Digital Command and Control System Soldier-Machine Interface for Ground Combat Systems

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Abstract

Force XXI is the vision to synthesize the technology, doctrine, and organization of the U.S. Army so that it can fight and win the wars of the 21st Century. Digitization - taking advantage of the microprocessor revolution - is a key enabler of the Force XXI plan. In the Crewman's Associate Advanced Technology Demonstration (ATD), crew stations for ground combat systems are being developed that allow the soldier to use digitization to maximize weapon system performance. The soldier-machine interface to a digital Command and Control system is an integral part of the crew station design.

1. INTRODUCTION

A soldier-machine interface to a digital Command and Control (C2) system for a ground combat system is described in this paper. This interface is part of a larger effort to develop a crew station optimized for the digitized battlefield. This crew station was developed as part of the Crewman's Associate program. Crewman's Associate is one of the U.S. Army's Advanced Technology Demonstrations (ATD).

The paper is organized as follows: Immediately following this introduction, a Background section explains why new combat system crew stations are required. The Command and Control System Description describes the Force XXI Battle Command to which the crew station must provide a soldier-machine interface. The following section, Crew Station Objectives, lists the operational objectives of the crew station as related to the Command and Control system. The process used to develop the crew station is detailed in the Crew Station Design Process section. The Crew Station Design section provides a top-level overview of the crew station components related to the Command and Control system. The next section, the Digital Command and Control System, provides a description of the soldier-machine interface to this subsystem. The next section summarizes the Benefits provided by the crew station. How the crew station will be tested is described in the Testing section. Finally, a Conclusion is offered to summarize the paper.

2. BACKGROUND

Digitization of the battlefield will affect the warfighter at every echelon. "Operationally, digitization will provide enhanced situational awareness with friendly and enemy tracking; a common battlefield view; fratricide reduction; self-location and navigation; horizontal information exchange; target hand-over; and facilitation of force synchronization."1

To achieve the provisions of the digitized battlefield, ground combat systems will require: 1) advanced sensors, both imaging and non-imaging, providing unprecedented quantities of raw data, 2) high-speed processors, providing information gleaned from sensory inputs, and 3) access to shared databases, containing information from throughout the Force, that can provide unparalleled real-time situational awareness.

"Much of the emphasis to date in the digitization initiative has focused on the hardware and software required to support it. However, of equal, if not more, importance is the effective integration of the digital subsystem(s) with the soldiers who will operate and maintain it. Failure to address soldier-system integration issues early in the digitization program will result in sub-optimal or even negative effects in operations and/or maintenance of the

1 MG Joe W. Rigby, “Acquiring the Digitized Force,” Army RD&A Bulletin, (November-December 1994), 14-15.
systems being ‘digitized.’ The Crewman’s Associate effort directly addresses this concern.

Also, many of the digitization efforts to date have only addressed the requirements of the upper echelon Commanders. In contrast, the Crewman’s Associate effort specifically supports lower echelon requirements, the combat crewmen that are directly responsible for putting “steel on steel.”

3. COMMAND AND CONTROL SYSTEM DESCRIPTION

The soldier’s ability to communicate on the future battlefield will be greatly enhanced. Future combat systems operating on a digitized battlefield will be provided real-time force synchronization and situational awareness. Five major functions provided by the digitized battlefield are: 1) horizontal integration, 2) distributed databases, 3) combat identification, 4) target hand-off, and 5) command and control. Also, automated logistics functions aid the crewmen.

4. CREW STATION OBJECTIVES

The crew station of the digitized combat system must provide the soldier an interface which allows him to take advantage of the capabilities described in the previous section. The objective of the soldier-machine interface to the digital Command and Control system is to increase the operational effectiveness of the weapon system by providing the crewmen with the following capabilities:

- Decreased time to create and send digital C2 reports
- Improved operations on the move
- A user-friendly interface to the digitized battlefield of Force XXI
- Improved continuous operations (CONOPS)

5. CREW STATION DESIGN PROCESS

The performance objectives were pursued by applying the Army’s Systems Engineering process, with a heavy dose of Human Factors Engineering. Part of the Human Factors Engineering process is the application of, and adherence to, human factors design principles. Four of the design principles applicable to ground combat systems that were selected and used are described in the following paragraphs.

5.1. Hands on Primary Controller

The crewman’s hands should stay on his primary controller while executing critical tasks. Critical tasks are defined as those that must be performed during combat, while in contact with the enemy. Adhering to this principle provides two benefits:

- Reduced task execution timelines. If tasks can be performed without the crewman reaching, the time required to perform tasks can be decreased.
- Decreased fatigue. Minimizing motion will decrease crewman fatigue. Over a short period of time, the fatigue resulting from hand and arm movements is minimal. Given a 96-hour continuous operation, however, these motions can culminate in significant fatigue. Their reduction will increase crew performance during such operations.

5.2. All Critical Information in the Primary Vision Zone

All critical visual information should be in the primary vision zone. Critical visual information is defined as information that the crewman needs to see while in contact with the enemy. The primary vision zone is the area that can be seen by a crewman without any head movements; simply with eye pupil movements. As with the first design principle, two benefits accrue when critical information is displayed in the primary vision zone:

- Reduced task execution timeline. If the tasks can be performed without the crewman moving his head, and also without forcing him to continuously visually reorient himself after looking at displays at different viewing distances, the time to perceive information is decreased, leading to task time reductions.
- Decreased fatigue. Minimizing head movements minimizes physical fatigue. Also, minimizing visual reorientation minimizes cognitive fatigue. Due to these reductions, the crew station is more conducive to continuous operations.

5.3. One Step Functions

In the combat system of the digitized battlefield, there will be a much greater degree of electronic integration. Functions that are currently mechanically actuated will be electronically actuated. This makes it possible to base the crew station design more on the crewman’s needs than on mechanical constraints, and to execute a function consisting of multiple tasks with one action.

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2 MG Wallace C. Arnold, “MANPRINT and the Digitized Battlefield,” Army RD&A Bulletin, (November-December 1994), 39-41.
5.4. Consistent Mental Model

It is important that the soldier-machine interface design be controlled by a single entity to ensure that a consistent interface is presented to the crewmen. The crewmen must be presented with one consistent interface to all the subsystems; it should be transparent to the crewman that he is actually interfacing with multiple subsystems developed by different contractors. An example of this is Microsoft Office. Once you know how to "Cut and Paste" in Word, you also know how to do it in Excel and PowerPoint. The user learns how to perform a function once, and then does it the same way across all applications.

6. CREW STATION DESIGN

Figure One graphically depicts the ground combat system crew station optimized for the digitized battlefield. A description of the components and features of the design applicable to the C2 soldier-machine interface follow.

6.1. Multifunction Displays

Located directly below the panoramic display are three multifunction displays (MFDs). "Multifunction" means that the displays are not dedicated; they can be set up by the crewman to display information from, or the status of, a number of different subsystems. The MFDs can be set up for any of the following:

The MFDs are located in the crewman's Primary Vision Zone. Also, by using identical displays, and by avoiding dedicated interface hardware, a Consistent Mental Model can be presented to the crewmen.

6.2. Hand Controller

Centrally located below the MFDs is the primary controller, a two-handed yoke. This yoke (Figure Two) is a critical component of the crew station.

Figure Two. Primary Controller
Functionality built into this yoke controller makes it possible to realize one of our key design principles: \textit{Hands on primary controller}. The functions that must be controlled during critical periods of combat are accessible to the crewman without his hands leaving his primary controller. The most important feature of this yoke in regards to the C2 soldier-machine interface is the Bump Switch. Located on the right grip, it is used to interface with the MFDs.

7. DIGITAL COMMAND AND CONTROL SYSTEM

In this section, the soldier-machine interface to the digital Command and Control (C2) system is described. First, the requirements of the digital C2 system will be identified. Design principles for the C2 system will be listed next. An overview of the C2 soldier-machine interface will then be given. Finally, how the interface is used to execute two sample C2 tasks will be described.

7.1. Requirements

The interface described in this section meets the requirements defined in the following documents:

- "Operational Requirements Document for Force XXI Battle Command Brigade and Below," 01 July 1994
- "Force XXI Battle Command User Functional Description," 01 July
- "Variable Message Format Technical Interface Design Plan," Volumes I, II, and III, 31 July 1995

7.2. Design Principles

The design of the Crewman’s Associate crew station soldier-machine interface was guided by the use of the human factors design principles cited earlier in this paper. Likewise, design principles tailored to the requirements of a C2 system were used. They are described in the following paragraphs.

7.2.1. Intelligent Placement of Cursor. The time spent by the crewmen manipulating the MFD cursor must be minimized if task execution time-lines are to be reduced. This is done by automatically placing the cursor where it is needed. For example, if it is standard operating procedure for Task A to be executed after Event X, the system should automatically place the cursor where it is needed to execute Task A following each Event X.

7.2.2. Minimize Drag and Click. For desktop computing, it is common to move the screen cursor in a continuous fashion, dragging it along and clicking at the appropriate location. While user-friendly, it is relatively slow, and is difficult to accurately do in a combat system that is moving rapidly over rough terrain. Instead of dragging and clicking, the cursor moves with discrete movements, and is “bumped” from selection to selection with a bump switch. Using bumping movements is quicker, and improves operations on the move.

7.2.3. Automated Data Input. Two major developments in ground combat systems for the digitized battlefield make possible the automated input of data into C2 reports. First is the addition of sensors, both smart and dumb. Fuel level, ammunition level, system readiness, etc., will all be sensed and digitized. Likewise, the automatic recognition system will provide information on enemy forces that currently only the crewmen can provide. Second, the systems will be electronically integrated. All data and information that is sensed and digitized will be available anywhere within the system. Many report fields that are manually filled currently, therefore, will be automatically entered by the system.

7.3. Description of Design

The top level C2 screen, C2 Operations, is shown in Figure Three. From this screen, the soldier can access reports, report queues, and radio and DATE/TIME/GGRID setup. The top level screen is divided into two functional areas: the C2 Status Area (header portion of the screen), and the Report Access Area (body portion of the screen).

The C2 Status Area displays a current count of the number of reports in the incoming and outgoing queues by precedence, the active radio channel, and the current date, time, and grid position. This information appears on all pages of the top level screen.

The Report Access Area is composed of three pages: Combat 1 (Figure Three), Combat 2, and Pre/Post. The Three pushbuttons to the right of the screen provide navigation between the three pages. The reports are divided between the pages such that those reports that are sent during combat most often are on Combat 1. Those reports that are sent less often are on Combat 2. Those reports sent before and after combat are on Pre/Post.
From the Operations screen, the crewman can monitor the number of incoming reports, incoming overlays, and outgoing reports, on the two top left areas of the screen (Figure Four). The number of reports that have not been viewed is updated for each level of precedence as incoming reports are received. The precedence levels are: Emergency (E), Flash (F), Immediate (I), Priority (P), and Routine (R).

Incoming reports are announced by a tone, simultaneously presented when the report is received and the INCOMING REPORTS area is updated. Incoming reports with a precedence level of Flash or higher (e.g. air alerts, NBC alerts, warning orders, FRAGOs, and OPORDs) are accompanied by a voice message and a visual cue. The auditory message is a digitized voice stating the report name twice. For example, the auditory cue for an air alert is “Air Alert, Air Alert.” Simultaneously, the INCOMING REPORTS area on the screen will quickly flash to reverse video and back again at three Hertz for the duration of the auditory message.

To view an incoming report, the INCOMING REPORTS area must be selected. This is done one of two ways: 1) Bump the cursor to the INCOMING REPORTS area using the bump switch (Figure Two), and depress the bump switch, or 2) Touch the INCOMING REPORTS area on the MFD (which is a touch screen). Upon selection, a list of the incoming reports will appear. An example is shown in Figure Five. The crewman will select the report he wants to view, via the bump switch or the touch screen.

To create and send a report, the crewman selects the report type in the Report Access Area on the Operations screen. Depending on the report type, many of the fields will be automatically filled (those that are not will be filled by the crewman either bumping and selecting, or using the touchscreen and keypad). The crewman then depresses his bump key again, which selects the screen area on which the cursor resides (YES response to the SEND SPOT REPORT NOW? query) thus sending the report (See Figure Six).

### 7.4 Example Operations

To illustrate how the soldier-machine interface is used to read an incoming C2 report and to prepare an outgoing C2 report, two examples are given below. Note that each of the two sample tasks cited below take about one second to execute.
Incoming Reports and Overlays

Outgoing Reports

Figure Four. Incoming and Outgoing

Figure Five. Incoming Reports Screen
**CREW/SYSTEM ACTION** | **DESIGN PRINCIPLES**
---|---
System automatically places the cursor on INCOMING REPORTS area | Intelligent placement of cursor
System automatically places the cursor on NBC Alert report icon | Intelligent placement of cursor
Soldier makes both selections by depressing bump switch on the yoke | Minimize drag and click
Soldier views report without having to move his head | Hands on Primary Controller

Table Two: Read Incoming Report

**CREW/SYSTEM ACTION** | **DESIGN PRINCIPLES**
---|---
System automatically places the cursor on SPOT Report area | Intelligent placement of cursor
Soldier selects SPOT Report by depressing bump switch on the yoke | Minimize drag and click
SPOT report fields are filled by the system | Hands on Primary Controller
Soldier verifies report contents without having to move his head | Automated data input
System automatically places the cursor on SEND | All Critical Information in the Primary Vision Zone
Soldier sends report by depressing bump switch on the yoke | Intelligent placement of cursor

Table Three: Send Report

**Figure Six. Send Report**
7.4.1. **Read Incoming Report.** The crewman hears an auditory message, “Gas, Gas.” He depresses his bump switch twice consecutively, and then looks at the MFD to read the report. (Table Two illustrates how the soldier-machine interface adheres to the crew station design principles and the C2 design principles for reading an incoming C2 report.)

7.4.2. **Send Report.** The crewman lases an enemy vehicle, and thus needs to send a Spot report. The crewman depresses his bump switch, looks at the report to verify the content, and then depresses his bump switch again. (Table Three illustrates how the soldier-machine interface adheres to the crew station design principles and the C2 design principles for sending a C2 report.)

8. **BENEFITS**

As stated earlier in this paper, the objective of this crew station development effort is to increase weapon system operational effectiveness by improving the soldier-machine interface. With regards to the interface to the digital C2 system, the following crew station objectives have been met:

- The time to create, send and read digital C2 reports has been minimized, as illustrated in the examples given.
- Operations on the move have been improved due to: 1) the decreased steps required to execute tasks, 2) the elimination of dragging the cursor, and 3) by allowing the crewmen to keep their hands on the yoke during task execution.
- The crewmen now have a simplified, user-friendly interface to the digitized battlefield of Force XXI.
- The ability to effectively perform CONOPS has been improved due to the decreased fatigue associated with operating this crew station.

9. **TESTING**

To test this soldier-machine interface, man-in-the-loop simulators are being built that emulate the Crewman’s Associate crew stations. The simulators are high-fidelity and compatible with the Defense Simulation Internet. These simulators will then be used as part of a virtual Battle Lab Warfighting Experiment (BLWE).

In the BLWE, the mission scenario consists of six mission vignettes. Both objective and subjective data will be captured to measure crew performance and crew workload. To establish a baseline, the first phase of the BLWE was run using the Abrams M1A2 simulators at Ft. Knox in the Mounted Warfare Test Bed (May 95 - Jun 95).

The Abrams M1A2 is the Army’s flagship ground combat system. It is the Army’s first development of a digital combat system for the digitized battlefield. The performance data captured during the Abrams M1A2 simulation experiment will be used for comparison to the Crewman’s Associate crew station soldier-machine interface to determine if the objectives (i.e. reduced time to create and send C2 reports) were truly met. The Crewman’s Associate crew station simulators will be tested in the Spring of 1996.

10. **CONCLUSION**

The ground systems of the digitized battlefield will have greater capabilities than ever before. It is vital, however, that the soldier-machine interfaces to these systems be optimized so that the full potential of the weapons systems may be realized.

In the Crewman’s Associate ATD, a ground combat system crew station soldier-machine interface for the digitized battlefield was developed using human factors design principles, resulting in improved combat operational effectiveness. The crew station soldier-machine interface has been emulated in a high-fidelity man-in-the-loop crew station simulator. The simulator will be used in a virtual Battle Lab Warfighting Experiment to test the interface, and to determine if performance objectives have been met.

11. **REFERENCES**

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