

Virtual Combat Vehicle Experimentation for Duty Cycle Measurement

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ABSTRACT

This paper describes a human-in-the-loop motion-based simulator which was designed, built and used to measure the duty cycle of a combat vehicle in a virtual simulation environment. The simulation environment integrates two advanced crewstations which implement both a driver's station and a gunner's station of a simulated future tank. The simulated systems of the tank include a series hybrid-electric propulsion system and its main weapon systems. The simulated vehicle was placed in a virtual combat scenario which was then executed by the participating Soldiers. The duty cycle as measured includes the commands of the driver and gunner as well as external factors such as terrain and enemy contact. After introducing the project, the paper describes the simulation environment which was assembled to run the experiment. It emphasizes the design of the experiment as well as the approach, challenges and issues involved. It presents the experiment results and briefly discusses on-going and future work.

INTRODUCTION

One of the goals of the RDECOM-TARDEC Power and Energy (P&E) program is to advance the design, development, and testing of hybrid electric power and propulsion technology for advanced combat vehicles. This is being accomplished through the integration and evaluation of power and energy technologies from various Army Technology and Objective (ATO) programs. The by-product of the TARDEC P&E program will be a compact, integrated system that will provide

efficient power and energy generation, and power management, suitable for spiral integration into the Future Combat System (FCS) Manned Ground Vehicle (MGV) program.

To effectively develop an advanced power system for combat vehicles, accurate estimates of power loads throughout the complete range of operations are required. A comprehensive combat vehicle usage profile, or "duty cycle", which would provide these power load estimates, does not exist at this time. The TARDEC P&E program is attempting to remedy this situation by establishing multiple combat vehicle duty cycles. These duty cycles will be derived from the virtual representations of advanced combat vehicles and combat scenarios using both warfighter-in-the-loop and power system hardware-in-the-loop simulation described in detail in the remainder of this paper. These duty cycle measurements combine engineering-level power supply systems with performance-level models of power consumption devices within a warfighter simulation of combat mission scenarios.

For our purposes, a military vehicle's *duty cycle* is specific to the mission and platform type but is a design- and configuration-independent representation of events and circumstances which affect power consumption. Such events and circumstances encompass (1) vehicle operation such as speed, grade, turning, turret/gun activity, and gun firing plus (2) external scenario components that affect power consumption like incoming rounds, ambient temperature, and soil conditions. The event inputs can be distance-based when the vehicle is moving or time-based when the vehicle is stationary, or triggered with some other state condition.

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To measure such a duty cycle, the TARDEC Simulation Laboratory (TSL) has been building a motion base/warfighter-in-the-loop simulation capability in which Soldiers can virtually operate their vehicles in relevant combat scenarios. This capability is then used to perform experiments in which duty cycle information is captured. These experiments are called duty cycle experiments (DCEs).

TARDEC has thus far completed three DCEs. The first, executed in November 2005, was called DCE1. It consisted of a single vehicle with a driver on a motion base simulator. It is more fully described in [1,7]. The second experiment, conducted in June-July 2006, was called DCE2. This experiment simulated a single FCS Mounted Combat System (MCS) vehicle and incorporated both a driver and a gunner. The experiment is described in [2,3,6]. The latest experiment conducted in May-June 2007 was called DCE3. This experiment simulated two MCS vehicles, one under motion and one static, both with a driver and a gunner. The DCE3 experiment is described in the remainder of the paper. The three DCE experiments are compared and contrasted in Table 1.

Table 1. Comparison of the three DCEs.

	DCE1	DCE2	DCE3
Date	Nov '05	June '06	May '07
Participants	Civilian	Military	Military
Runs	7	12	12
Scenarios	1	1	2
Vehicles	1	1	2
Roles	Drive	Drive/Gun	Drive/Gun
Motion base	RMS	RMS	TMBS
Length	11 km	13 km	61/38 km
Duration	25 min	25 min	100/40 min
Long Haul		Yes	Yes
BLOS			Yes
NV/IR			Yes
Moving troops			Yes
Wingman			Yes

Each of the three DCE experiments was designed to measure an accurate duty cycle given the available resources and technology. As a matter of standard practice, each participant was asked to comment on the quality and realism of the simulation. This feedback was used to improve the subsequent experiments. For DCE3 the objectives centered on executing a relevant scenario, providing a wingman to the primary vehicle, and providing infra-red (IR) and night vision (NV) capability to the crews. Each of these objectives was attained in the DCE3 experiment. A particularly novel aspect of the DCE2 and DCE3 experiments was the hardware-in-the-loop (HWIL) integration of the P&E Systems Integration Lab (SIL) to function as the power train of the primary vehicle. This aspect of the simulation is referred to as the *long haul* or *RemoteLink* component in the remainder of the paper.

As mentioned earlier, the fundamental objective of the DCE3 experiment was to measure the duty cycle of an MCS vehicle in a relevant scenario. Such a duty cycle consists of participant behavior (as represented by their use of vehicle controls) and external circumstances (enemy, ground, lighting, weather). For this participant behavior to be realistic, the simulation environment must be as accurate as possible. We therefore invested a lot of time and effort in the fidelity of the scenario, tasks and virtual environment. For the scenario we derived two independent variants, one provided by Ft. Knox and one based on CASTFOREM both implemented in OneSAF Test Bed (OTB). The tasks of driving and gunning were accomplished via controls and displays provided by an advanced prototype crewstation called the Crew-integration and Automation Test-bed (CAT) crewstation. The virtual environment was rendered as motion, visuals and sound. The motion was provided by the Turret Motion Base Simulator (TMBS); the visuals were provided by the Night Vision Image Generator (NVIG); the sound was generated by a product called SimCreator®, which also functioned as our integration framework. Furthermore, to integrate the P&E SIL, we developed a custom solution for the robust integration of the SIL into the real-time environment.

In the remainder of the paper we discuss the experiment design with regard to the scenarios and run sequences. We then discuss the simulation architecture and design to include a description of the major components. We discuss the implementation of the long haul connection to the P&E SIL. Finally, we present some representative results and offer some conclusions.

EXPERIMENT DESIGN

As mentioned, the DCE3 experiment used two independent combat scenarios. The reasons for this are two-fold. First, to make the fullest use of our participants' time, we wanted them to spend the most time "on simulator" as possible. Second, we received candidate scenarios from two different sources both of which had appealing features. They were markedly different so we chose to use both. The first and what we called primary scenario was developed by the Unit of Action Maneuver Battle Lab (UAMBL) at Ft. Knox, KY. The second scenario was derived from an execution of the Combined Arms and Support Task Force Evaluation Model (CASTFOREM). Both scenarios employ the MCS's main and auxiliary weapon systems in line-of-sight (LOS) engagements and employ what are called beyond-line-of-sight (BLOS) engagements. In BLOS engagements, targets may be engaged which are not in direct view. The UAMBL scenario emphasized LOS engagements and the CASTFOREM scenario emphasized BLOS engagements. Furthermore, both scenarios are executed on Ft. Knox terrain using the same route. These scenarios are briefly described in the following sections.

UAMBL SCENARIO

The scenario delivered by UAMBL was written for a company-sized element consisting of one (Mounted Combat System) MCS platoon and two Infantry Carrier Vehicle (ICV) platoons whose mission is to enter hostile territory, assault an objective, and rapidly return. It is set at night so all driving/gunning occur through NV/IR displays. It is specifically written for the MCS platoon as the simulated entity and occurs in three phases: phase 1 consists of a rapid advance to an objective, phase 2 consists of a support by fire position at the objective, and phase 3 consists of the exit operation to return to friendly

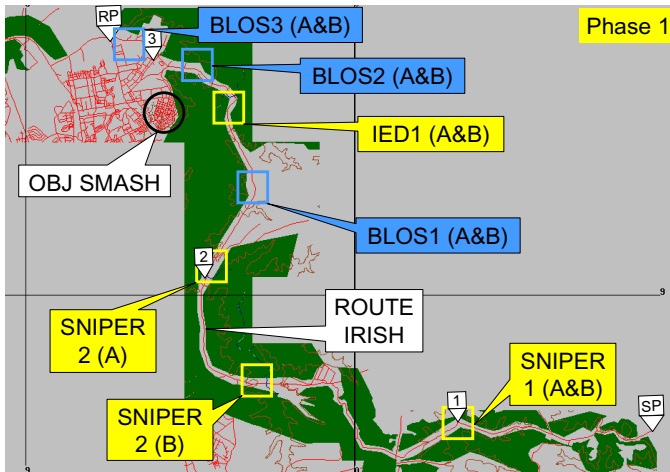


Figure 1. Phase 1 of the UAMBL Scenario.

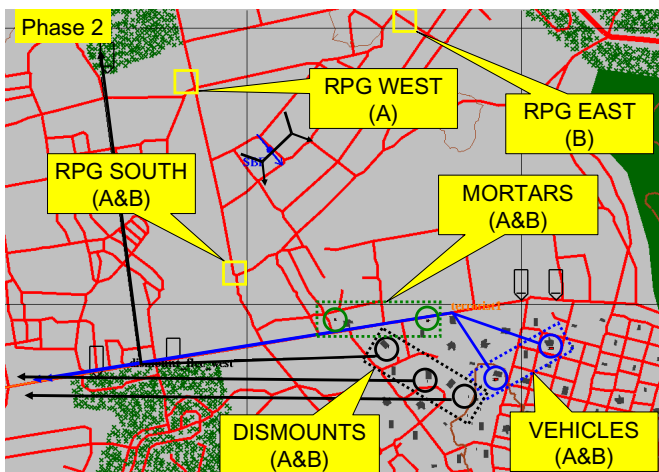


Figure 2. Phase 2 of the UAMBL Scenario.

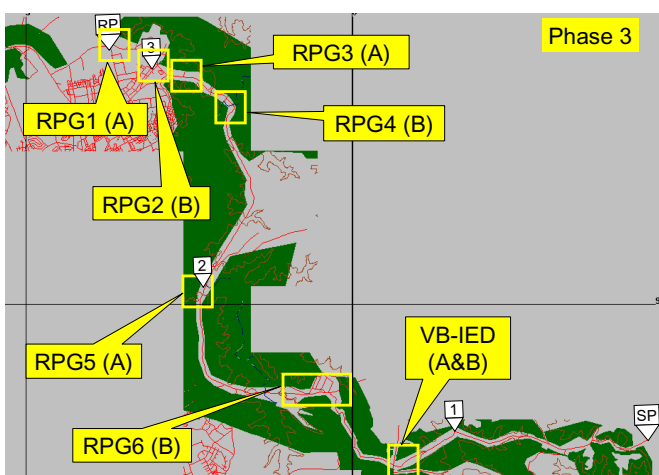


Figure 3. Phase 3 of the UAMBL Scenario.

territory. We elected to implement all three phases of the scenario for our simulation.

In phase I, the engagements occur on the route IRISH which may be seen in Figure 1. The goal for phase 1 is to reach the objective as soon as possible. The platoon encounters a few enemy ambushes on the route and an improvised explosive device (IED). They preemptively engage the objective with BLOS while en-route. Phase 2 begins once the support by fire (SBF) is set (see Figure 2). During the SBF the platoon continues to engage the enemy in relation to the objective. Engagements consist of vehicles, dismounts, mortar teams and RPGs. In phase 3 the company reconstitutes its column and returns along route IRISH (see Figure 3). The enemy organizes ambushes along the exit route with RPGs. The enemy also positions a Vehicle Borne IED (VB-IED) for the returning company. The company may address the VB-IED with a BLOS engagement or a LOS engagement.

CASTFOREM SCENARIO

The CASTFOREM scenario was developed for DCE3 using a scenario situated on a different terrain. The scenario described how an FCS brigade rapidly moves from a staging area to a position in close contact with enemy forces in preparation for an assault on an enemy stronghold. The scenario incorporates the rapid advance and positioning of forces as well as the engagements with perimeter forces along the way. To simplify the implementation, the scenario was transposed from its original terrain onto the Ft. Knox terrain. Unlike the UAMBL scenario, this scenario traversed the route in only one direction. The engagements which occur along the route are shown in Figure 4. As may be seen, the engagements are mostly BLOS. The few LOS engagements which occur are against 2-3 dismounts.

EXPERIMENT EXECUTION

Twelve Soldiers participated in the DCE3 experiment; four Soldiers per week for three weeks. Additionally, a senior NCO (E7/E8) participated for all three weeks as

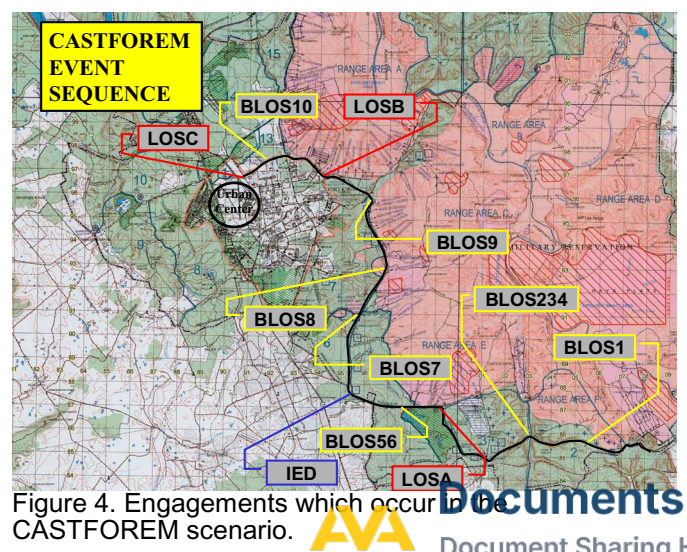


Figure 4. Engagements which occur in the CASTFOREM scenario.



Figure 5. (left) TMBS with crewstation platform, enclosure and two CAT crewstations attached and (right) two CAT crewstations on the crewstation platform.



Figure 6. Secondary (wingman) crewstations. (left) Secondary gunner's station consisting of one touch screen display and a joystick controller. (right) Secondary driver's station consisting of a day-view display, a steering wheel, and two pedals.

the platoon commander. This NCO was referred to as the “proxy commander.” The four participating Soldiers were divided up into two crews each consisting of a driver and a gunner. One crew served as the primary crew and the other served as the secondary crew. The primary crew operated the vehicle on the motion base while the secondary crew operated the stationary vehicle. The motion base along with the primary crew interface may be seen in Figure 5. The secondary crewstation may be seen in Figure 6.

Two scenarios were necessary to prevent the gunners from memorizing the scenario.

The Crew Station / Turret Motion Base Simulator (CS/TMBS) was used for all tests and operated by TARDEC engineers. The tests were conducted from 21 May – 14 June 2007, with 12 Soldiers as participants from Ft. Bliss, Texas. Each participant was given an initial overview/brief of the test objective and a safety

By design, each crew was given an opportunity to function as both the primary and secondary crew each experiment day. For one run they would be the primary and next the secondary. Furthermore, each crew would maintain their assigned roles (i.e., driver and gunner) for the first two experiment days (Monday and Tuesday); for the next two days (Wednesday and Thursday) they would swap roles. This scheduling scheme is illustrated in Figure 7. There the Soldiers are labeled S01 through S04. The rows indicate their assignment to teams and roles; the columns indicate the time sequence of the four configurations shown. On Tuesday, for example, the crews would execute the “A” version of the scenario. They would then switch from primary to secondary and execute the “B” version of the scenario. The A and B versions of the scenario differed in red force positioning.

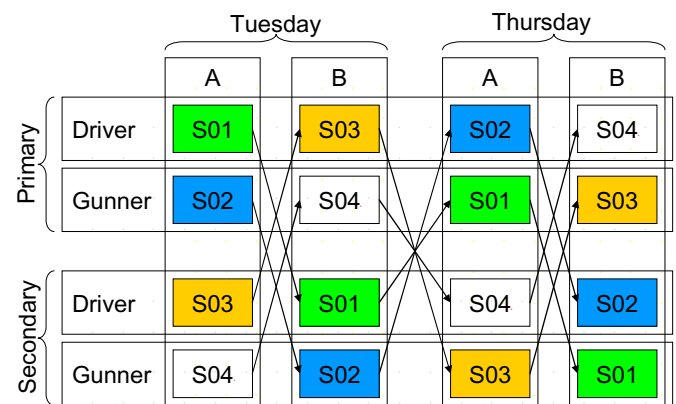


Figure 7. Configuration of four soldiers into teams and roles throughout the experiment week.

brief of the simulator before participating in the actual experiment. The participants filled out a “Demographics and Personal Experience Questionnaire” which gathered information on their background and experience. The experiment procedures were the same each test day. They consisted of experiment preparations each morning that included warming up and exercising the CS/TMBS, prepping the software by configuring and starting up the software programs for the scenarios, terrains, tactical map, and powering up the CAT crewstations. To execute each experiment, the participants boarded the CS/TMBS and were seated and belted in the CAT crewstations. Each was administered a “Motion Sickness Questionnaire” prior to and following each experiment so that the operator could gauge whether the occupants were feeling any motion sickness. Upon completion of the experiment, the subjects were administered qualitative surveys and questionnaires regarding their experience and opinions on the experiment.

SIMULATION ARCHITECTURE AND DESIGN

The DCE3 experiment was comprised of several independent systems that were integrated to provide the

functionally necessary to support two operators, each controlling a crewstation cockpit on a 6-DOF motion platform in an immersive synthetic battlefield environment. In this section we discuss the design and architecture and of the simulator which was used to execute the experiment.

The major components of the DCE3 simulator are the TMBS, crewstation enclosure, the CAT crewstations, the secondary crewstations, the ESS rack and the set of computers used to run the simulator. There were two CAT crewstations mounted on the TMBS (shown in Figure 5) for the primary crew. The secondary crewstations, were stationary and located in the laboratory.

The simulator that was built to conduct the DCE3 experiment consisted of 30 Intel®-based PCs inter-networked with five independent 100 MBPS switched Ethernet subnetworks. The interconnections and placements of these components in the system are illustrated in the wiring diagram shown in Figure 8. In this figure, the location *TMBS* denotes those components on the motion platform, the *AREA 5&6* denotes the lab area containing the TMBS, the *CONTROL ROOM* denotes the area where the

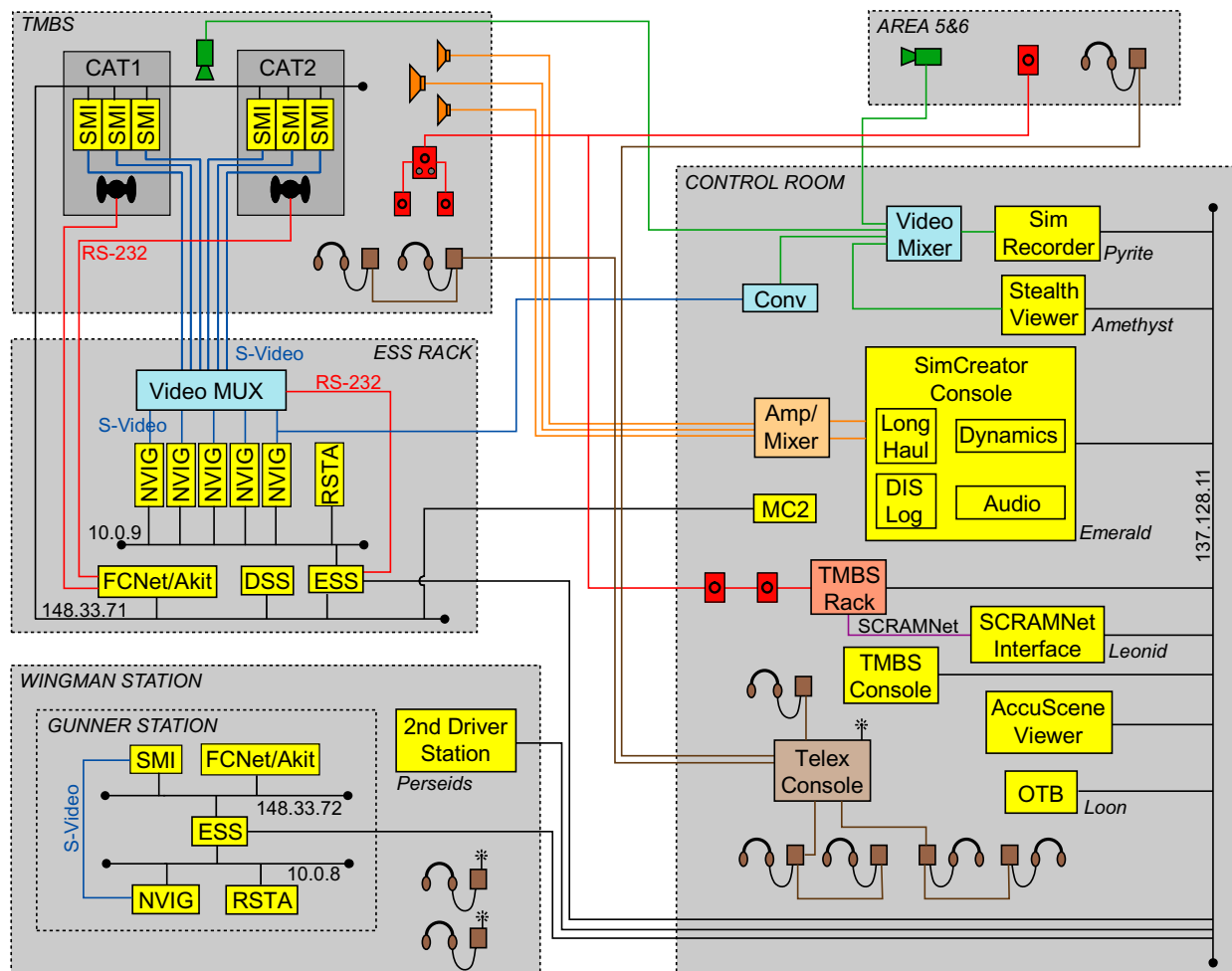


Figure 8. Computer and network architecture of the DCE3 simulator as implemented. PCs are shown as yellow boxes. Location-based groupings are indicated with grey boxes.

simulation operators were positioned, the *ESS RACK* is the 19" rack also located in the control room and the *WINGMAN STATION* is located in the control room as well. The primary means of communication among these computers is the TSL local area subnetwork (137.128.11.*) shown on the right. Also shown are the signal flows associated with the CAT crewstations (which have dedicated subnetworks), the audio subsystem, the video monitoring and recording subsystem, the communication system, the E-stop system and the motion control system.

As can be seen the simulator was comprised of a variety of existing subsystems all integrated to form the whole. The integration was mostly accomplished by means of SimCreator, which is a commercial product developed by Realtime Technologies, Inc. (RTI) [8]. It was used to seamlessly integrate the main processes on *Emerald*, *Leonid*, *Amethyst*, and *Pyrite*. *Emerald*, a quad-core Windows XP® PC, lies at the heart of the simulation architecture. It executes one process per core; these processes are vehicle dynamics, the long haul interface, the DIS logger and the audio process. *Leonid* served as an interface between SimCreator and the TMBS by placing motion commands on the SCRAMNet® interface. *Amethyst* ran the stealth viewer which gives a "parasail" view of the primary vehicle (using SimCreator's IG). *Pyrite* runs sim-recorder which records four video channels and one audio channel in MPEG format.

Several other computers were not integrated using SimCreator. *Loon* is a Linux PC running OneSAF Test Bed (OTB) which is responsible for generating the red forces. The AccuScene Viewer generates a stealth view of the battle rendering all entities on the DIS network. The TMBS console is responsible for controlling the VME controllers in the TMBS Rack; it is the sole interface to the TMBS. The MC2 laptop was used to "drop" BLOS targets into the simulation environment. The primary CAT crewstations exclusively communicate with the simulation via the ESS box, thus abstracting their internal complexity away from the simulation architecture. The secondary (wingman) station is abstracted in a similar

sense. The secondary driver station (*Perseids*) is a stand alone SimCreator process which implements the secondary vehicle dynamics and communicates with the secondary ESS directly. The primary and secondary vehicle stations are completely independent and communicate using only the DIS protocol.

The primary driver's and gunner's interfaces were provided by the CAT crewstation (see Figure 9). The CAT crewstation is a stand-alone simulator used to evaluate operational effectiveness of a two-man crew for future combat vehicles. The crewstation consists of three 43cm x 33cm (17" x 13") touch screen panels, several dedicated pushbuttons, a yoke, and foot pedals. The operator interface on the crewstations is controlled by the Soldier-Machine Interface (SMI) computers which communicate with the Embedded Simulation System (ESS) over a dedicated Ethernet subnet (TCP/IP and UDP). Video is provided to the CATs by up to three Image Generator (IG) computers via a standard S-Video interface. The IG computers generate their scenes using the Night Vision Image Generator (NVIG) developed by Nigh Vision Labs (NVL) of the U.S. Army Communications and Electronics Research Development and Engineering Center (CERDEC). The IG channels are directed to the proper SMI display by means of a video multiplexer which is controlled by the ESS. The RSTA server is responsible for performing line intersection queries for ballistics and laser range finding. The FCNet process is responsible for modeling the vehicle's weapons. The A-kit is responsible for abstracting the ESS from the rest of the system. The DSS computer is responsible for generating the target lists as specified by the MC2 laptop.

The Desktop CAT is a PC-only implementation of the CAT crewstation, which does not require the crewstation hardware to run. One such station was used to implement the secondary gunner's station. It consisted of 1 SMI channel, 2 NVIG channels (1 IG and 1 RSTA server), the Akit/FCNet computer and the ESS computer. Each of these serves the identical role they do in the primary station. The Desktop ESS had to be modified to allow for a gunner-only operation mode, with all of the driver actuation commands coming from SimCreator.

SimCreator was used to model the FCS-like vehicle dynamics and the turret/gun system mounted on the vehicle. SimCreator communicated with the crewstation through the Embedded Simulation System (ESS). ESS and SimCreator used a common socket-based communications protocol called OE, which was designed to emulate shared memory across a network. It provides facilities for creating message stores for continuous data such as driver and gunner actuators and vehicle state, as well as message queues for passing discrete events such as gun fires and EM armor discharges. Unlike previous experiments, the ESS was modified to so that all weapon modeling and vehicle dynamics was handled by SimCreator. In this experiment, the ESS acted as a message distribution system between all the components in the simulation.

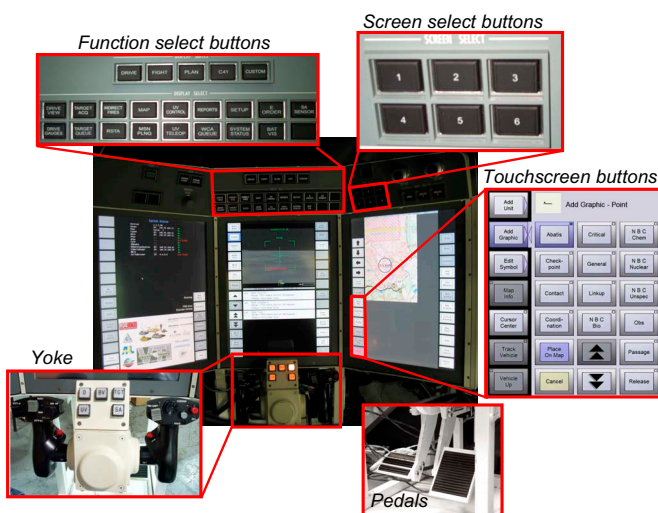


Figure 9. CAT crewstation interfaces.