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Soldier Machine Interface for Vehicle Formations: Interface Design and an Approach Evaluation and Experimentation

by Keryl A. Cosenzo, Erin Capstick, Regina Pomranky,
Tony Johnson, and Sanjiv Dungrani

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14. ABSTRACT
This document presents interface designs developed through a number of technology development and experimentation efforts at the U.S. Army Tank Automotive Research Development and Engineering Center and U.S. Army Research Laboratory, respectively. Through these efforts, a functional Soldier Machine Interface (SMI) was developed using Future Combat System concepts to support the tasks of monitoring and maintaining coordinated movement of platoon size units conducting a tactical road march. This report provides an in-depth description of the approach used to develop the SMI and the features of the SMI. In addition, we describe a modeling and simulation environment that is being used to support human-in-the-loop experiments to evaluate the current SMI and examine the impact of the SMI on the supporting operator's roles.

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1. Introduction

As the emerging technologies of the Army's Future Combat System (FCS) are introduced into the battlefield, Soldiers increasingly will face new challenges in workload management. A shifting force structure will bring increasing responsibilities for the next generation Soldier, who will be tasked with effectively using and protecting robotic assets in addition to performing other missions. In order to assess the capabilities and operational value of new concepts associated with FCS objectives, the U.S. Army Tank Automotive Research Development and Engineering Center (TARDEC) and U.S. Army Research Laboratory (ARL) have developed a functional user interface and are conducting experiments to examine various human-machine interface concepts for manned and unmanned systems. Through experimentation we are able to quantitatively verify the capabilities and operational value of new concepts, techniques, and procedures (*1*). This work is part of a joint TARDEC-ARL research program, the Robotics Collaboration Army Technology Objective (RC ATO). The goal of the program is to develop a common user interface that maximizes multi-functional Soldier performance of primary mission tasks by minimizing required interactions and workload in the control of ground and air unmanned systems and minimizes unique training requirements. Program objectives include analyzing and evaluating the effects of automated technologies, interface design concepts, and associated control devices with respect to Soldier workload.

This report describes a functional Soldier Machine Interface (SMI) that was developed using FCS concepts to support the tasks of monitoring and maintaining coordinated movement (i.e., formation) of platoon size units that include manned and unmanned systems. We provide a detailed description of our design approach and the resultant features of the SMI. In addition, we describe a modeling and simulation environment that is being used to support human-in-the-loop experiments to evaluate the current SMI and examine the impact of the SMI on the supporting operator's roles. The experiments and the associated results are not presented in this report but will be published in a future report.

2. Background

2.1 Current Force

The ability to move through the battle space is the fundamental requirement for conducting an operation in the theater of war. This movement should be as rapid as the terrain, the mobility of the force, and the enemy situation will permit (*2*). In current operations there are two types of movements, a tactical movement (movement in preparation for contact) and a maneuver movement (movement while in contact with the enemy). Prior to initiating any type of movement, planning must occur. Figure 1 shows the flow of events in mission execution including planning, monitoring, and execution. Knowledge of critical elements, such as Mission, Enemy, Terrain, Troops Available, Time and Civilians (METT-TC), is integral to mission or battle execution and continually influence the components of the mission cycle (*3*).

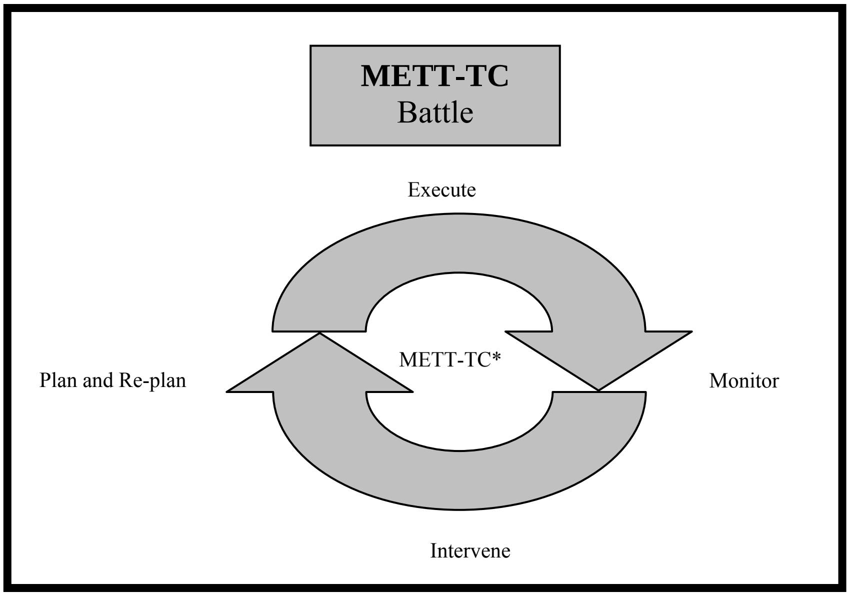

Figure 1. METT-TC.

METT-TC drives the battle decisions at the tactical level; however, no matter what decision is made, security is maintained at all times. A well planned and executed tactical maneuver (i.e., formations and techniques) is just one of the ways unit security is ensured at all times for both offensive and defensive operations. One way security is maintained is through formations and techniques. Formations are the arrangements of units (i.e., squads and above) in relation to each other. Techniques are the position of units (i.e., sections and above) and the sequential movement of those in relation to each other during movement. Forces on the battlefield use the best combination of formations and techniques to maximize control, security, and flexibility for a given situation. There are standard positions which allow leaders to control team members to maintain cohesion and momentum. For example, security forces reduce their exposure to the enemy during movement through use of the terrain, avoidance of possible kill zones, dispersion, observations, and the use of measures to counter enemy observation and fires. Further, there are standard techniques, tactics, and procedures (TTPs) for formations (*4*). For example, in current operations, the lead vehicle in most types of formations is traditionally the Platoon Leader's vehicle. If something happened to that lead vehicle, the command would transition down to another vehicle in the platoon, and the Tank Commander in that vehicle would become the Platoon Commander for the remaining unit. The mission may continue until all resources are depleted, depending on the order from the Company Commander. Ultimately, the Platoon Leader has primary responsibility of maintaining a formation (*4*).

Communication between formation elements is crucial to the leaders' situational awareness (SA) of the status of each element in a formation. Currently, there are many tools that a Platoon Leader can use to maintain SA of that status. Some of the more well-known tools at the Platoon Leader's disposal are Force XXI Battle Command Brigade and Below (FBCB2), Blue Force Tracker (BFT), satellite imagery, and Airborne Warning and Control System (AWACS) imagery. FBCB2 provides the commander a common operating picture (COP) of the blue forces in the form of a map with moving vehicle icons that denote the grid location of each platform within the FBCB2 network. Vehicle location is periodically updated every n^{th} minute or every n^{th} distance based on the refresh rate (user defined). Also, FBCB2 can produce overlays that denote routes, phase lines, objectives, named areas of interest (NAI), target areas of interest (TAI), etc. BFT is similar to FBCB2 in overall purpose as it also provides a COP of the blue forces. Satellite and AWACS imagery can provide the leader with a bird's eye static view of the unit formation as well as the mission route. Also in the commander's arsenal are Unmanned Aerial Vehicle (UAV) visuals (e.g., streaming video) that can be used to keep constant watch on the entire unit or provide an advance look at portions of the upcoming route. Even with all the technology available today, a leader uses the most primitive SA tools, such as line of sight (LOS) through the front and side windows and the side view mirror to keep an eye on vehicles in front of or behind him.

The platoon generally knows where it is going (e.g., route from start point to the objective area), as it is briefed by the Platoon Leader during the presentation of his operations order based on initial planning. Formation elements currently communicate with each other through a variety of means such as various radios (Single-Channel Ground-Air Radio System (SINGARS), Enhanced Position Location and Reporting System (EPLRS), etc.), FBCB2, and if all else fails, hand and arms signals (*5*). The radio is the most common form of inter-formation communication, most likely due to quickness and ease of use. FBCB2 is often used for recurring updates such as situation reports (SITREPs) and Spot reports. To keep the radio lines clear, Soldiers often use the quick and easy free text messaging provided through FBCB2. Finally, if technology fails, or if noise discipline and/or radio silence is in effect, Soldiers are trained in hand and arm signals that allow members of the unit to pass information along. In current operations, procedures related to formations are relatively fixed. For example, there are two separate convoy types, the logistics convoy and the combat convoy. A logistics convoy is typically in defense mode since they follow the Blue Force (BlueFOR) in a linear battlefield and the BlueFOR (e.g., the combat convoy) provides fire support for the logistics convoy. In a nonlinear battlefield and one with advanced technologies, the logistics convoy will need to shift its mindset to think about offense as well defense.

2.2 Future Force

In the future, the forms of maneuver, tactical formations, and movement techniques used today will continue but the TTPs for implementing them will change (*7*). The Army will be integrating firepower either as separate vehicles or as part of the logistics supply vehicles. Small combat units will continue to use standard movement formations (e.g., wedge, column) and techniques (traveling, traveling overwatch, and bounding overwatch). Further, the movement techniques or formations at company level and below remain similar but the battlespace they will operate in will expand with technological advances.

Movement techniques and formations will include the use of sensors (unmanned and manned), information superiority, and networked fires. This modification will change and increase the complexity of the Platoon Leader's monitoring task and the tasks of the individual members of the platoon. FCS will also be intermingling unmanned systems with manned systems. The introduction of unmanned systems with autonomous capabilities will pose new challenges for conducting military movements. Unless a standardized electronic command language (such as the Battle Management Language (BML)) is instituted in the operational force structure, the Platoon Leader will not be able to send a verbal communication direction to unmanned systems as he does to vehicle commanders or drivers. Instead this communication will need to be directed to a Robotics Technician, who is responsible for the unmanned system. This combination yields three types of control modalities for vehicles in the group (e.g., platoon): manned vehicle driving, unmanned vehicle driving (teleoperation), and supervisory control of the unmanned system. Manual driving allows for immediate reaction to obstructions; a manned vehicle driver can make on the spot and immediate changes. For teleoperation of an unmanned system, the Robotic Technician may have to deal with issues related to indirect driving, such as latency, the lag between his driving action (increase speed of robot) and the robot's response. The Robotic Technician also has to manage multiple tasks (driving the robots, responding to Platoon Leader communications), which can affect his ability to teleoperate. For supervisory control, the Robotics Technician controls the vehicle through a series of higher order commands (e.g., follow waypoints). Autonomous mobility can pose a threat to the unmanned system and the other units. If an unexpected formation change is required, a manned vehicle can easily make the adjustments necessary for the new formation. The unmanned vehicle would likely have to halt while a new plan is initiated and executed, and by that time circumstances may change again, prompting yet another formation change. This action may also slow or stop the entire unit, which can put the entire group at risk. Given issues related to vehicle control, it may be a challenge to configure and maintain a desired formation especially in complex terrain with a mix of manned and unmanned systems. Interfaces and procedures need to be developed to overcome the potential problems associated with convoy operations and formations.

Even with the plethora of tools and communication devices available, a gap still exists that does not allow the leader to be completely and simultaneously aware of the status of each element in his unit. In the future force, it is anticipated that the Platoon Leader's ability to achieve and maintain SA will be enhanced with advanced formation planning and maintenance tools to include map displays with planned and current routes, status information on each of the vehicles in the formation, and alerts regarding formation vehicle issues. However, it is important to pay special attention to how we organize and present this information to the Platoon Leader so that it increases his SA and does not result in information overload.

3. RC Soldier Machine Interface

3.1 Design Approach

A primary objective of the RC ATO is to create a SMI that is directly relevant to the FCS program. In June 2007, interface design concepts were developed for the RC SMI. The tasks included in the interface concepts were those relevant to the roles of Platoon Leader and Robotics Technician: (1) create and execute a maneuver plan (including formation parameters), (2) monitor an unmanned vehicle's progress, and (3) teleoperate an unmanned vehicle. Figure 2 outlines the process used to define the SMI. FCS Goal Directed Task Analysis documentation and previous TARDEC lessons learned were used to create a task analysis and design concepts. FCS design documentation used to develop the RC SMI included the FCS SMI Standard, Warfighter Machine Interface Services (WMIS), flash files (screenshots), WMIS user interface specifications, and Unified Modeling Language (UML) models. From these documents, TARDEC and DCS identified the key aspects, behaviors, and functionality of the FCS user interface.

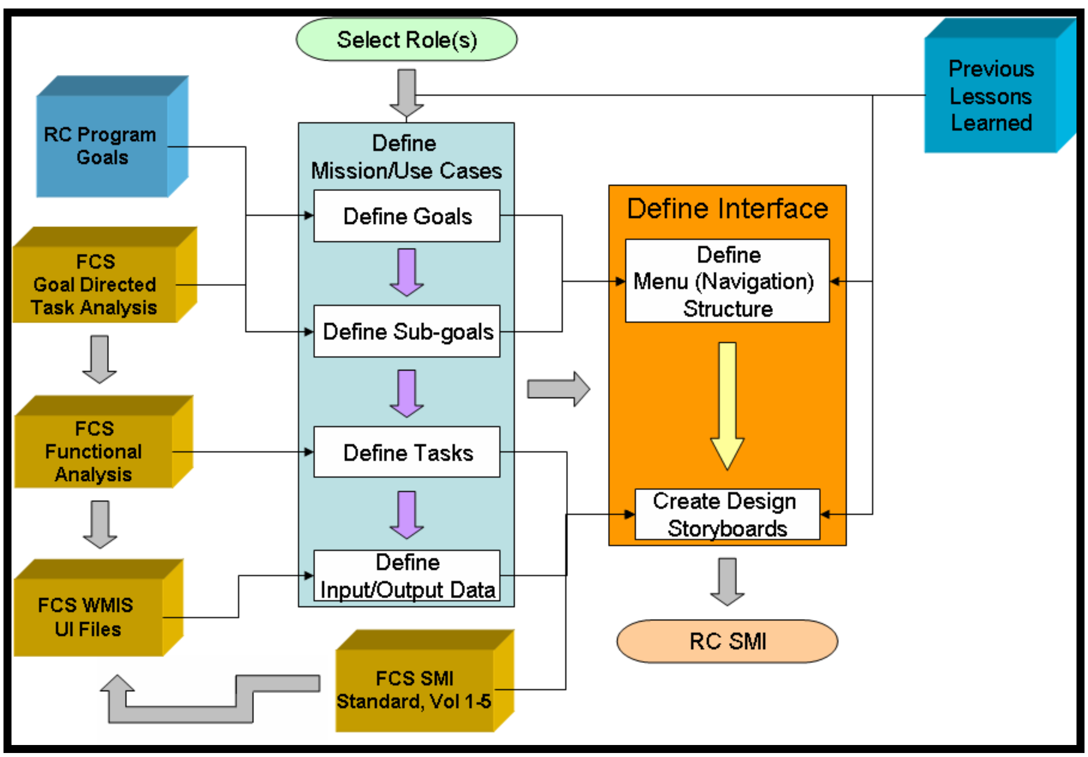

Figure 2. RC SMI design approach.

The RC SMI uses the screen zone concept defined by FCS (figure 3), which includes small portals, large portals, tabs, subtabs, and helper zones (toolbar) (*6*). Wherever possible, the FCS design has been directly emulated. The SMI has been implemented on RC's Mission Module Work Station (MMWS) (figure 4) hardware, which is a surrogate representation of the crewstation concept for the FCS Manned Ground Vehicle (MGV) variant crew compartments (figure 4).

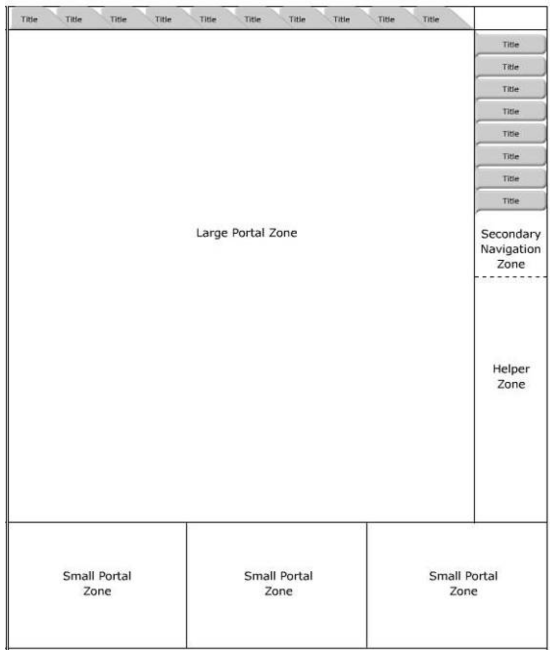

Figure 3. FCS Template: basic portrait display configuration.

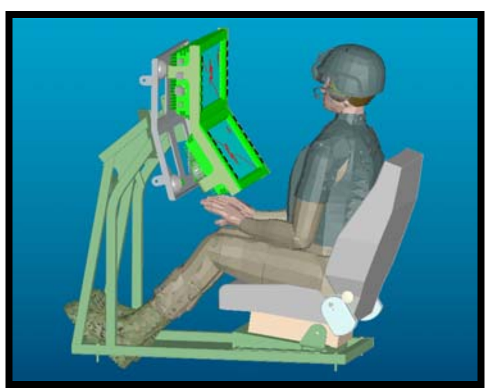

Figure 4. RC MMWS.

3.2 Goals and Assumptions

The FCS WMI is currently being defined, so there are certain topics that have not been addressed yet or are in process or are partially defined. To date, formation-related functionality has not been addressed by the FCS program. To fill this gap, additional functionality has been blended into the FCS design to address the RC program objectives to include the ability to plan, maintain, and monitor a formation. Formation functionality was implemented within the SMI with the RC program goal of developing an aid and/or interface features to reduce the workload of individual users. Key questions addressed in the design process were as follows:

1. How do we present the status of the formation to facilitate monitoring?
2. What information do we present to the user?
3. What information is presented at what time?
    a. What is presented when things are okay versus when things are going wrong?
4. Who gets what information (i.e., roles)?
5. What modalities are used to present information?
    a. What information should be presented in the visual mode versus the auditory mode?

After defining these goals, a task analysis was completed to determine a user's needs (related to formations). We discovered the primary tasks related to formations were configuring, monitoring, and maintaining vehicle positions. The information needed to support these primary tasks is outlined below:

1. To configure or maintain a formation (parameters are set by operator) an operator will need to be able to enter/adjust the following:
    - Formation type
    - Number of march units
    - Vehicle positions
        - Lead vehicle
        - Other positions—2, 3, 4…
        - Change the order of the vehicles
    - Distances
        - Open (vehicles further apart) or Closed (vehicles closer together)
        - Time-distance factors are used to perform calculations for planning movements and are critical to convoy planning
        - Lateral offset (right or left)
        - Aft offset (following)

- Sensor coverage
- March rate (speed)
    - Max speed
- Time constraints
- Start formation
- Pause/stop formation
    - Entire formation
    - Individual vehicles
- Take vehicle(s) out of formation
- Clear parameters—remove all the parameters for the follower vehicles
- Save formation parameters (template)
- Delete formation template
- Alerting thresholds (settings for determining a vehicle is out of formation)
    - Distance related
    - Speed related
    - Sensor coverage related

2. To monitor formation status of an individual vehicle(s) an operator will need to know the following:

- Current formation type
- Current formation status (executed, paused, OK, caution, warning, etc.)
- Distance from leader
- Distance from other vehicles in formation
- Position relative to leader
- Current sensor coverage/sector of observation
- Areas that have been covered by vehicle
- Percent complete (based on leader's plan—time and distance)
- Graphical representation of the original (leader's) plan/route

- Deviation—actual position/coverage area relative to where it should be in formation, including distance, direction, coverage:
  - Where it should be
  - Where it is
  - Deviation distance—how far out of formation (number of meters)
  - Direction of deviation
  - Speed deviation (kph under/over speed)
- Criticality of deviation
- Recommend action(s) to decrease/eliminate deviation
- Speed
- Fuel status
- Ammunition
- Heading
- Obstacles
- Malfunctions
- System confidence
  - For example, instead of modeling the world, there are multiple algorithms that run in parallel (global positioning system (GPS) bread crumbs, road following, etc.). Each algorithm provides a confidence and control output. The confidence levels are weighted and fused to provide an overall system confidence (0 to 1 value).

3. To monitor the formation status of the entire formation(s) an operator will need to know the following:

- Status (distances, timing) of the convoy execution. The following variables use algorithms to derive the status reports:
  - March Unit Road Space: The length of roadway which all the march units in a column or serial occupy, RSpaceMU.
  - Time Gap: The total time of all time gaps between march elements and serials, TGap.
  - Total Road Space: The length of any column or element of a column or the length of roadway which a column occupies, TRSpace.

    - Pass Time: The length of time required by a column or its elements to pass a given point on the route, PTime.

- Current sensor coverage/sectors of observation (combined coverage of whole formation)
- Areas that have been covered by formation
- Percent complete (based on leader's plan—time and distance)
- Graphical representation of the original (leader's) plan/route
- Deviations: Vehicles that are out of formation—actual positions/coverage areas relative to where they should be in formation, including distance, direction, coverage:
    - Where should the vehicle be?
    - What is the vehicles current location?
    - Deviation distance—how far out of formation (number of meters)
    - Direction of deviation
    - Speed deviation (kph under over speed)
- Criticality of deviations
- Recommend action(s) to decrease/eliminate deviation
    - For example, vehicle 2 needs to speed up to X kph (to minimize formation oscillations). At some point, it will then need to slow back down to its previous formation speed.
- Vehicle speeds
- Vehicle headings
- Obstacles
- Malfunctions

3.3 Development and Evaluation

The development of the current RC SMI represents the culmination of prior SMI development and evaluation efforts. The Vetronics Technology Integration (VTI) program developed a multimodal SMI for on-the-move operations. Intelligent vehicle technologies, autonomous mobility provided by waypoint navigation, obstacle avoidance, tactical behaviors, and vehicle/road following were integrated onto a modified Stryker Infantry Carrier Vehicle platform as shown in figures 5 and 6 (*9*).

Figure 5. The Crew Automated Testbed Advanced Technology Demonstration (CAT ATD) (left) and the Robotic Followers Advanced Technology Demonstration (RF ATD) (right).

Figure 6. VTI crewstation.

Formation functionality has been previously implemented on the VTI SMIs in the form of one formation parameter, which was displayed on a high level vehicle information status bar for each vehicle in the formation (figure 7). Each status bar provided the vehicle's distance from the formation leader in text. Formation progress could also be monitored on the map surface, which provided GPS-updated icons, much like FBCB2 (figure 8). A map-based formation screen was also developed for configuring and monitoring a formation (figure 9).

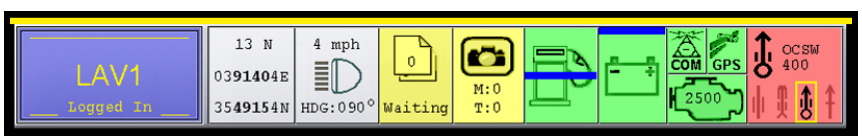

Figure 7. VTI asset status bar (formation information not shown in this image).

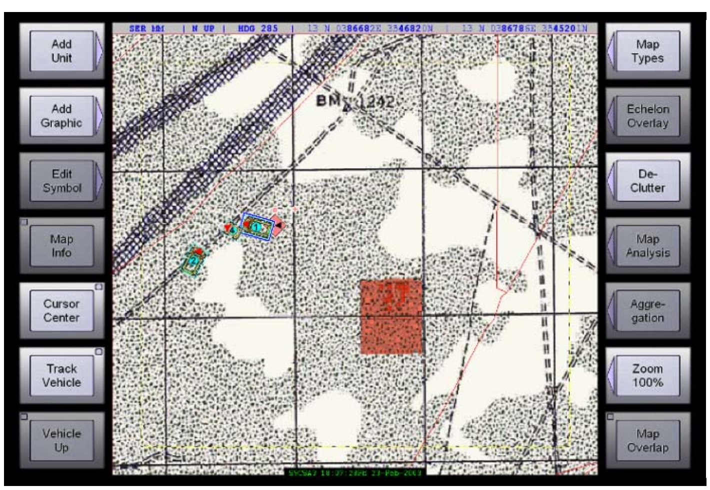

Figure 8. VTI map display.

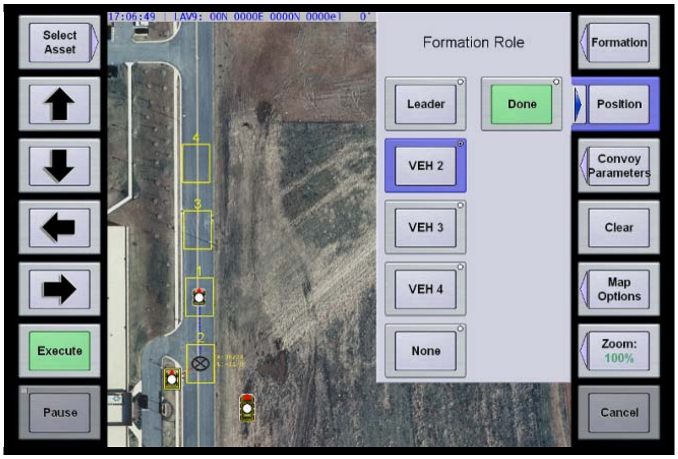

Figure 9. VTI formation screen.

Subsequently, a series of field test formation trials were performed to categorize and quantify the current state of development of the tactical behaviors/formations interface. These combinations of tools were tested at RUX06 field experiment (*8*) and shown to be problematic. The map level detail was insufficient if the operator needed to view the entire mission space. Further, when the vehicle was moving, the status bar information was not comprehendible.

Additional lessons learned were documented and improvements recommended from a series of engineering evaluations (*10–12*). The users preferred one screen that would provide full control of all assets involved in a convoy formation, including monitoring and intervening in the behavior of the assets. The users preferred automation within some of the map interactions. For example, they preferred the center of the map to follow the formation and have the map zoomed based on the spacing of the vehicles. The capability to display the vehicles with their true orientation or have the formation always directed towards the top of the screen would allow the operator to monitor a vehicle's orientation to the world or simplify the monitoring of a vehicle's orientation to the others in the formation. The users preferred access to information on the parameters set for a formation, but also wanted status on the relation of the vehicle positions and orientations to one another using symbology on a map and relevant vehicle parameters such as speeds, heading, and communications status. Additionally, users were not interested in determining how far out of formation a vehicle was, but only that it was out of formation. The users requested an indicator on the formation screen to highlight the vehicle in trouble. The users also wanted the capability to assign a formation type to portions of a route or an entire route (i.e., designate within a plan, select a waypoint, and tell asset "this formation type here"). They also wanted the ability to change formation parameters on the fly. These recommendations were addressed in the current RC SMI design discussed in the next section.

3.4 Design Features

Based on the engineering evaluations and lessons learned to date, multiple formation features were integrated into the RC SMI. The goal of these formations features is to reduce operator workload, while providing an indication of formation status that can be used to maintain a formation and easily communicate formation status to others. Multiple features have been implemented with the goal of prioritizing which features are most successful. When SMI presentation space is limited, it is important to determine the most critical information to display. The RC ATO used the menu structure shown in figure 10, which is a derivation of the current FCS menu structure, modified to support specific technology development activities.

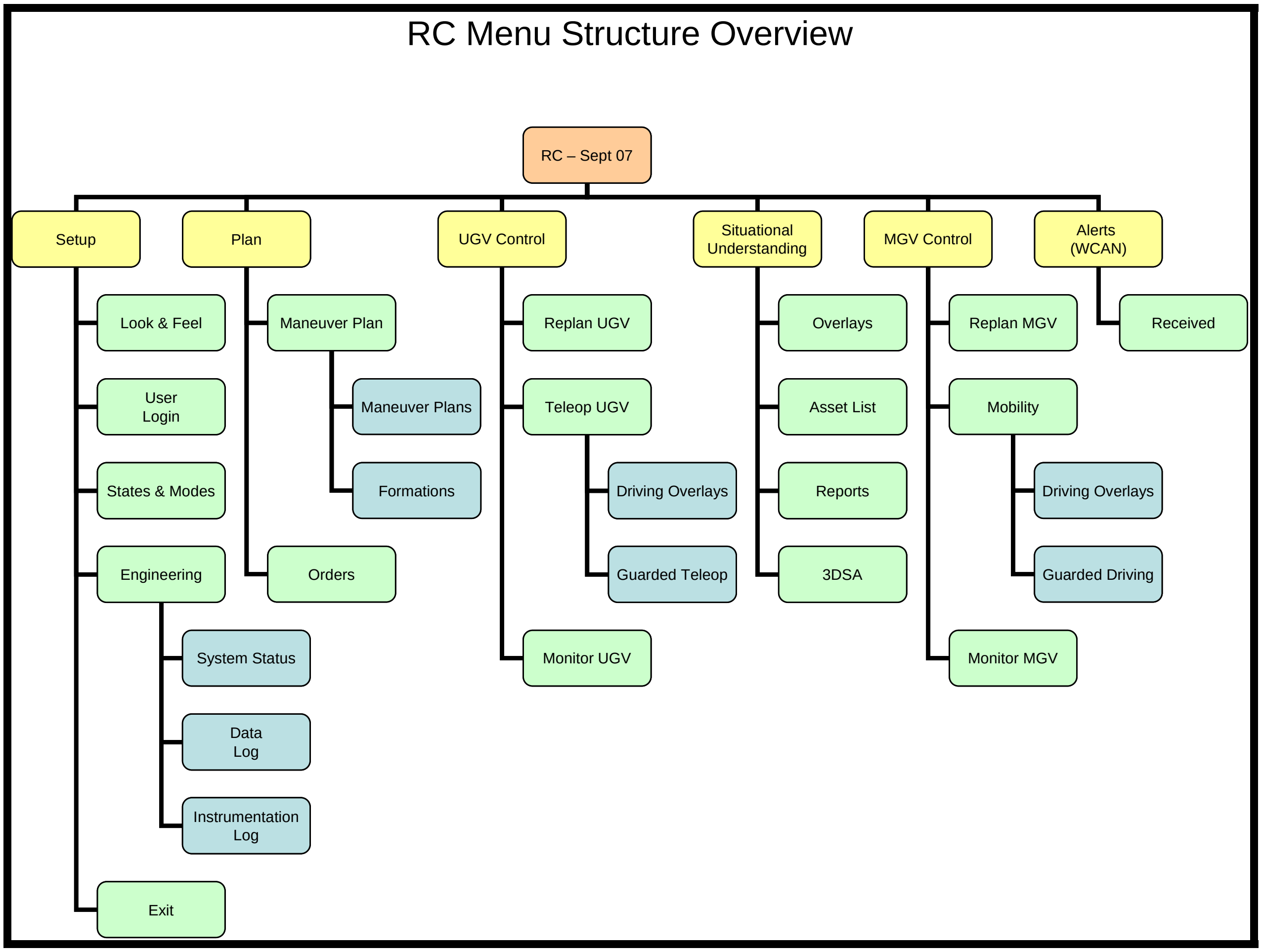

Figure 10. RC menu (navigation) structure.

3.5   Formations Large Portal

Based on features identified in the task analysis and previous lessons learned, a large portal screen dedicated to formations was created within the FCS navigation structure (figure 11). The decision to dedicate a screen was primarily based on the amount of information and control options that could be presented to a user in a test environment. When attempting to combine these features into other existing COP-like FCS screens, it was difficult to accommodate all the desired features, while leaving the original functionality of that FCS screen intact. The flexible navigation structure of the FCS SMI allows certain tabs and associated subtabs to be provided to a user based on their role.

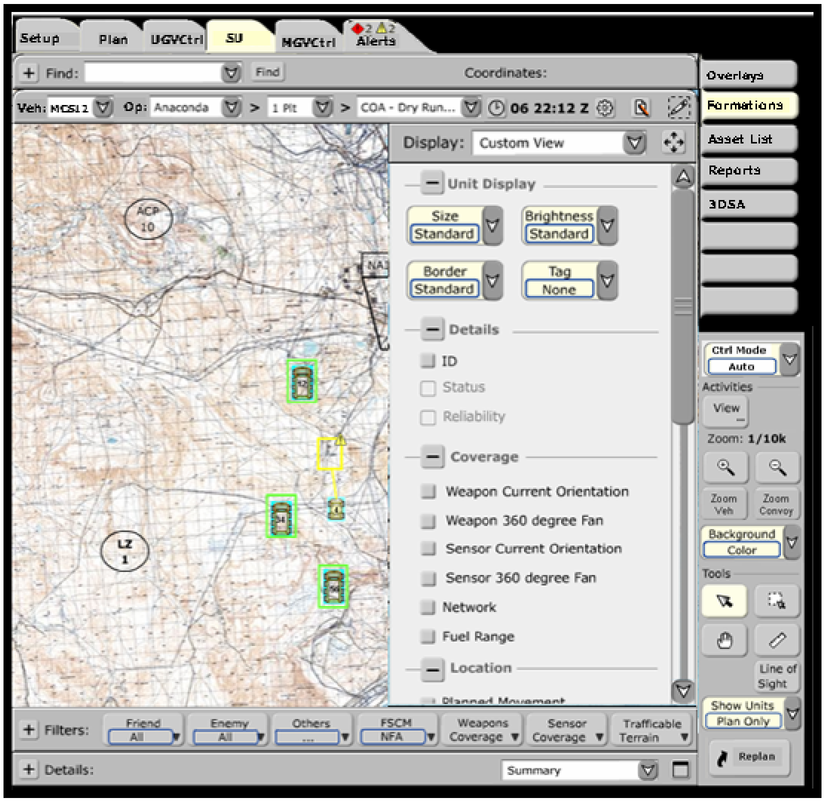

Figure 11. Situation understanding (SU)-formations large portal.

The formations large portal screen provides unique map control options in the toolbar and the View menu. Features that are expected to be mission critical or frequently used have been placed in the toolbar. Other features that may be one-time setup or less frequently accessed have been provided in the View menu:

- **Track Vehicle:** to keep the map centered on a selected vehicle.
- **Zoom Vehicle:** to auto zoom map to a TBD level, centered on an asset.
- **Zoom Convoy:** to auto zoom map to a TBD level, centered on the middle of the convoy.
- **Track Up:** to orient map with the selected vehicle/convoy facing up. When not selected, north is up (Track Vehicle or Track Convoy must be selected for this to be available).
- **Track Convoy:** to keep the map centered on the center of the convoy.
- **Change map type, background:** to declutter the screen.

3.6 Formation Parameters

Multiple formation parameters are used to define a formation. These parameters then become essential in determining whether vehicles are in formation. Current applications do not directly associate formation parameters with a formation status. Doing so may decrease the amount of workload associated with monitoring the formation as well as increase the passing of critical information along in order to maintain the formation.

FCS provides a Details part containing detailed information related to a task within the large portal zone (figure 12). The RC SMI uses this concept to display formation parameters.

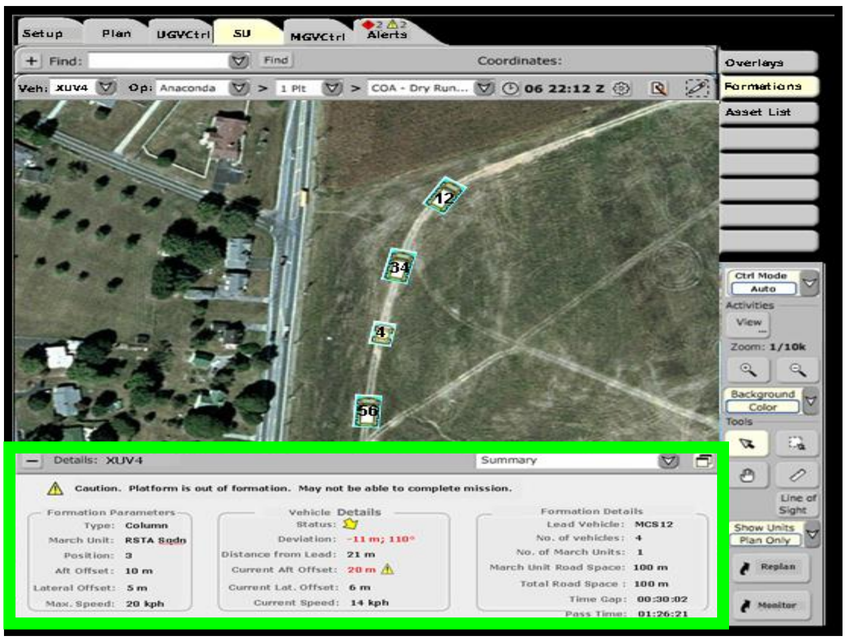

Figure 12. Details part.

Much of the feedback from previous efforts indicated a desire to view status information on an entire formation in one view as well as to be able to view information at the vehicle level. Both of these concepts have been incorporated into the FCS Details structure. A user can select any vehicle within a formation to review the details associated with that vehicle (figure 13).

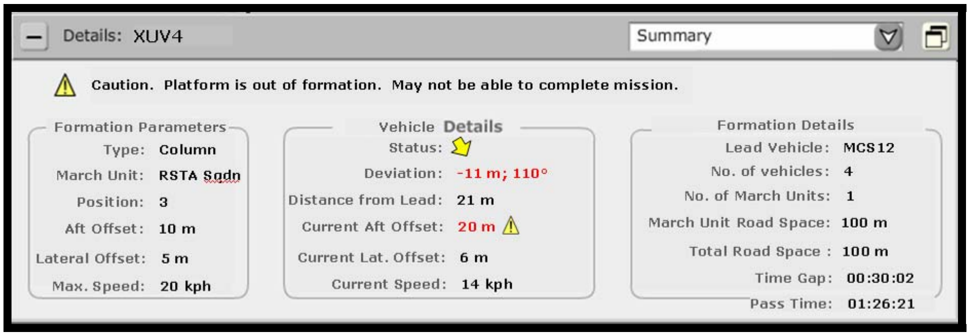

Figure 13. Individual vehicle parameter details.

A user may also select the lead vehicle to review parameters at the vehicle level as well as an FCS table containing critical parameters for all vehicles within a formation (figure 14). Customization of the table columns allows the user to tailor the information to their needs/role. The formation Details part also allows users to update formation parameters on the fly, increasing the ability to maintain a formation when mission changes arise (figure 15).

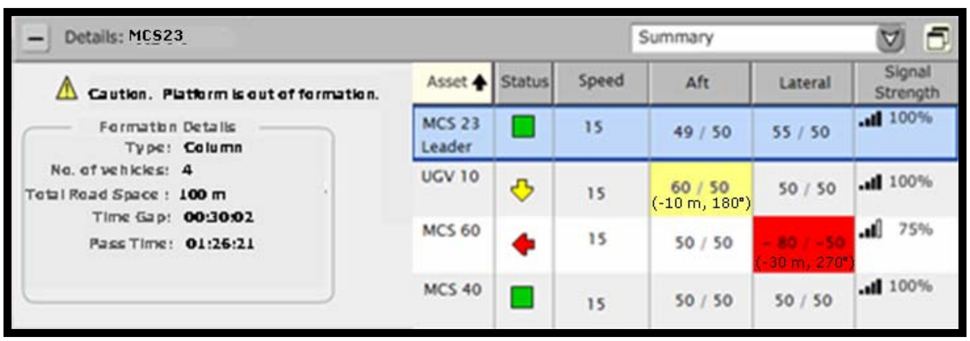

Figure 14. Formation parameter details.

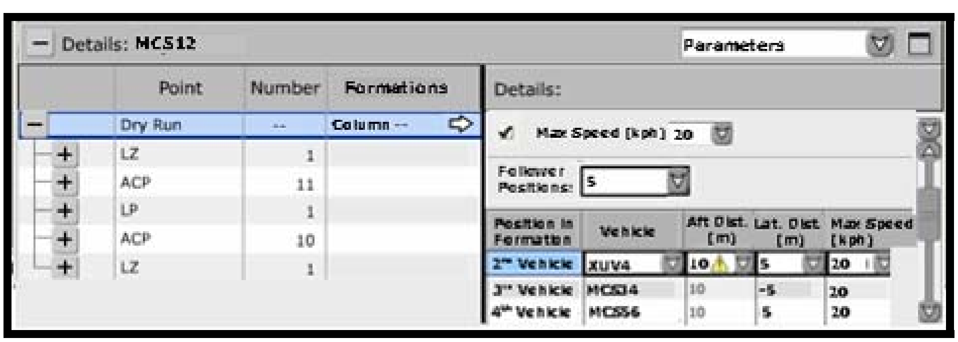

Figure 15. Formation parameters update.

3.7 Map Overlays

A series of map overlays are intended to allow a user to more quickly assess formation status. One set of overlays is intended to be "on" at all times, providing an unobtrusive indication of how the formation vehicles are doing. Another set of overlays may clutter the map very quickly, but could be used to get more specific information on a vehicle in order to communicate the status of that vehicle. The following map overlays are intended to be useful for general monitoring of formation progress. They include the Leader Plan overlay, Plan History overlay, Planned Location Box overlay, Planned and Current Distance overlay, and Alert Notifications. The expectation is that the overlays would be turned on for the entire duration of a mission. In order to make the overlays more visible and readable against varying map backgrounds, a white shadow style is used behind lines and text (not represented in all figures below). Color is also used throughout most of the overlays to distinguish them from one another and as a secondary indicator of vehicle formation status (alerting). The **Leader Plan** shows the path the lead vehicle will take, whether in autonomous mode or not (figure 16, left). The waypoint icons may be toggled on/off independently from the plan line for additional decluttering purposes. The **Plan History** overlay (gray portion of route) shows the path the lead vehicle has completed (figure 16, right).

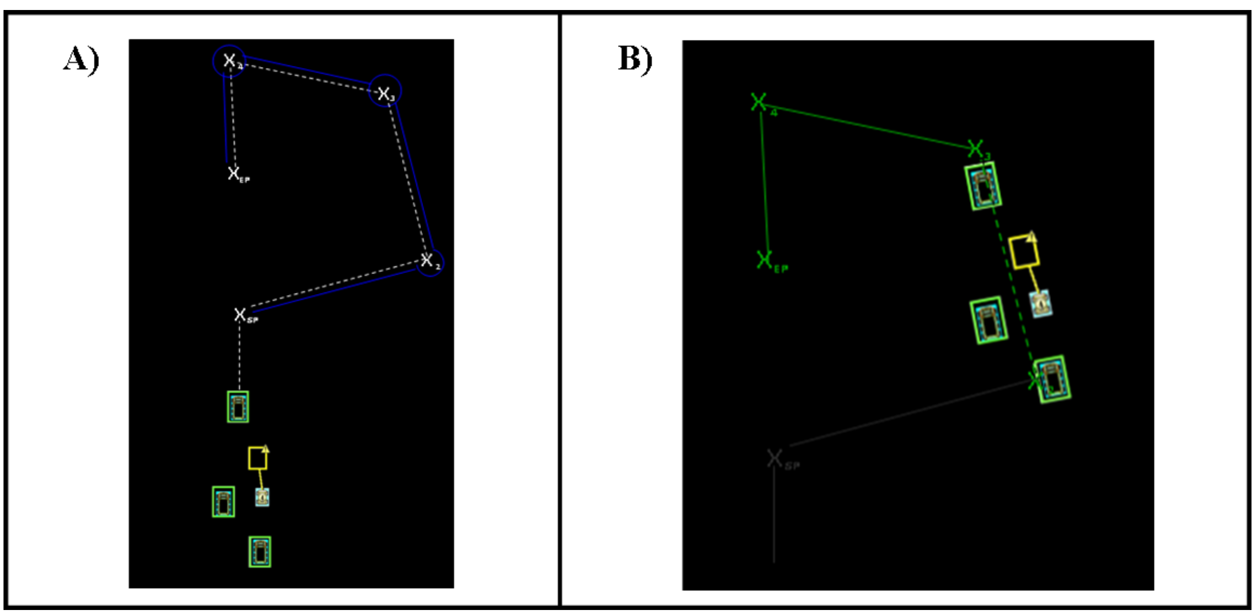

Figure 16. (a) Leader Plan overlay and (b) the Plan History overlay (gray portion of plan).

The **Planned Location Box** (yellow and blue in image) is associated with each following vehicle in the formation. The overlay shows where each vehicle should be according to the leader's plan and the formation parameters set by the user (figure 18). Box color is used to indicate the formation status of each vehicle. The colors are based on FCS SMI guidelines.

- Blue—within thresholds. Blue seems most visible on multiple map background types.

- Yellow—caution, out of thresholds
- Red—warning, way out of thresholds

The **Deviation Line** (shown with vehicle 4 in figure 16) is present when a vehicle crosses the threshold and is "deviating" from the formation parameters. The Deviation Line extends from the Planned Location Box to the vehicle icon (figure 17). It is intended to show the path the vehicle needs to take to get back into formation. The same color assignment is used to denote formation status. The Deviation Line overlay also provides the distance, i.e., number of meters the vehicle is out of formation (not shown in figure 17).

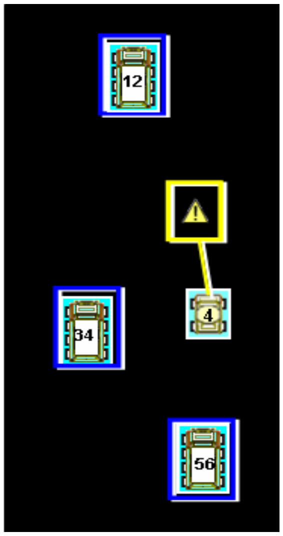

Figure 17. Planned Location Box and Deviation Line overlays.

The Planned Distance from Lead Line and Current/Actual Distance from Lead Line overlays are intended to be used for troubleshooting formation deviations. It may be useful to allow a user to toggle them on/off for the entire formation or just for a selected vehicle. The **Planned Distance from Lead Line** extends from the back of lead vehicle to front of the Planned Location Box (figure 18, left). Blue indicates that it is a planned distance (to distinguish it from the Current/Actual Distance overlay). Text can also be turned on to display the planned distance from the lead vehicle. The **Current/Actual Distance from Lead Line** extends from the back of the lead vehicle to the front of the vehicle icon (figure 18, right). Green indicates that it is a current/actual distance (to distinguish it from Planned Distance overlay). Yellow and red are used to indicate a caution and warning threshold has been exceeded. Text can be turned on to display the current distance from the lead vehicle.

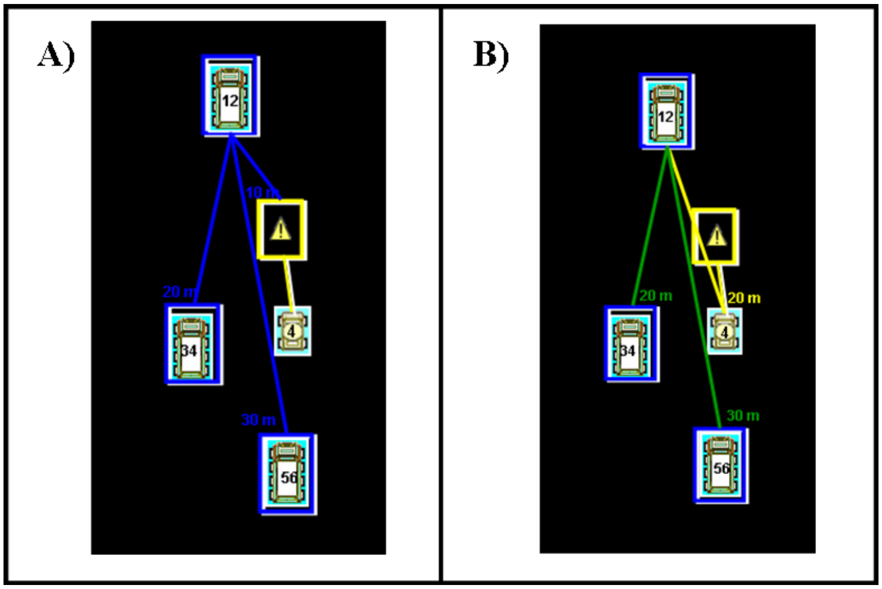

Figure 18. (a) Planned Distance from Lead Line and (b) the Current/Actual Distance from Lead overlays.

The Planned and Current Aft Distance and Planned and Current Lateral Distance overlays are also thought to be useful for troubleshooting formation deviations at an individual or entire formation level. The overlays allow the user to overlay information specific to individual formation parameters (e.g., aft and lateral distances), whereas previous overlays provide a straight line distance between vehicles. The Aft Distance from Lead overlays provides information related only to the aft distance parameter entered by the user (figure 19, left). The **Planned Aft Distance Line** extends from the back of the lead vehicle to the front of Planned Location Box, perpendicular to the asset. This overlay is always blue to distinguish it from the Current Aft Distance. The **Current Aft Distance Line** extends from the back of the lead vehicle to the front of vehicle icon, perpendicular to the asset. This overlay also provides threshold information by changing colors. Green indicates that it is a current distance within the threshold value (to distinguish it from Planned Distance overlay). Yellow and red are used to indicate a caution and warning threshold has been exceeded. The Lateral Distance from Lead overlays provide information related only to the lateral distance parameter entered by the user (figure 19, right). The **Planned Lateral Distance Line** provides a visual indication of the lateral distance from the lead vehicle in terms of the Planned Location Box. This overlay is always blue. The **Current Planned Distance Line** provides a visual indication of the lateral distance from the lead vehicle in terms of the actual vehicle icon. This overlay also provides threshold information by changing colors. Green indicates that it is a current distance within the threshold value (to distinguish it from the Planned Distance overlay). Yellow and red are used to indicate a caution and warning threshold has been exceeded.

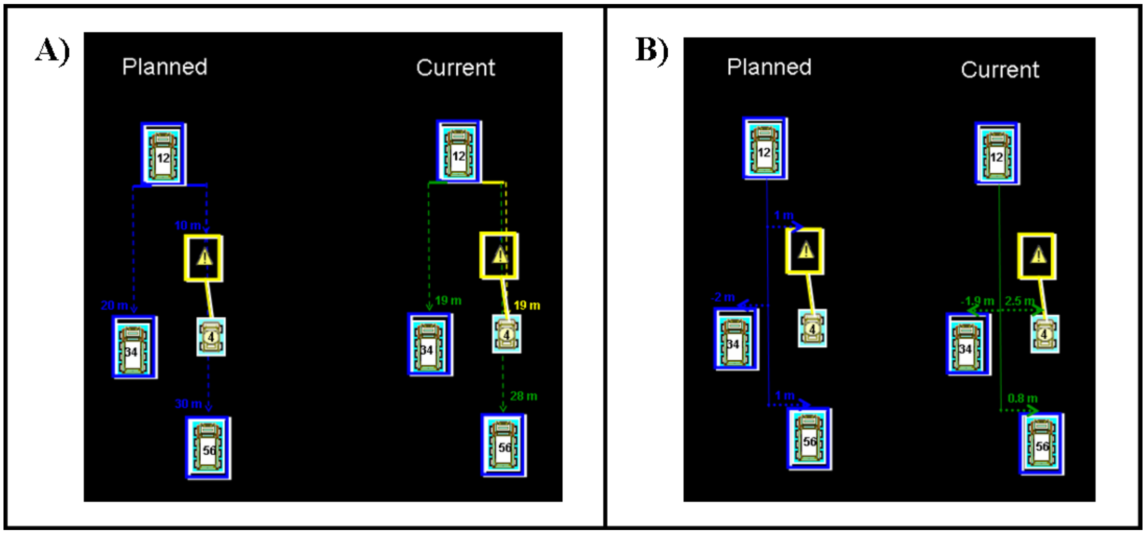

Figure 19. (a) Planned and Current Aft Distance overlays and (b) the Planned and Current Lateral Distance overlays.

3.8 Alerts

The RC SMI uses a Warning, Caution, Advisory, and Notification (WCAN) system (*6*) developed for FCS to provide alert notification in multiple zones within the SMI so that a user will be aware of a WCAN without having to refocus from the task they are completing when the alert comes in. Figure 20 illustrates the zones within the SMI where one individual alert will be indicated (Map Surface, Details Part, Alert Portals, and Alert Counter on Tab).

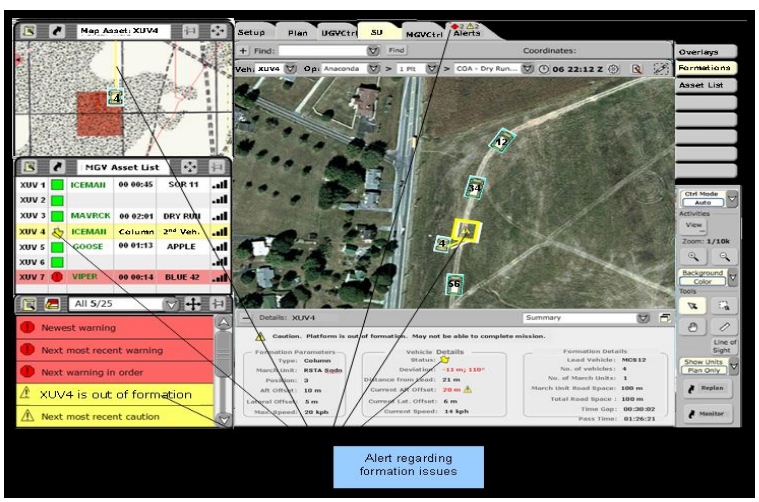

Figure 20. Alert notification.

The RC design reflects the FCS alert structure in its entirety. There were, however, no alerts defined specific to monitoring coordinated movement. This section documents the concepts defined to alert a user to issues within a formation. FCS features a set of general status indicators that use shape and color to indicate generic, alert, equipment, and network status (example in figure 21). The basic generic indicators were modified to create a set of formation status indicators.

Generic Status Indicators			
Warning	**Used to supplement the warning color ("Red")**	**Octagon w/ *Warning color* background**	
Caution	**Used to supplement the caution color ("Amber")**	**Triangle with *Caution color* background**	
OnSchedule	**Schedule viewer – on schedule past milestone; also, supplements the OK color ("Green")**	**Square with *OK Color* background**	
OnScheduleFuture	**Schedule viewer – on schedule projected milestone**	**Square with transparent background**	

Figure 21. FCS generic status indicators.

An arrow shape is used in place of the stop sign and triangle to provide general formation status to the user (figure 22). Figure 22 indicates that XUV4 is 11 m southeast of where it should be (10 m back and 1 m east). This information is highlighted in red and the triangle caution symbol indicates that the aft distance is the critical reason for the deviation.

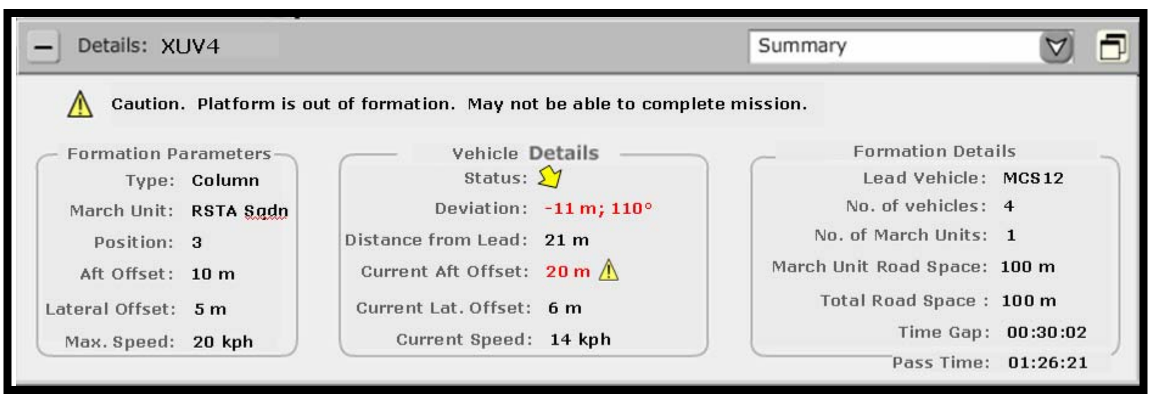

Figure 22. Formation alerting example.

At low map zoom levels, this arrow also becomes the map icon for the entire formation (figure 23). The arrow status indicator/icon is used in the parameter details area of the formations large portal as well as an available asset list small portal (figure 23) that provides basic status information on all vehicles involved in a user's mission. The arrow provides formation alert status as well as directional information on where the asset is in relation to where is should be (see example in figure 23). Parameters related to a formation deviation are also highlighted using color and the FCS alert status indicators so the user can quickly identify and communicate what the vehicle is doing to cause it to fall out of formation.

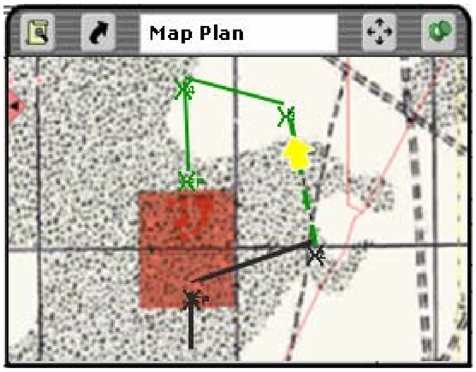

Figure 23. Formation map icon (yellow arrow).

The goal of every formation alert is to not only notify the user of a problem, but also provide as much information on the deviation, so the user can effectively communicate the issue and correction without drastically increasing their workload. It should also be noted that the RC SMI software provides flexibility in setting parameter thresholds (e.g., distances that trigger an alert). This flexibility improves the ability to analyze alerting procedures.

3.9 Vehicle Sensors

Given the nature of FCS closed hatch operations, vehicle sensors available to the user may replace rear-view mirrors and head-out-of-hatch monitoring. If bandwidth allows, it may be beneficial to extend this concept to provide the Platoon Leader with access to sensors on multiple vehicles within the formation. A concept that requires further exploration includes alerts, status information, or other aids as overlays on sensor video imagery. For purposes of this effort, the Platoon Leader has access to sensor feeds on vehicles within his formation. These sensor feeds are accessible from the RC Unmanned Ground Vehicle (UGV) Control – Teleop large portal (figure 24).

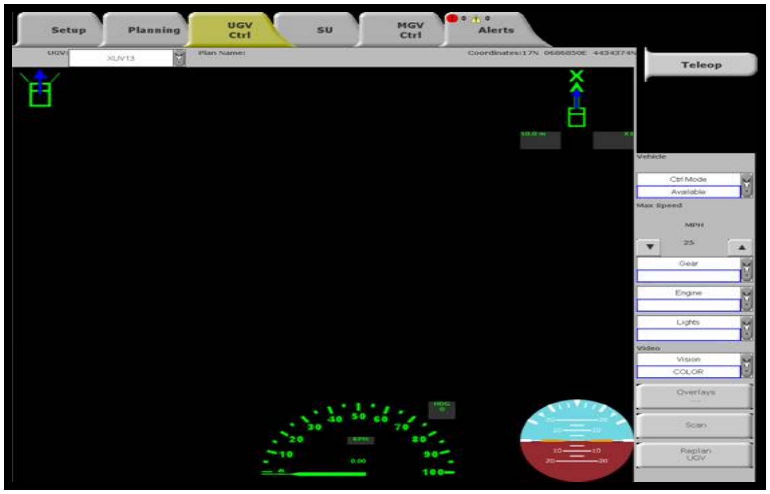

Figure 24. UGV Control – Teleop large portal.

The end results of these interface features is a functional SMI that implements FCS concepts. The features described in the preceding sections were developed to support the tasks of monitoring and maintaining coordinated movement of platoon size units. The next step in the design cycle is evaluation of the interface concepts.

4. Modeling and Simulation Environment

4.1 General Description

A series of experiments are being conducted to evaluate the benefits afforded by the FCS-like formation features in the RC SMI on Soldier performance. To this end, the RC SMI is being compared to current force technology. Additionally, different user roles and responsibilities associated with maintaining coordinated movement are being tested. The results of the experiments are not presented in this report; however, our approach for this experimentation and follow-on interface design and evaluation efforts are described in detail.

Human-in-the-loop simulation is being used in the development and refinement of the RC SMI. The environment allows for repeated testing with high face validity and analytical rigor. Through the use of this environment, we can conduct high fidelity simulation experiments and provide design recommendations quickly and more cost effectively than through field testing. This approach is not intended to supplant field testing but to complement and potentially enhance the results of field testing. Human-in-the-loop simulation can be used as an initial step to test out concepts in interface design, manning, techniques, and procedures.

The environment used to administer these experiments consists of several modeling and simulation subsystems operating within a service-based architecture and communicating within a private simulation sub-network (figure 25). The distributed processing components share a common network hub class that facilitates data exchange. The system components are described in detail in the following sections.

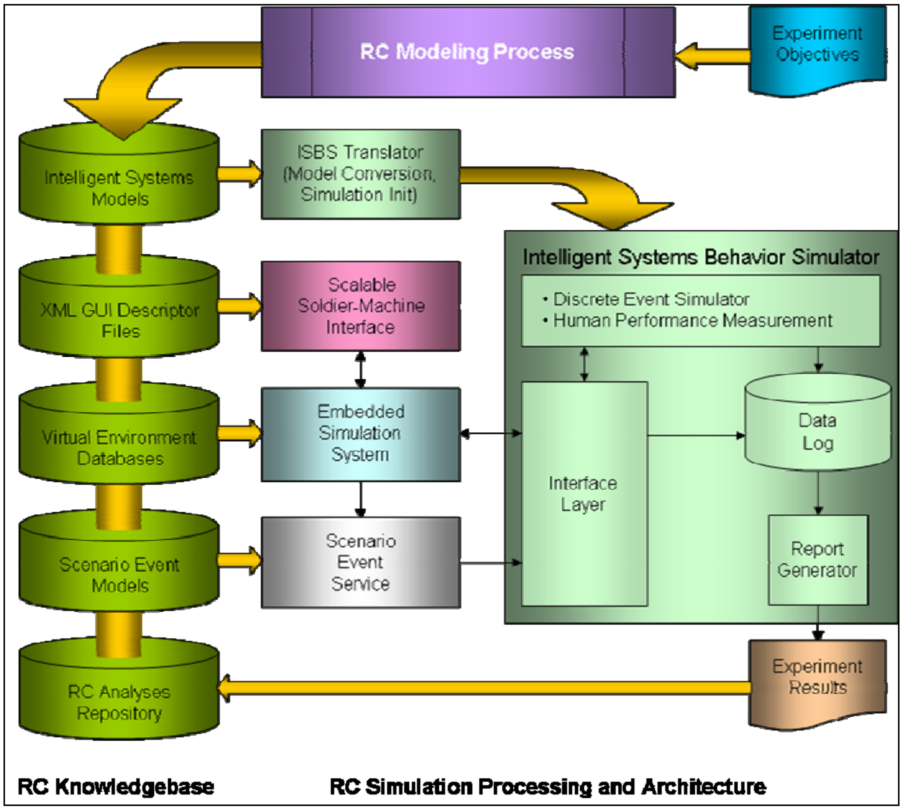

Figure 25. Simulation environment software components.

4.1.1 Intelligent Systems Behavior Simulator

The Intelligent Systems Behavior Simulator (ISBS) is a modeling and simulation environment that facilitates the development and execution of models representing intelligent agents. The ISBS provides the ability to define behaviors, allocate behaviors to human or computer (software agent) deployments, and analyze deployment effectiveness within specified scenarios in accordance with a set of metrics.

For example, for the formations experiments, the ISBS models an Autonomous Mobility (AM) as the mode of vehicle navigation. The AM model is used for the mobility of all vehicles without alteration based on vehicle type. The AM system model controls the progression of each vehicle along the assigned route. The ISBS uses a laser radar (LADAR) sensor model to build a cost map based on the terrain features of the virtual environment. The AM model uses the cost map to determine the best options for maneuvering the vehicle along the route (e.g., avoiding obstacles, capturing waypoints, etc.).

The AM planning process is performed in a control loop that balances considerations of the current vehicle state (from the Embedded Simulation System (ESS)), the emerging cost map, and the a priori route, which is a series of waypoints spaced at approximately 10 m intervals.

The planning result, a temporary steer-to point, is used to determine adjustments to the vehicle actuator data (steering and speed control). The actuator data is then sent to the ESS at the end of each processing cycle to update the vehicle state.

4.1.2 Embedded Simulation System

The ESS represents the virtual operational environment for the experiment, including a virtual platform (vehicle) representation and instantiation of the One Semi Automated Force (ONESAF) Test Bed (OTB) objects, which represent environmental entities and scenario event triggers. It provides stimulus to the modeled intelligent agents over a wide range of channels from communication traffic to a simulation of visual information (e.g., LOS testing).

The ESS also provides the vehicle dynamics modeling for this experiment. All four vehicles in convoy are created by the ESS as separate instances of a ground platform with its own dynamics model. Each vehicle object receives the vehicle actuator data, which includes steering, throttle, and brake levels as input, and produces corresponding vehicle position and attitude data based on the vehicle dynamics model calculations.

4.2 Specialized Simulation Components for SMI Evaluation

A key concept in conducting an experiment is to provide a controlled environment in which all events can be scripted. For the SMI evaluation and roles experiments, a Formation Manager model was developed to control vehicle position within the formation during the road march until commands from the event server were received to cause formation deviations. A Formation Management model is implemented to ensure that the vehicles maintain a valid formation until they encounter scripted events that force user intervention. While this attempt to provide a strictly deterministic measurement of formation deviation handling by the participants is highly effective, it is not one hundred percent foolproof, i.e., there can be occasionally unscripted formation deviations, a situation which needs to be accounted for in the final data analysis.

A column formation has been modeled for the first SMI experiment. Specific values for lateral and aft separation determine whether a following vehicle was considered to be “out of formation” (or deviating) with respect to the lead vehicle. The convoy was established using a leader-follower technique in which the lead vehicle left “bread crumbs” (or intermediate waypoints) at timed intervals for each of the remaining vehicles to follow. Thus, all followers are independently tied to the leader using this method. Figure 26 illustrates the concept of the bread crumbs and the distance measuring method.

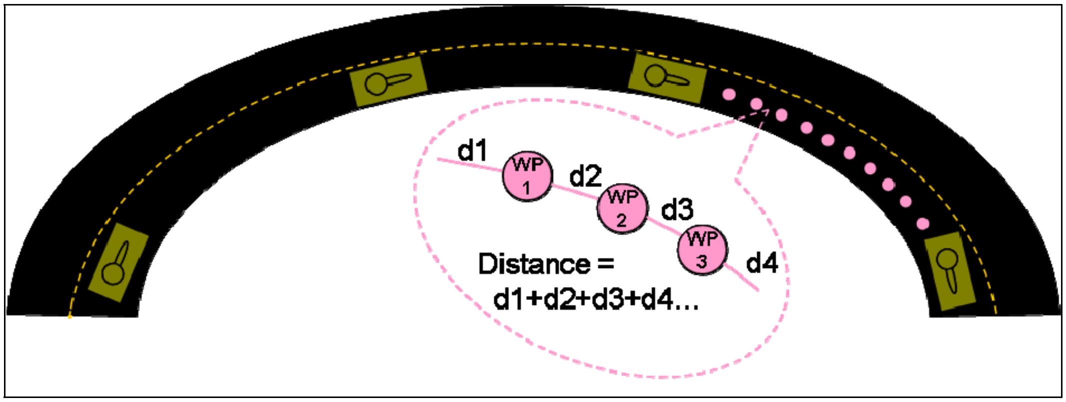

Figure 26. Vehicle following technique.

A formation deviation is the circumstance in which one of the following vehicles moves outside of the area specified as its position. If a following vehicle moves too far to the left or right, or too far forward or backward with respect to the follower, it is considered to be out of formation. The purpose of the Formation Manager model is to monitor vehicle position and adjust the speed as necessary to keep the vehicle in formation with respect to aft separation. The leader-follower technique inherently keeps vehicles within the lateral separation boundaries. In order to introduce the scripted deviations, which challenge the participant to recognize and react to the problem, the Event Server sends commands, based on the position of the lead vehicle, to the ISBS for the various types of misbehaviors. The Formation Manager is designed such that the misbehavior messages from the Event Server affect only the intended vehicle.

4.2.1 Scenario Event Service

The Scenario Event Service is a system component that monitors the position of the virtual vehicles via the simulation network and interjects commands designed to trigger vehicle "misbehaviors." All scenario events are scripted as "event zones" using pre-determined geographic coordinates in the OTB. As the lead vehicle in the convoy enters the event zones, the Scenario Event Service issues an appropriate event command to the ISBS, which in turn overrides the Autonomous Navigation System (ANS) for the designated vehicle. Established event types for these experiments are shown in table 1.

Table 1. Scenario event list.

Number	Enumeration	Description
1	POSCOMM	Positive communication (call sign)
2	NEGCOMM	Negative communication (call sign)
3	XYOFFSET	Position misbehavior (heading offset)
4	SPEEDABS	Absolute speed value
5	SPEEDDELTA	Speed misbehavior (speed offset)
6	CONVOYSpeedDelta	Speed offset for the entire convoy
7	CancelMisbehavior	Cancel current event for specified vehicle
8	Stop	Stop

4.2.2 Data Analysis and Reporting Tool (DART)

The ISBS and SMI log scenario event data, vehicle data, and participant user-interface actions during data collection. DART (figure 27) is a MATLAB application that is used post-mission to collate data from simulated vehicle log files and the crew station log file. Additionally, an audio recording of the mission is transcribed for each test run. The data reduction process is complete upon analyzing the event data and calculating the experiment measures from the raw data.

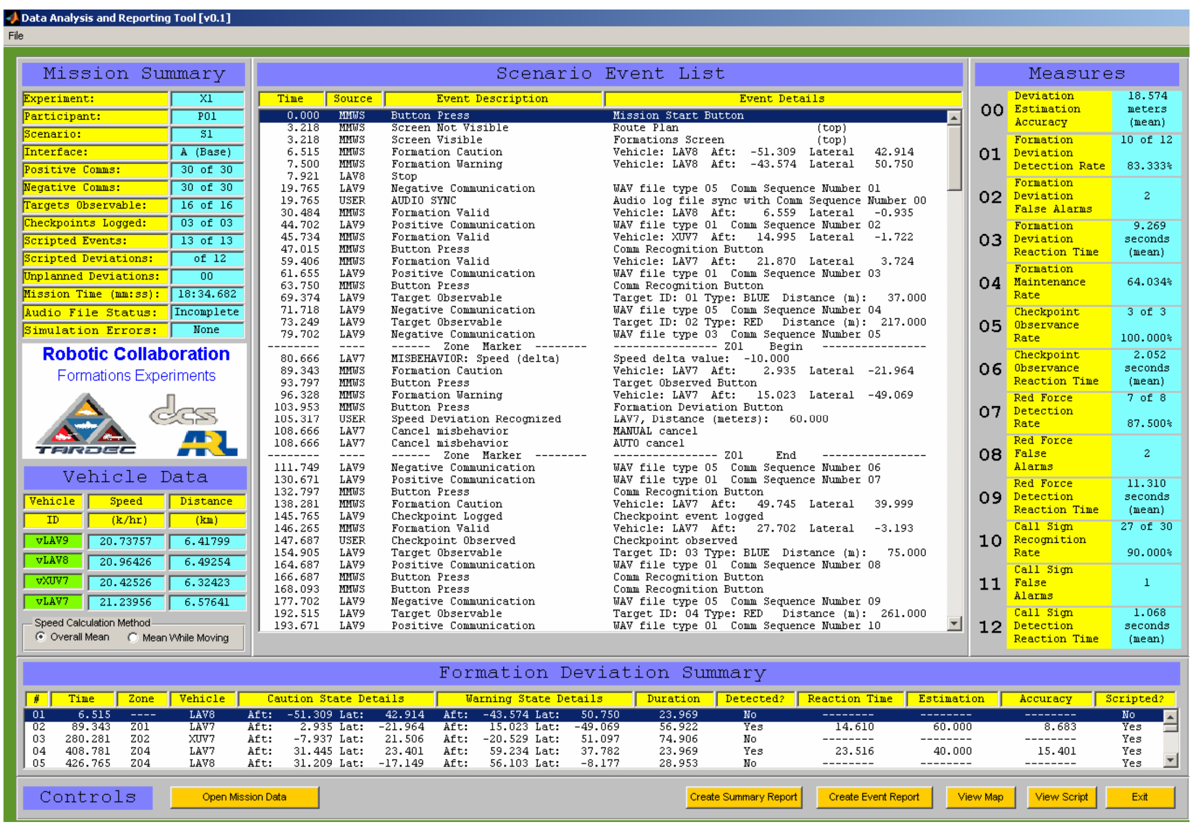

Figure 27. DART.

DART provides an interactive analysis capability, allowing the experimenters to review data for errors and anomalies by checking the complete list of merged events that were logged during a mission. The report writing function is useful for exporting the experiment measures for use in a statistics package.

4.3 Hardware Components

The simulation environment consists of several distributed systems connected via the simulation network. Table 2 lists the platforms used to host each of the system components and figure 28 illustrates the hardware interface.

Table 2. Hardware inventory.

Component	Item	Quantity
ESS	Mobility model—Shuttle XPC Barebone SD39P2 with Intel Core2 Duo E6700 2.66GHz processor, 19 in. flat panel display	1
ESS	Display channel—Shuttle XPC with Intel Pentium 4, 3.2 GHz processor, 19 in. flat panel display	1
Event Server	Shuttle XPC Barebone SD39P2 with Intel Core2 Duo E6700 2.66GHz processor, 19 in. flat panel display	1
ISBS	Dell Inspiron 9400, Intel Core 2 Duo processor T7200 (4MB/2.00GHz/667MHz) with 17 in. display	4
Misc.	Speakers (pair)	1
Misc.	USB microphone	1
Misc.	Ethernet hubs	2
MMWS (SSMI)	Computer 1, Intel Core 2 Duo 2.16 GHz, 1.0 GB RAM, GDLS Custom Video Card	1
MMWS (SSMI)	Computer 2, Intel Core 2 Duo 2.16 GHz, 2.0 GB RAM, GDLS Custom Video Card	1
OTB	Dell Inspiron 8600, 15 in. 1920x1200, 2 GHz Intel Pentium M, 1 GB RAM	1

Note: GDLS = General Dynamics Land Systems, SSMI = Scalable Soldier Machine Interface, and USB = universal serial bus.

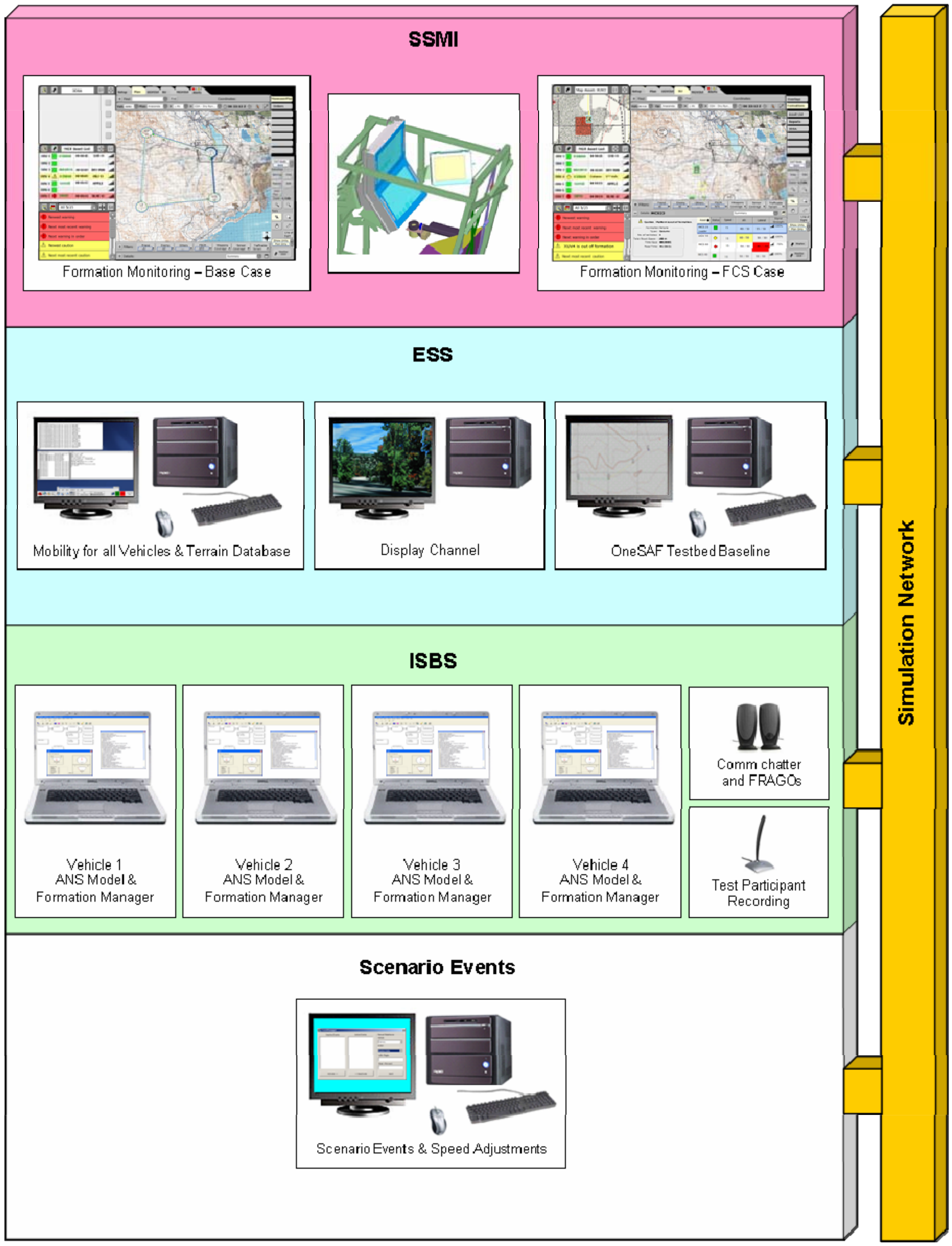

Figure 28. Hardware configuration diagram.

A clock synchronization command is issued as part of the setup and configuration procedures that are performed prior to the beginning of each test run. This procedure is intended to establish a common source for time, since mission log files were being generated on six different systems, each with its own clock.

4.4 System Deployment

The simulation environment features a service-based architecture, implemented in an object-oriented design. Figure 29 illustrates the processing deployment, indicating the specific functionality for each system component and the associated system interfaces.

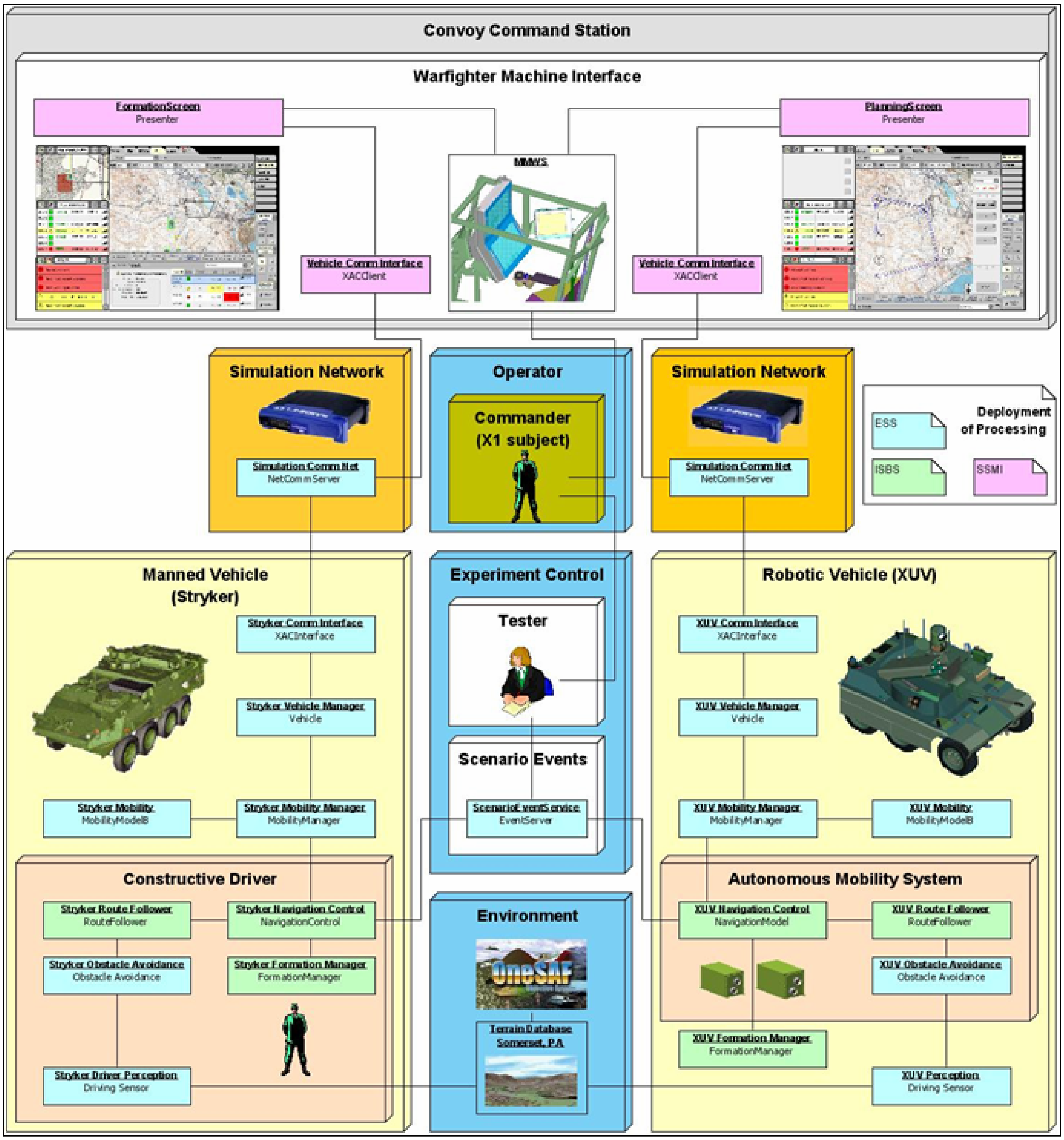

Figure 29. Object deployment diagram.

5. Conclusions

FCS is the U.S. Army's program at the heart of the Army's transformation efforts. It is to be the Army's major research, development, and acquisition program consisting of 14 manned and unmanned systems tied together by an extensive communications and information network. A primary objective of the RC ATO has been to create a SMI that is directly relevant to the FCS program and this effort focused on functionality specifically associated with military maneuvers and formations for the future force.

This report discusses the challenges associated with military formations for the future force. In general, the forms of maneuver, tactical formations, and movement techniques will remain the same, but the TTPs for implementing them will change (*7*). In the future, the Army will be integrating firepower either as separate vehicles or as part of the logistics supply vehicles. Small combat units will continue to use standard movement formations (e.g., wedge, column) and techniques (traveling, traveling overwatch, and bounding overwatch). Further, these formations and movements will occur in a larger battlespace and will include advanced technologies such as sensors (unmanned and manned), information superiority, and networked fires. This modification will increase the complexity of Soldier tasks and will pose new challenges for conducting military movements. We discussed the generic information needs to support future formations. These information needs are applicable to the current and future force, including operation with manned and unmanned systems.

We provided example designs (i.e., RC SMI) that support these information needs and that fit within FCS design parameters. More specifically, RC SMI facilitates some of the key mission applications including mission planning and preparation, situational understanding, battle command and mission execution, and warfighter-machine interface. Wherever possible, the FCS design has been directly emulated and additional functionality not currently addressed by FCS was added. The RC SMI uses the screen zone concept defined by FCS, which includes small portals, large portals, tabs, subtabs, and helper zones (toolbar). The RC SMI incorporates enhanced design elements, such as automated map overlays and alerts, to aid the future Soldier in conducting missions (e.g., convoy monitoring, robot monitoring and control, maintaining SA of the area of operations). An assessment of these design parameters is not included in this report.

To enable future assessments of these design parameters, a simulation environment was developed and a detailed description of this capability is included in this report. The simulation provided a realistic representation of the vehicle behaviors across a variety of terrains and featured distributed processing of the vehicle models, user interface, and scenario event services. Conducting experimentation within a high-fidelity simulation environment enables the participant to have an immersive experience with the SMI, which in turn provides the experimenters with a richer data set to evaluate the SMI. The data capture capability of the experimental environment is the final element of the operational environment, which allows researchers to analyze the data collected with confidence in the reliability of the statistics.

Through experimentation, our goal is to identify key features of the RC interface that support the monitoring and maintenance of formations. More specifically, with our simulation capability we can quantify the benefits of the RC SMI over current force technology. Further, we will be able to evaluate how the task of maintaining and monitoring a formation may change with the introduction of unmanned systems and depending on the Soldier's role in this mission. The results of our design and evaluation efforts will provide much-needed feedback from the engineering community as well Soldiers to FCS. The lessons learned from our efforts will continue to drive future advancements as part of the RC ATO as well as future joint Science and Technology efforts between TARDEC and ARL's Human Research and Engineering Directorate (HRED).

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Acronyms

AM	Autonomous Mobility
ANS	Autonomous Navigation System
ARL	U.S. Army Research Laboratory
AWACS	Airborne Warning and Control System
BFT	Blue Force Tracker
BlueFOR	Blue Force
CAT ATD	Crew Automated Testbed Advanced Technology Demonstration
RF ATD	Robotic Followers Advanced Technology Demonstration
BML	Battle Management Language
COP	common operating picture
DART	Data Analysis and Reporting Tool
EPLRS	Enhanced Position Location and Reporting System
ESS	Embedded Simulation System
FBCB2	Force XXI Battle Command Brigade and Below
FCS	Future Combat System
GDLS	General Dynamics Land Systems
GPS	global positioning system
HRED	Human Research and Engineering Directorate
ISBS	Intelligent Systems Behavior Simulator
LADAR	laser radar
LOS	line of sight
METT-TC	Mission, Enemy, Terrain, Troops Available, Time and Civilians
MGV	Manned Ground Vehicle
MMWS	Mission Module Work Station

NAI	named areas of interest
ONESAF	One Semi Automated Force
OTB	ONESAF Test Bed
RC ATO	Robotics Collaboration Army Technology Objective
SINGARS	Single-Channel Ground-Air Radio System
SITREPs	situation reports
SMI	Soldier Machine Interface
SSMI	Scalable Soldier Machine Interface
TAI	target areas of interest
TARDEC	U.S. Army Tank Automotive Research Development and Engineering Center
TTPs	techniques, tactics, and procedures
UAV	Unmanned Aerial Vehicle
UGV	Unmanned Ground Vehicle
UML	Unified Modeling Language
USB	universal serial bus
VTI	Vetronics Technology Integration
WCAN	Warning, Caution, Advisory, and Notification
WMIS	Warfighter Machine Interface Services

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