under the training state, the system provides support for different scenarios containing various numbers of simulated or real assets that are portrayed in a virtual world and loads map, terrain, and battlefield visualization data in the virtual environment. This display is also used to view the After Action Review (textual feedback on mission performance) from the ESS and video playback from training exercises.

Battlefield Visualization

The Battlefield Visualization display is useful in the pre-planning stages of the mission. The operator can use this display to preview the terrain that will be encountered by the vehicles during the mission, providing the operator with the ability to plan routes more efficiently and allow terrain evaluation for potential opposing force (OPFOR) observation posts (OP) and other tactical options. This display also includes overlays which indicate sensor visibility limits and weapons ranges based on terrain features.

Map

The map display is used to maintain situational awareness of the battlefield area of operations. This display allows the operator to monitor the spatial relationships between vehicles, encountered units and obstacles, and terrain features such as roads and waterways. Numerous measures or graphics can be added to represent operational measures such as phase lines, named areas of interest, and enemy unit locations, etc. Map types, zoom levels, and orientation may be set to the operator's preference.



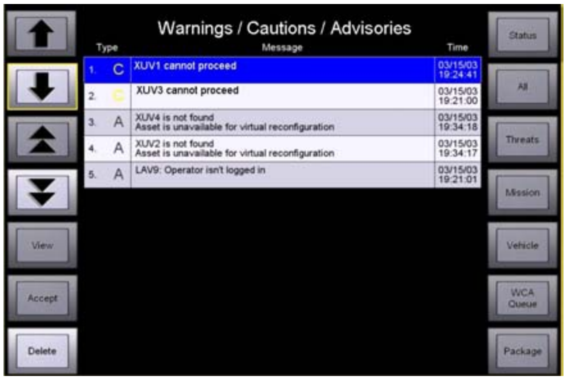
Mission Planning

The Mission Planning display is used to designate vehicle routes and actions taken at various points along the route. For example, this display is used to identify the areas where RSTA will be taken. Once a plan has been established, this display can be used to start, pause, resume, and stop execution of the plan. Similar to the Map display, the background map type, zoom level, and other settings may be customized to the operator's preference.

UV Status & Control

The UV Status display is used to monitor the status of a vehicle. By utilizing colors and icons, a large amount of information is displayed in a compact area. Information such as speed, heading, position, fuel and battery level, health of various systems such as communications and navigation, weapon status and ammunition count, RSTA information, and plan execution data is available in this location. More detailed diagnostic information is available through the Info button on a selected asset. This display is also used to control robotic following; that is, for placing unmanned vehicles into convoy mode with a defined time to start and following distance.

Warnings, Cautions, and Advisories (WCA) Queue



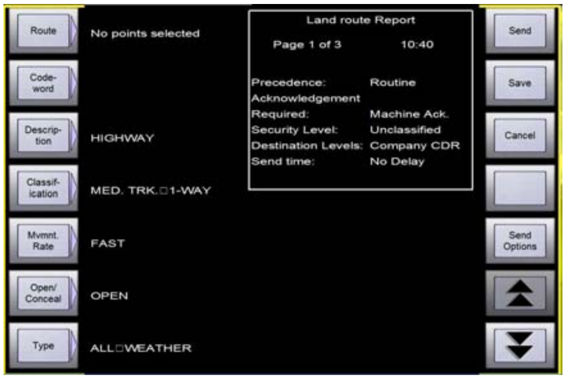
Warnings / Cautions / Advisories

	Type	Message	Time
1.	C	XUV1 cannot proceed	03/15/03 19:24:41
2.	C	XUV3 cannot proceed	03/15/03 19:21:00
3.	A	XUV4 is not found Asset is unavailable for virtual reconfiguration	03/15/03 19:34:18
4.	A	XUV2 is not found Asset is unavailable for virtual reconfiguration	03/15/03 19:34:17
5.	A	LAV9: Operator isn't logged in	03/15/03 19:21:01

WCA's are first announced by overlaying the center bottom display with a semi-transparent message box color coded to the appropriate severity of the problem. The WCA Queue display contains a history of all alerts which have been received. The contents of this display are sorted and color-coded based on their severity. In addition, each alert is date and time stamped.

Reports

The Reports display allows the operator to view reports sent to him and to create outgoing reports. A wide range of reports is supported. Some of the commonly used reports are the Obstacle Report, the Situation Report, and the Call for Fire Report. Some fields in the reports may be filled in by selecting the appropriate information on another display, such as selecting a location on the map.



No points selected

HIGHWAY

MED. TRK.□1-WAY

FAST

OPEN

ALL□WEATHER

Land route Report

Page 1 of 3 10:40

Precedence: Routine
Acknowledgement Required: Machine Ack.
Security Level: Unclassified
Destination Levels: Company CDR
Send time: No Delay

Reconnaissance, Surveillance, and Target Acquisition (RSTA)

The RSTA display allows the operator to perform reconnaissance on an area of interest. The images which are provided to the operator are permanent, detailed images which the operator can then analyze with the tools provided in this display, such as zoom, filter, and polarity. Details about each image, including items such as the location, bearing, and camera type, are also presented to the operator. The RSTA images, Automatic Target Recognition (ATR) and Moving Target Indicator (MTI) are presented to the operator in a hierarchical structure which indicates the relationships between the images.

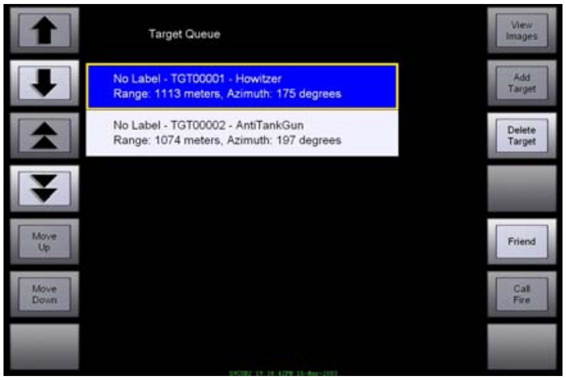
Mosaic
XUV3, MosaicID: 0x10001
Location: 13 387512.06 E 3547601.25 N
Camera: Color Video, FOV: 6.30

Target
XUV3, MosaicID: 0x70001 [0x10001]
Location: 13 387766.66 E 3547442.25 N
Camera: FLIR, FOV: 6.30
Type: ATR
Confidence: 97
Range: 300, Bearing: 0

Target Acquisition

The Target Acquisition display is used to select, aim, and fire the available weapons. The target acquisition camera's position is controlled by the yoke. Imagery from the camera is displayed on the screen. The procedure to fire a weapon requires simultaneous use of the yoke to control azimuth and elevation of the weapon system. From this display, the operator can also select weapon modes, camera modes, load method, scan patterns, fuse settings, and choose specific types of ammunition. Information such as ammunition count and camera and weapon orientation is displayed graphically. The operator also has immediate access to the vehicle's location, date and time, and counters indicating the number of WCA messages and the number of reports. Note: the operator can switch which asset is being used for target acquisition.

Target Queue

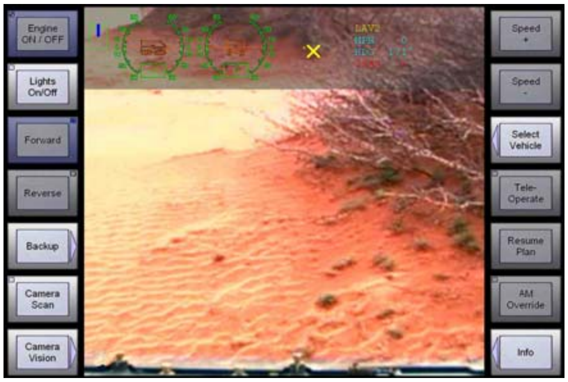


No Label - TGT00001 - Howitzer
Range: 1113 meters, Azimuth: 175 degrees

No Label - TGT00002 - AntiTankGun
Range: 1074 meters, Azimuth: 197 degrees

The Target Queue is used to manage targets that are available to all assets under the control of the crewstation. Targets may be added through the target identification in RSTA, or by specifying units on the map display as targets. The target queue is shared between the operators and among all of the assets. To maintain operator situational awareness, the distance and azimuth angle of the target from the CAT vehicle are shown.

UV Teleoperation



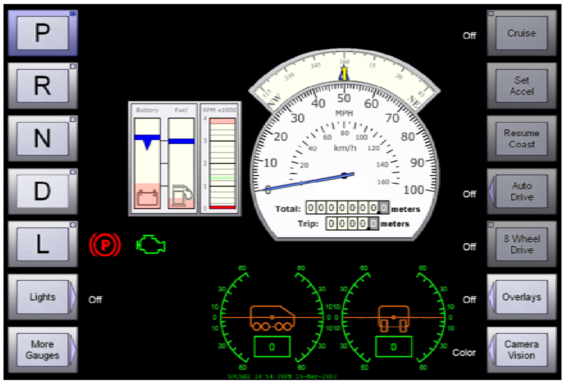
The primary mode of operating vehicles is through autonomous navigation; however, there are times when the vehicles become stuck or confused requiring a human intervention. When these conditions arise, the teleoperation display is used to manually control the movement of an unmanned vehicle. The imagery displayed on the screen is the view from the camera mounted on the vehicle that is being teleoperated. The operator has immediate access to the tilt and roll, waypoint data, speed, and heading. This display can also be used to change the vehicle direction, reverse along the traveled path, and select camera settings. Teleoperating an unmanned vehicle requires the operator to use the teleoperation display, the yoke, and the pedals simultaneously. Note that the operator can switch which unmanned asset is being controlled.

Indirect Vision Display (IVD)

Three forward looking, fixed angle, fixed zoom cameras comprise the indirect vision view. Color cameras are available for day driving and forward-looking infrared (FLIR) cameras are available for night driving. Each crewstation *screen* always presents the same camera view (i.e. the left screen will show the left IVD). The soldier may have any number of indirect vision views visible at any time, from none to all three. The only requirement is that the center IVD must be open when the soldier is driving the vehicle. A tire position indicator, the current gear, speed and heading are always shown at the bottom. When the vehicle is in reverse, the center IVD switches to a rear facing camera.

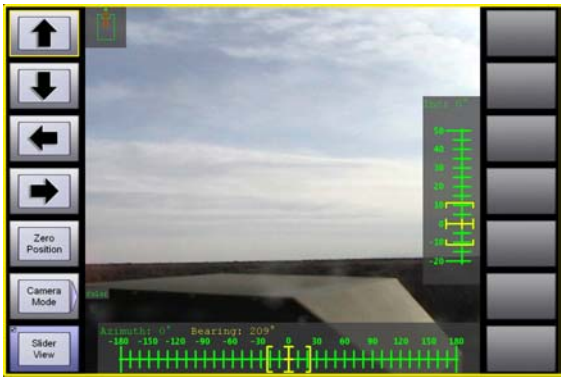
Driving Gauges

The driving gauges display is a representation of the driving parameters of the CAT vehicle, including speed, heading, available fuel, engine RPM, current gear. The speed gauge and odometer have a “standard” dashboard look and the warning lights use ISO 9000 standard images. When the soldier is not actively driving the vehicle, the gauges have a colored overlay to indicate this. The soldier selects the type of camera (color or FLIR) for the IVDs from this display.



Situation Awareness Sensor

The situation awareness sensor (still under development) will provide the soldier with a rotatable and tiltable camera view (color or FLIR) of the immediate surroundings of the CAT vehicle. This position may be controlled either by the yoke or by direct selection on the screen.



2.2.3 RF and XUV

The RF and XUV provide robotic maneuver capabilities. The XUV provides a physical RSTA capability.

The RF (Figure 4) is a retrofitted Stryker identical to the CAT except it does not contain any crewstations. It is capable of remote teleoperation, semi-autonomous operation on its own, or guiding on (following) another vehicle. This configuration proved to be an extremely robust maneuver vehicle. The COUGAR weapons turret is mounted on the RF. Remote operation of the COUGAR weapons turret is through the crewstation in the CAT.

Figure 4: RF w/ Cougar.

The XUV (Figure 5) also provides a robust maneuver vehicle capable of remote teleoperation, semi-autonomous operation on its own, or convoying behind another vehicle. The RSTA turret is mounted on the XUV. The RSTA turret provides panoramic mosaic images with ATRs and MTI capabilities. Soldiers can task the system to collect sub-mosaics in both color and infrared to improve the camera resolution for areas of interest, snapshots to collect target images for identification, and lasing for distance computation and absolute target location which is automatically placed on their digital map in the crewstation.

Figure 5: XUV with RSTA.

2.2.4 Embedded Simulation System

The ESS provided the virtual immersive view of the terrain, targets, and friendly vehicles in both the virtual SIL experiments and the live/virtual mix for the field maneuver demonstration.

The ESS consists of:

One SAF Testbed (OTB)	To place targets and friendly forces in the virtual environment and control their behaviors
World Model	Terrain database created from DTED data of the particular area of operations
Entity Models	High fidelity representations of vehicles, dismounts, and objective ARV
High Fidelity Maneuverability Models	Simulates various vehicle maneuverability in various kinds of terrain
RSTA	Provides simulated imagery, ATR, and MTI capability
Weapons Models	Provides virtual weapons capability for the Javelin and OCSW
Battlefield Visualization	Provides a birds eye view of the DTED rendered battlefield
After Action Reporting	Provides both combat performance data collection and video playback capability

During the *virtual* demonstration, the ESS provided all imagery that the soldiers would normally view through live camera feeds for RSTA, target acquisition, indirect driving, and battlefield visualization. The ESS provided rendered visuals of the physical environment from a DTED database as shown in Figure 6.

Figure 6: Simulated Environment from ESS.

2.2.5 Automated Deep Operations Coordination System (ADOCS)

A modified version of General Dynamics C4 Systems Division’s ADOCS workstation (see http://www.gdc4s.com/Products/adocs.htm) was used to support a headquarters planning cell and mission management capability. The modified version provided the ability to create operational overlays on the workstation that would then be transmitted electronically to the remote CAT crewstations.

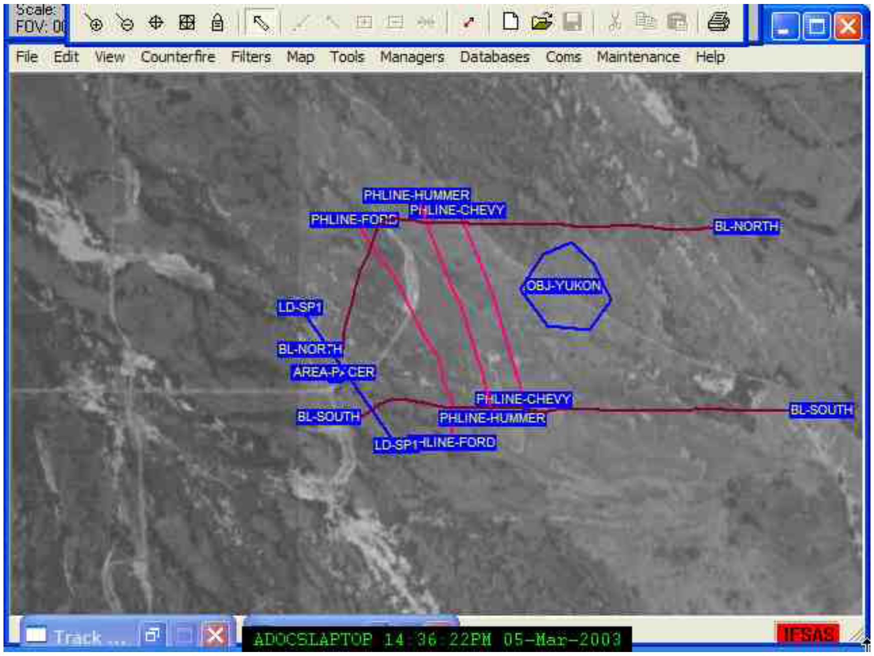


Figure 7: ADOCS Workstation View.

During mission execution, the ADOCS workstation supported text messaging between the headquarters element, threat reports, SPOT reports and other messaging. ADOCS also provided a tracking capability that dynamically showed the location of friendly assets from messages sent from each of the remote vehicles. This functionality emulated the common operational picture as the friendly force locations were displayed on both the ADOCS workstation and the CAT mission planning and mapping displays.

2.3 System Capabilities and Description – UCD Configuration

For the UCD configuration, we were emulating the Future Combat Systems (FCS) Lead Systems Integrator’s (LSI) vision of a future command vehicle with the objective system. They envision a commander’s station, driver’s station, and four robotic control stations. To emulate this requirement we used a manned driver station in the LAV who interacted with the two robotic control stations to reposition as necessary.

In the UCD configuration either of the operators in the rear compartment of the CAT was capable of planning and controlling multiple ARVs during maneuver, scouting, and combat engagements. Part of the exercise was to determine an effective operator to ARV control ratio.

The UCD consisted of a SIL where all out the window imagery was provided by the ESS (target acquisition, RSTA, and teleoperation); a live / virtual mix where the teleoperation was real streaming video but RSTA and target acquisition were virtual from an ESS mounted in the vehicle; and finally a live-fire where all video was provided by real assets.

Specific to the UCD configuration, the RF vehicle (Figure 4) was outfitted with the COUGAR weapons turret (Figure 8).

Figure 8: COUGAR Weapons Turret.

COUGAR Turret

The COUGAR turret was developed by the US Army Aviation & Missile Research, Development, & Engineering Center (AMRDEC) to provide remote control and firing of weapon systems. Prior to this development it had been mounted on the vehicle occupied by the soldiers but provided enhanced survivability to the soldiers because they could remain concealed during weapons engagements.

The UCD program advances the state of the technology by putting the COUGAR turret on an unmanned ARV with mounts for up to 2 Javelin missiles and an M-240 machine gun with 200 rounds of ammunition. The COUGAR turret is controlled by the soldier's using the crewstation in the CAT. Using the Land Warrior interface to the Javelin missile, the missile can be effectively fired on a target while the soldiers are positioned hundreds of meters away from the firing location. The weapons remain under positive control of the soldiers for engagements of both hard and soft targets. Target acquisition video and Javelin sensor video is streamed back to the CAT vehicle for soldier identification, targeting, engagement, and battle damage assessment tasks.

2.4 System Capabilities and Description – VTI Configuration

The VTI configuration focused on vehicle operations as an armored combat vehicle. All weapon systems were from the perspective of the crew's own-ship (their own vehicle) rather than remotely mounted weapons. The robotic vehicles were used in convoy mode to follow the CAT vehicle in a configuration for Multifunction Utility/Logistics and Equipment (MULE) vehicle support to both mounted and dismounted troops.

For the VTI, simulated advanced automatic target recognition (ATR) and associated target queue was implemented that takes advantage of the anticipated advanced battlefield situational awareness.

Operators were able to use the multi-function touch screens to select targets from the target queue and have their weapons automatically align with the last known position of the target. In addition, they could manually designate targets that may have been previously undetected. Queue management included identifying potential targets in the queue as friendly when visually identification was completed.

3.0 HUMAN-CENTERED DESIGN

In order to achieve a coherent soldier-machine interface design that could support all the mission requirements and system capabilities described above, the various integrated product teams supported the human factors engineering (HFE) design staff by helping with an approach called human-centered design (HCD). The key focus of the design approach is to design the interface to fit the human operator and *not* patch the engineering interface later to put a human operator into it.

The key to successful HCD is to get a sample population of users involved from the very beginning of the design cycle. Designers and developers need to be educated to today's tactics, techniques, and procedures (TTPs) as well as appropriate tactical jargon and standard operational procedures and make use of today's approach while revolutionizing the capability.

3.1 HCD Purpose and Approach

HCD is about helping human operators make the right decisions to achieve a desired goal through the efficient and effective application and control of their user interface. As such, addressing issues of the user-interface is *not* about addressing the traditional human factors of the interface but, rather, it is about defining the information that needs to be presented to the human in a high-stress environment that will lead to better decision making and then finding the best ways to compute and convey that information. Therefore, the process begins with an analysis of human decision making requirements.

This approach for human-centered design bases the tasks and user-interface information requirements on the decisions that the humans must make. The basic process of decision-centered design that has emerged can be thought of as follows:

The *goals* of the human/humans…drive the...

↳ *Decisions* that must be made by the humans…that drive the...

↳ *Situation Awareness* that the humans must maintain to make an informed decision…that drives the...

↳ *Information* needed by the humans to maintain situation awareness…that drives the...

↳ *Tasks* that the humans must do to gather information…that drive the...

↳ *User-interface design* to support efficient and safe task performance.

Essentially, the last two steps lead into the traditional user-centered design process that includes characterizing users, developing guidelines, and prototyping and testing the user-interface. The big difference is in the process of defining the tasks and information needs of the displays. Instead of taking a "functional" perspective (i.e., what the humans have to *do*), the decision-centered approach takes the perspective of what the humans need to *know*.

Each of the above steps is described in more detail below.

3.1.1 Identifying the Goals of the User

The first step of decision-centered design is for the design team to define the goals of the humans in the system. This typically involves interviewing representatives of all relevant stakeholders in this system – commanders, operators, and related positions. It is incumbent upon the design team to understand the goals from all appropriate perspectives. In this program, we needed to define the goals for the different levels of the command hierarchy within the context of the concepts of operations for a company headquarters and a deployed platoon. The initial difficulty, of course, is that the "concepts of operations for robotic vehicles" and TTPs are still fluid and are being developed through use of the VTI CAT crewstations and associated robotic assets.

3.1.2 Identifying Decisions Made by Humans towards the Satisfaction of Goals

The second step is the definition of the specific decisions the humans have to make to achieve their goals. Critical Decision Methodology (CDM) is a good method for this. CDM has been used in dozens of studies of decision making and problem solving in domains as varied as engineering, critical care nursing, fire ground command, battle planning, corporate information management, and commercial and helicopter piloting. A CDM session is organized around an account of a specific incident. The incident must be the participant's own, i.e., it must come from his or her own, experience. The specific episode carries context with it and reveals how particular aspects and events in the environment impel the decision maker to action. CDM interviews require an initial step, that of guiding the participant to recall and recount a relevant incident. Once that step has been accomplished, the interviewer conducts three information-gathering sweeps through the incident. These sweeps are: Timeline Verification and Decision Point Identification, to structure and organize the account into ordered segments; Progressive Deepening, to develop a comprehensive, detailed and context-specific account of the incident from the perspective of the decision maker; and What-if Queries, in which the decision makers discuss the incident in terms of potential errors and expert-novice differences. Detailed descriptions of CDM and the work surrounding it can be found in Hoffman, Crandall, and Shadbolt, 1998; Klein, Calderwood, and MacGregor, 1989.

Again, the difficulty with conducting this analysis early in the VTI program was that we were dealing with missions and technologies that are ill-defined. To facilitate this approach we created an early rough sketch of a notional design and a couple of potential scenarios before our second subject matter expert meeting. We then had soldiers from Ft Knox return for a notional design review where they were able to identify areas of concern or make points about where technologists were building a design path that would not be of benefit in the soldier's tactical domain.

3.1.3 Defining the Situational Awareness Variables

The process of defining the situational awareness variables relates to analyzing what the humans need to consider when making the decisions. The first step was to determine just what situational awareness factors a warfighter needed to be aware of within the framework of combat and scout missions. Not just what is available, but what does he or she really want to know at the point at which each decision must be made?

This analysis provides the most important foundation for successfully creating user-centered systems that support situation awareness and decision making.

To conduct this analysis, the design team met with the soldier's and worked through the scenarios further, building upon their decisions and documenting what aspects of the situation they needed to consider in making each decision.

3.1.4 Defining the Information Required

The next step in the process required that the design team analyze what information humans need to see to maintain and develop the situational awareness. While the situational awareness parameters may be vague and "wishful," the information required to make decisions must be rooted in the reality of what we can get to them. Information can be "processed", "raw", or involve computational aids or support. For example, processed information may involve a visualization of vehicle locations that integrates information from a variety of sources. Raw information may be data straight from the robotic vehicles themselves. Computationally aided information may come from running raw and processed information through algorithms so that the information presented to the operator was close to what he or she needed to know to make the right decisions.

This analysis must also link the available data and algorithms, as determined through the rest of the engineering process, as closely as possible to the situational awareness variables that the human needs to understand in order to make optimal decisions. The information requirements analysis is where the hardware and software engineering meets the human engineering by determining how close we can get to giving the human exactly what they need to *know.*

This analysis was largely a review of the situational awareness variables coupled with the design team's work as part of the hardware and software engineering teams. The design team must use their judgment as supported by subject-matter experts to determine what specific information can be provided to the humans to support the maintenance of situation awareness. The autonomous mobility capabilities of the robotic vehicles include additional capabilities as the technology matures. A capability such as using the AM sensor to scan a local area while the vehicle is stationary was a capability that existed but until interviews with the hardware engineers remained unknown. These are important details to discover.

As stated earlier, these first four steps will provide the basis for determining what humans need to be able to most effectively control soldier-robot teams.

3.1.5 Defining the Tasks

At this point, the tasks that the soldiers must perform emerged from a review of how the gathering and processing of the information required by them were best grouped into logical activities. These tasks then become the basis of interface design and a straw man TTP for employment of robotic assets.

3.1.6 Designing the User Interfaces to Support the Humans' Tasks

Finally, the design of the user-interfaces applied the traditional usability engineering process presented in Figure 9. This process is the current standard in developing complex user-computer interfaces.

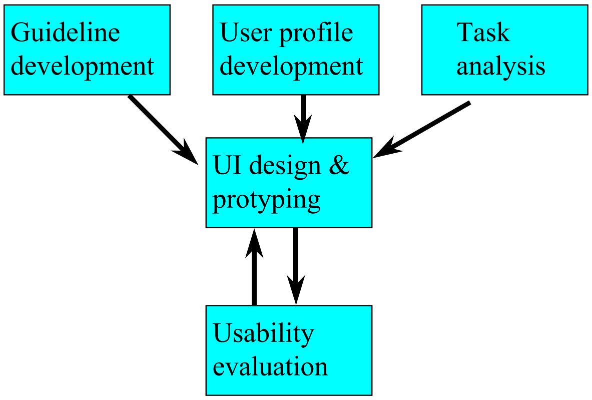


Figure 9: Usability Engineering Process.

In sum, the HCD process takes the perspective that most, if not all, required human activity should flow from an analysis of the decisions that users must make to achieve their goals. HCD centers on defining the decisions that the human must make to achieve mission objectives. The decisions then become the focus of the human-centered design process. From decisions, we determine a) the elements of the decision require immediate situation awareness, b) the information requirements to maintain and support situational awareness, c) the tasks that would be required to gather and store the information, and d) the user-interface that would be required to perform the tasks. Using this approach, the system is designed from the decisions outward as shown in Figure 10.

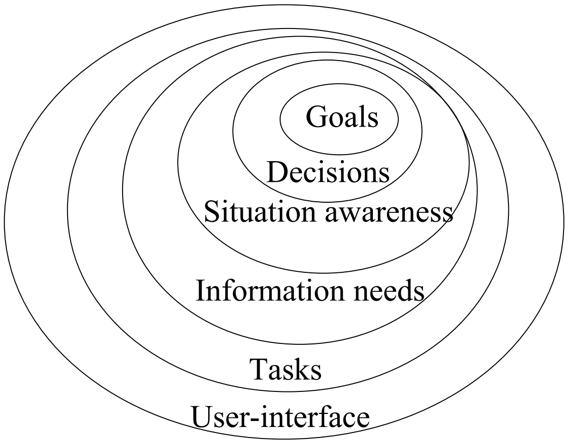


Figure 10: Human-Centered Design Philosophy.

It is an approach that is intended to support human operators in increasingly complex, cognitive activities, as the hierarchical control and exploitation of unmanned assets with mixed goals most assuredly is. These complex activities include subtle perceptual judgments, assessment of complex situations (characterized by fluidity, ambiguity and uncertainty), decision-making, problem solving, trouble-shooting, and planning. HCD is an approach that is intended to build on traditional system design approaches that characterize the required tasks, functions, and system goals, and that describe TTPs. It is intended to characterize and describe the complex aspects of the task that must either be done by a human or that require complex assessment and decision support provided by advanced technologies.

3.2 Workload Modeling and Performance Prediction

Another thrust used early in the design process, shortly after developing the straw man mission scenario, notional interface, and draft TTPs was to implement executable performance models of anticipated soldier procedures in a workload model.

We used the Improved Performance Research Integration Tool (IMPRINT); a simulation package developed by Micro Analysis and Design (MA&D) under a contract for the Army Research Laboratory – Human Research and Engineering Directorate (ARL HRED). IMPRINT is a discrete event simulation package that allows users to develop task network models, which can represent complex systems and processes. IMPRINT is designed to simplify the development of human performance models, especially models of military processes; as such, it was deemed an ideal tool to use for prediction of soldier workload in the new system. IMPRINT provides rich libraries and task analysis methods that can be used during the model development to assess the impact of task demands on an operator's performance and workload levels at any given point throughout a mission.

In order to assess the performance of the soldiers utilizing the crewstations, a human performance model was developed in IMPRINT version 6.25b. The purpose of this modeling effort was to predict operator workload, identify points of operator overload, and to evaluate the effectiveness of operators utilizing the crewstation.

IMPRINT provides three different analysis techniques for assessing operator workload.

- Visual, Auditory, Cognitive, Psychomotor (VACP)
- Goal Orientation
- Advanced Workload

The Goal Orientation and VACP analysis techniques were selected for development of the model because data can be collected under each of these modeling techniques without interfering with the other method.

Under the VACP method (McCracken & Aldrich, 1984), workload for a task is defined as the sum of the VACP resource requirements for that task. For example, consider a task which has the following VACP resource requirements.

- Visual – 7.00
- Auditory – 2.00
- Cognitive – 4.60
- Psychomotor – 2.20

In this case, the total workload for that task is the sum of all requirements for the task, 12.8 (7.00+2.00+4.60+2.20). Total operator workload can then be defined as the sum of the workload for all tasks performed at the instance of interest.

Goal Orientation analysis (Sargent & LaVine, 2000) provides the concept of a human goal. Goals are defined as a set of conditions in the state machine that must be satisfied to show that a goal has been achieved. A human goal is initialized in IMPRINT when a set of conditions hold true; this then begins the simulated process an operator must perform in order to successfully accomplish the goal. Several options in IMPRINT can be used to determine how the goal affects the state of the mission. These actions can define whether the goal preempts the mission until the goal is finished or if the goal can occur without interfering with the mission execution. Similarly, goals can influence the execution of other goals. Goals may interrupt other goals, abort other goals, or occur concurrently with other goals. A goal's priority determines its response to another goal's initiation. In this modeling effort, goals were used to represent required crew actions, such as reacting to incoming fire or communicating with external parties. Goal orientation uses VACP for the determination of workload within goals.

The benefit of these models was that the design team was provided with a discrete task representation of a very complex system that allowed the results to be examined in relation to the set of discrete tasks. The team was also able to quantify the predicted workload results that allowed examination of multiple scenario configurations and operator to asset ratios with less time, resources, and expenses associated with human-in-the-loop experiments. The model's modular design facilitated easy and quick adjustment of the scenario and operator's working environment to assess and predict how the operator is likely to perform under varying conditions.

The information gleaned from the IMPRINT model results provided a guideline for what amount of workload was imposed on the operators, what tasks the operators could successfully perform under those workload levels, and the maximum predicted asset to operator ratio. When portions of the operator's interaction with the notional design were modeled, the simulation results allowed quick discovery of high workload interfaces or conditions. The design team was then able to focus iterative design effort to mitigate these risky elements resulting in a far better human-centered interface design.

3.3 Final Design

The next step in the process was to iterate the design based on all the human engineering and workload prediction information that was collected. The final design resulted in the set of displays introduced with the description of the CAT vehicle and provided a comprehensive set of functionality to support the move, look, shoot, communicate, and unmanned asset control while "on-the-move" that the system specification required. Following the HCD approach, the next step was to re-involve the user through a series of structured walkthroughs of the paper design.

Throughout the design process, the design team was required to define the purpose of the particular interface *and* the mental model providing the rationale in operator terms (tactical relevance) why a particular design was defined. This served as a valuable element of the design that supported better understanding between the geographically distributed program participants and served as an excellent method to convey the need for the particular design to the software implementers.

3.4 Structured Walkthroughs and Feedback

Soldiers from the Unit of Action Maneuver Battle Lab at Ft Knox spent four days reviewing the paper design and mockups from an operational perspective. They were able to specify in operational terms where the design didn't make sense or could be better implemented to meet the operational and tactical needs of the defined mission objective. Based on their comments, another iterative loop of the design cycle occurred finalizing the interface design.

3.5 Implementation and Test

The next step was to implement the paper design in software. General Dynamics Robotic Systems was responsible for developing the crewstation software. As noted earlier, each defined display contained the designer's mental model of why the design was implemented the way it was. The design team continued to be integral to the crewstation software development efforts by answering programmer questions and expanding on the mental model when the programmer's did not understand the intent of a particular interface. The detailed documentation necessary to capture the design team's mental models for the programmers also provided an excellent basis for the development of training materials.

In addition to helping explain design implications, the human engineering design team acted as the system testers. This proved invaluable as the programmers would come up with innovations on their own that exceeded what the design team had envisioned possible in the development environment. Many of the innovations were accepted and incorporated into the final system design while the overall cohesiveness of the design was maintained from the HCD perspective.

3.6 Feedback and Design Iteration

The last stage of the design process was actual human-in-the-loop experimentation under realistic operational conditions in a Simulation Integration Laboratory (SIL) and in the actual vehicles. We had four soldiers acting as two separate crews operate the system through three weeks of simulated and three weeks of real operational maneuver exercises. This resulted in the discovery of numerous software bugs that were not discovered during testing and approximately 60 additional design improvement suggestions from the users. The training and experimental protocol used is defined in the next section.

After completion of the crew experimentation, the system will undergo engineering evaluation and the next loop in the iterative design cycle will begin to implement the useful design suggestions discovered during experimentation and to add functionality for additional mission capabilities such as control of MAVs and UGS'.

3.7 HCD Summary

The intent of HCD is to achieve a better design through early resource investment in the system design process.

Historically, systems have been fielded with pre-planned product improvement programs defined to address the short-comings of the design or technology. The soldiers told us that they expect a system to undergo at least three pre-planned product improvements before the system is mission effective. Pre-planned product improvements are very expensive because product baselines and configuration control have been established. Design modifications require expensive retro-fit to fielded systems and while retro-fit are in progress, system availability is diminished.

Early resource investment in HCD is a cost saver as good design early in technology development significantly reduces costs later in the life of the technology, when formal baselines and the fielding of systems are more likely to freeze the design.

4.0 CREW TRAINING AND EXPERIMENTATION

The rapid and demanding development schedule imposed on the VTI program resulted in a focused training and experimentation program. We are able to conclude some interesting observations as we watched the dedicated crews go from no knowledge of the system to good proficiency. As the crews' proficiency increased, we also noted a change in perception from the soldiers' regarding the usability of the system.

This information was extracted out of extensive usability and workload surveys. The training program and experimentation program combined could be used as a model for future training programs. The program consisted of hands-on formal training, virtual experimentation where we observed significant learning effects. A Live/Virtual mix experimentation program where vehicle motion effects were introduced, and finally it culminated in a completely live operation where targets were engaged using unmanned vehicles.

4.1 Formal Training

Formal training consisted of both classroom training and hands-on training with the Simulation Integration Laboratory which consisted of two crewstations with the ESS support. The soldiers were instructed on the capabilities of the system in the classroom setting, they then received hands-on instruction, and finally returned to the classroom for review and question and answer sessions. The training was broken down into part-task training for each one of the CAT vehicle crewstation displays as presented earlier in the paper. The training was sequenced from the soldiers gaining an understanding of the purpose and architecture of the system, through setup of the system to actual use of different mission payloads. This formal training lasted one week and each of the soldiers demonstrated an average performance capability after completing one week of training.

4.2 Virtual Experimentation

After completing the formal training the program plan was to conduct tactical operations using the SIL similar to what they would encounter in field maneuver operations. Unfortunately, the formal training was conducted in mid-December and the virtual experimentation phase did not begin until the 2nd week of January. A significant degradation in knowledge, skills, and abilities (KSA's) was observed. We estimate that two additional days (one planned and one during the first day of attempted data collection) were spent refreshing the soldier's KSA's on system operation. Given the number of interfaces and complexity of the systems they were controlling, this was an exceptional learning curve. We then conducted almost three weeks of data collection within this virtual environment in the laboratory. Each day we observed an improvement in performance.

4.3 Live / Virtual Mix

The next phase of the program plan was to mount the embedded simulation system into the CAT and conduct on-the-move command & control operations of the real robotic assets (RF and XUV). Reconnaissance Surveillance and Target Acquisition (RSTA) from the surveillance aspect and Target Acquisition (ARV gunnery) functions were the only virtually simulated views. Teleoperation video, if needed, was actual video streams from the robotic vehicles. We emphasize that the soldiers were trained to minimize the use of any streaming video and rely on the AM capability of the vehicles. This is consistent with restricted tactical bandwidth demands and the reduction of electronic emanations from the robotic vehicles.

The live/virtual maneuver introduced vehicle motion effects for the first time. There is a body of physiological evidence that the US Army's Human Research and Engineering Division had collected from other formal experiments indicating that the soldier's would incur performance degradation effects when bunkered down in the back of a vehicle with only indirect camera views of the outside world. We did not experience these performance degradation effects and crew performance continued to improve. One supposition is that it was more exciting for the crew's to be using real physical assets rather than virtually simulated assets.

The only motion effect mentioned by the soldiers was when they were attempting to teleoperate a robotic vehicle while the CAT was in motion. Early in their experience they would counter-steer the robotic vehicle when they felt their own vehicle turning. Visual feedback was immediate and they corrected the control of the robotic vehicles without any degradation in mission performance. After approximately three days, the soldiers overcame this effect.

4.4 Live Fire Operations

The culmination of the program plan was the live-fire of a Javelin missile and M-240 machine gun on the RF mounted COUGAR turret as part of the Future Combat System's Unmanned Combat Demonstration. The system was adequately modeled in the virtual world so very little learning effect was observed when the soldiers' used all live assets. The demonstration lasted 18 minutes from beginning to end, the soldiers utilized AM for the XUV to position it approximately 1 km from its starting point and the RF had a two-stage mission with two different firing points totaling approximately 2.5 km of AM navigation. After RSTA was completed by the first soldier using a live RSTA camera with automatic target recognition and IR cameras, the target was located and identified. An approximate target location was verbally passed from the XUV controller to the RF controller and when firing point one was achieved, the target lock, range safety approval, and Javelin engagement all lasted less than 1 minute. Both live fires conducted resulted in direct hits. The RF then proceeded to a second firing point where dismount silhouettes were engaged and hit with the M-240 machine gun.

The soldiers performed with no interventions required from the technical support staff and demonstrated highly proficient operations for this scenario.

4.5 Training Model

Watching the progression of the soldiers from novice operators to skilled performers using brand-new technology enforces the belief that the structure used in this program would serve as a good template for all training programs. It was clear to us that the soldiers learned a great deal more out of the hands-on operation of the equipment than they did from the formal presentation-based lessons. Constant reinforcement and guidance during subsequent operations in the virtual, live/virtual, and live operations quickly accelerated their learning curves and they achieved full proficiency. Our estimate is that if the soldiers did not experience the delay over the holidays and many of the technical difficulties experienced with the SIL and ESS (new technology can be challenging at times) they could have been trained to full proficiency in three weeks.

5.0 EXPERIMENTATION RESULTS

Three significant experimental results were achieved through the program. The first was to demonstrate the technology in laboratory conditions (Technology Readiness Level 5) and during actual maneuver under realistic operational conditions (Technology Readiness Level 6). The second was to identify a realistic determination of the soldier to ARV control ratio. Finally, we conducted a comprehensive usability assessment to establish a baseline for the future design iteration of the overall system.

5.1 Technology Maturity

One of the program objectives was to demonstrate technology readiness level (TRL) 6 – System/Subsystem prototype demonstration in a relevant environment. The expanded definition for TRL 6 is a representative model or prototype system, which is well beyond the breadboard tested for TRL 5, tested in a relevant environment. This level represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high fidelity laboratory environment or in a simulated operational environment. We successfully fielded a Section level force (CAT vehicle, RF, and XUV) that conducted coordinated operations in an operational environment. In addition, we were able to simulate control ratios of 1 operator to up to 4 ARVs using the ESS.

Given our success in going from demonstrating the technology in a simulated operational environment as we did with the ESS, we can argue that we are progressing toward TRL 7 – System prototype demonstration in an operational environment. The expanded definition for TRL 7 is a prototype near or at planned operational system. This level represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as in vehicle, and that verification, validation, and accreditation (VV&A) of the system has been completed. Since our technology baseline including MAV's and UGS' has not yet been incorporated, the VV&A process hasn't started yet.

5.2 Warfighter Workload

We used structured surveys and guided discussions to obtain subjective measures of workload from the soldiers operating the system. In the operational environment the soldiers confronted, they encountered no instances of workload overload for soldier to ARV ratios of up to 1 soldier controlling two ARVs. However, this finding must be mitigated from prior observations of watching soldiers use the RSTA MPM when moving targets are present. All targets in this experimentation and demonstration program were static. As such, they soldiers had an easier task than trying to evaluate imagery of a moving target. Additionally, the RSTA MPM provides a moving target indicator (MTI) which inundated soldiers with imagery to analyze during previous experiments.

We believe that the soldier to ARV ratio of 1:2 is probably realistic with properly trained and proficient soldiers. During virtual experimentation with soldier to ARV ratios of 1:3 or 1:4, the soldiers often felt that they were primarily monitoring the movement and not taking an active part in the mission. Also some loss of situational awareness on the order of which asset was being observed was more prominent with ratios of 1:3 and 1:4 (Callen & Thayer, 2003).

5.3 Usability Assessment

In addition to the workload surveys and guided discussions, the users were given daily surveys and guided discussion on the usability of different portions of the system. This usability assessment is critical to establishing a baseline for the next iteration of the design cycle. As mentioned earlier, the soldiers provided approximately 60 suggestions for design enhancements and improvements that will help them better achieve their mission objectives.

Our findings were that the soldier's acceptance of the system when using all real assets was significantly better than when in a virtual environment or live/virtual mix environment. This could have been achieved from numerous software upgrades that occurred on multiple subsystems that improved performance, as well as increased familiarity with the system.

We observed a moderate level of soldier trust in the system when using real assets. They seemed to relate better to the physical assets rather than the simulated virtual assets. There was some level of soldier interaction with safety crews when their trust waned but for the most part, the system performed as the soldier's expected. Trust in automation will remain a research area during future experiments and demonstrations.

6.0 CONCLUSIONS

Use of a structured HCD approach achieved a fairly robust design for an advanced technology solution defined for the VTI program. The soldiers were able to accomplish the move, look, shoot, communicate, and control of unmanned assets, while "on-the-move" in a command vehicle. Considering that this was the first iteration through the iterative design cycle for the technology; and that the program was modified to meet the needs of alternate mission objectives, we are convinced that the HCD process has led to an effective design that helps the soldiers better accomplish their mission.

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