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Fielded Agent-based Geo-Analysis Network (FAGAN)

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14. ABSTRACT *(Maximum 200 words)*:
Traditional military command & control (C2) usually evokes images of operators in command centers. We consider mounted or dismounted Soldier going from points A to B in interconnected, information rich battlefield. This is C2 on a different scale. While the digital battlefield provides a tremendous amount of information to gain a tactical advantage, there are challenges to meet. The challenge is to sift through this information and identify critical information to help plan or re-plan the mission. The team of 21st Century Systems, Inc. and University of Missouri - Rolla is developing an agent-based decision-aiding system and technologies to train and assist the Soldier through that challenge. Our research examines planning and interactive terrain analysis incorporating spatial and temporal terrain details and dynamically changing intelligence information through battlefield networks. When given the mission intent, the system will be able to provide dynamic guidance for interactive terrain analysis and mission planning. Our system will be for the Soldier of the future trained in virtual, scenario-based simulation environments. Rather than developing specialized training environments, the emphasis of our system is embedded training of the Soldier so that the training interface is created around the Soldier's actual combat vehicle and systems.

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Executive Summary

The digital battlefield provides an explosion of information to gain a tactical advantage over an adversary. However, there is a significant challenge. That challenge is to provide a Soldier with terrain analysis that includes a logical overlay of received intelligence information to adjust the route plan – while in route – in order to achieve its mission. The team of 21st Century Systems, Inc. and University of Missouri – Rolla is developing an agent-based decision-aiding system and technologies to train and assist the Soldier through that challenge. Further research will examine interactive terrain analysis and planning incorporating spatial and temporal terrain details and dynamically changing intelligence information, via battlefield networks. The FAGAN application supports embedded training and is designed to perform equally well in simulated environment as during a real time mission. The FAGAN application also is designed to record appropriate data and operator interactions to support after action review (AAR). When given the mission intent and proposed course of action, the FAGAN system provides dynamic guidance for interactive terrain analysis and help refine the mission plan. Once the mission is in execution, FAGAN tracks the progress as the mission unfolds, by taking into account changes in the battlespace as they occur. Critical changes in the battlespace with potential to affect advance or change in mission will be indicated to the operator. FAGAN once fully developed will have the ability to initiate hierarchical mission planning and execution for the management of multiple distributed entities like an operational unit. Apart from being decision support system for terrain analysis, FAGAN concept provides more effective instructional feedback and training in battlespace analysis.

TABLE OF CONTENTS **Page**

List of Tables

List of Figures

A. Introduction

A.1. The Challenge

When one thinks of today's military real-time command & control (C2) systems, it usually evokes images of multiple operators in flying command posts, tactical command centers, or aircraft carrier information centers. But, what about the Soldier sitting in a HMMWV or Bradley trying to perform a mission by going from point A to point B without getting blown up? It's C2 as well, just a different scale. With the network-centric technology push to connect battlespace participants, it is a matter of time before C2-like capabilities will be available in combat vehicles and available to dismounted combat Soldiers. Current digitized C2 systems, as well as simulation training tools incorporate terrain analysis tools that provide visual output to a human observer to aid maneuver. However, the human is responsible for asking for the right analysis and interpreting that output on his/her own. Furthermore, before operators can understand the situation for a re-planning task, they must manually correlate and integrate many geospatial and temporal features. These features may include hydrology, agricultural, industrial, collateral damage issues, rail and road networks, threat positions and threat sensor envelopes, active airfields, and weather – to name a few. The Soldier in the battlespace must be able to do this in a "shoot and move" environment. Pathways that were safe this morning are not safe or passable this afternoon. The need for fast, accurate, network-centric information is great.

Horizontally integrated systems-of-systems acquisition is already starting with the DoD transformational force structures for the Army's "Objective Force," Navy's "Sea Power 21," and Air Force's "Air Expeditionary Force." Fielded weapon systems for the Objective Force will have wireless networking capability using Tactical Internet and Joint Tactical Radio System (JTRS). Now, what to do with the information? How best to collaborate route planning given the current hierarchical organization (squad, platoon, company)? Instant access to information and sharing will tend to flatten the hierarchy. The Soldier's on-the-move planning will need high speed access to terrain databases, constant blue force status updates, estimates of enemy order of battle, battlefield prep data, weather data, and so on. Squads, platoons and companies will be responsible for very large areas, spread out even more thinly than today, relying on each other for adjacent area data. Crew-served weapons and human-operated vehicles will be monitoring and controlling assigned robotic vehicles. To maintain overall C2 in this complex, fast, and dynamic environment, computer aided terrain analysis and automated generation of relevant overlays is absolutely crucial. Fewer people, more combat area coverage per Soldier, lower echelons controlling – all indicates the need for intuitive, interactive terrain analysis and visualization for planning activities such as ground routes, troop placement, air vehicle reconnaissance and deconfliction, robotic sensors, and so on.

The future combat systems concept is highly heterogeneous with numerous different actors with individual and collective tasks. These actors may include manned and unmanned ground vehicles, networked Soldiers, and weapon systems supported by different airborne and spaceborne civilian and military assets. Each of these actors is a source of information as well as user of the information in a networked battlefield. This explosion of information provides an opportunity to gain tactical advantage over the adversary but also poses a challenge. The challenge is to sift through this information and identify mission critical information to help plan or re-plan the mission. Here we develop tools and technologies to address the problem of interactive terrain analysis and planning under future combat systems concept. The challenge is to research and develop a decision-aiding mechanism for using new information sources to provide dynamically, route planning and re-planning (due to change in tactical scenarios), assistance to human operators in the battlefield.

A.2. The Opportunity

21st Century Systems, Inc.® (21CSI®) is a pioneer in designing, developing, and fielding agent-based decision support systems for time- and mission-critical applications for DoD and government applications. Researchers at University of Missouri-Rolla (UMR) have considerable research expertise in intelligent computing, terrain analysis, machine vision, path planning, 2-D and 3-D visualization, and virtual and augmented training. We have developed a concept for a fieldable terrain analysis tool that uses intelligent agents for decision-aiding and operator assistance and network connectivity for latest battlefield updates.

The concept is entitled "FAGAN," Fieldable Agent-based Geo-Analysis Network. The FAGAN concept is seen to be a field deployable tool for interactive geospatial and battlespace evaluation and dynamic mission planning. The team of 21CSI and UMR has brought together our strengths for research and development of a geo-analysis tool providing very capable route planning and mission execution in a dynamic battlespace environment. The opportunity is to improve human-centered operations of complex systems through training while minimizing the training time.

A.3. Overview

The overall objective of this project is to conduct research towards and evaluate feasibility of a C2 decision support tool that integrates terrain and networked intelligence information to support the Soldier's analysis and decision-making process for route planning and mission execution, whether in open field or in a urban area. The system is network centric and is expected to operate in real-time. It would work in the harsh environment of the battlefield; bouncing around in a vehicle hitting potholes, dodging bullets, and jockeying around rubble in the streets. When given the mission intent, the FAGAN system will be able to provide dynamic guidance for interactive terrain analysis and mission planning. Also the FAGAN system will track the progress as the mission unfolds, by taking into account changes in the battlespace as they occur. Critical changes in the battlespace with potential to affect advance or change in mission will be indicated to the operator. The system will also have the ability to initiate automatic route re-planning where possible. The same concept can be used in actual battlefield for guidance and planning, as well as for more effective instructional feedback and training in battlespace analysis. Path planning can take on a 4D solution for ground and air vehicles to execute the mission. That is to say, the planning will account for multi-vehicle mission requirements such as synchronization at given route waypoint. In short, we want a system that behaves similar to a terrain analysis technician (MOS 215D).

It is important to note that the current work seeks to provide a tool for aided route planning, incorporating spatial and temporal terrain details, and dynamically changing intelligence information. The current work does not seek to provide a tool for automatic path planning and does not make any claims on the optimality of the route. The optimality and eventual effectiveness of the route will be dictated by the operator input aided by the intelligent local terrain analysis provided by FAGAN system.

The Soldier of the future will increasingly be trained in virtual, scenario based simulation environments. Rather than developing specialized training environments, the emphasis has been on embedded training of the Soldier so that the training interface is created around the Soldier's actual combat vehicle and systems. A field deployable FAGAN system will be developed in this same spirit, so that it can easily interface with battlespace simulation systems such as OneSAF Test Bed, as well as with in-field live terrain, telemetry, intelligence, and C2 data.

B. Phase I Goals and Tasks

B.1. Overview

The Phase I work plan of the team of 21CSI and UMR consisted of four tasks over a 6-month period. Tasks 1 and 2 are performed by 21CSI. Task 3 is performed by UMR. Task 4 is jointly performed by 21CSI and UMR. Task 1 lays the scope of incoming information from simulation interfaces. Task 2 is the tool concept development using network sources, simulation interface, and intelligent agents from 21CSI's AEDGE®. Task 3 is the research and algorithm development of the planning and mission execution agents. Task 4 is demonstration of the key concepts of FAGAN using desktop computers.

B.2. Phase I Operational Scenario

In the battlespace context, there are three distinct dimensions of an operational tactical mission: conceptual, spatial, and temporal. The conceptual part of the mission addresses the issue of intent and purpose of the mission and includes overall goals, individual responsibilities, and the sequencing of tasks and events. At the conceptual level, the mission must conform to the correct protocols and rules of engagement. The spatial dimension of the mission plan seeks to execute the mission intent geospatially under the constraints imposed by the current terrain and any available spatially relevant intelligence information. The temporal dimension of the mission would seek to ensure desired evolution of the mission in time, while accounting for difference in spatiotemporal mobility of different actors and the dynamic nature of the battlespace.

An overall mission may involve many ground-based and airborne vehicles and Soldiers. Some of these vehicles may be manned while others are unmanned providing specific support to the manned vehicles. This can be thought of as a generalized multi-actor battlefield scenario where each actor (Soldier, TV, UGV, UAV etc) has their own specific assigned tasks and submissions. For the Phase 1 effort, we assumed a single operator system running on a ground vehicle like a HMMWV or a hand-held computer of a Soldier. This operator/actor is situated in a multi-level hierarchy and is responsible for a specific part (a task) of the overall mission. This task will have a specified intent (such as advance, reconnaissance, search and rescue, or search and destroy). The task will also have spatial and temporal component. Thus, for example, the specific task may be: "To advance from location A to location B in time T". The intent of the task here is "to advance", spatial component is a "route from location A to location B" and temporal component is "to accomplish the task in less than T time". In a typical scenario, a mission can be divided into two distinct phases, (a) planning (b) execution. Often there may be an in-between phase of training or rehearsal. In the current context, this training phase is simply an extension of execution phase where the dynamic behavior of the battlespace is simulated rather than real. Thus both the simulated training and actual operation can be conducted on exactly the same platform. In the above discussed task, the planning phase will require a route plan from location A to location B with the constraint that it must be executed in the specified time. Apart from this time constraint, the route plan should account for the constraints imposed by different factors such as the elevations of the terrain, location of obstacles (minefields), location of friend and foe, and weather conditions among others. The route and task planning will proceed with the best available information at the time of planning phase. This available information however, may or may not be current or correct. These uncertainties in the information used for planning along with the dynamic and ever changing nature of the battlespace, require a continuous verification and updating of the plan during the execution phase.

The current Phase I effort addresses the issues of route planning and execution in such a dynamic and uncertain battlefield environment. It is important to note that, in general, the intent of the task has the potential to change the behavior of both the planning and execution phase of the task. Thus for example, on a reconnaissance mission, stealth may be more important than the time taken for the task, while in a search and rescue operation shortest time to destination will be more desirable.

B.3. Task 1 Characterize Terrain Analysis & Interfaces for Tool Development

In this task we researched terrain analysis facilities in newest available version of One-SAF-Testbed –Baseline (OTB), and Force XXI Battle Command Brigade and Below (FBCB2) with particular attention to how the computational output of the terrain analysis features of these systems can be captured and utilized for our route planning decision-aiding concepts. Difficulty with both the OTB and FBCB2 has caused us to develop the initial concept using another product from 21CSI called Joint Force Open Component Simulator (JFOCS). JFOCS is designed to work with the AEDGE® environment, and provides many of the features of OTB.

Our tool concept uses information from JFOCS for high-level assistance with low level autonomous capabilities. The high-level functionality collaborates with the human user to increase the terrain analysis quality and off-loads lower functions that can be performed by a computer. We recognize that not all Soldiers use computers equally and therefore the user interface is required to be flexible in assistance, visualization, help, and tutoring. We will examine how the Soldier-in-the-field and Soldier-as-trainee influence the interfaces to provide a mixed-initiative interchange with an intelligent agent or tutor.

We have developed rudimentary data fusion support requirements on how terrain analysis data including weather can be integrated with intelligence information (e.g., estimated and last known enemy positions), to produce maneuver planning guidance to human operator or robotic platform. We also examined the terrain database requirements, including possibilities for user/sensor updating of terrain and weather information. For the Soldier-in-the-field concept, we will examine the interface requirements with in-field intelligence information, topological information and C2 networks (such as Tactical Internet (TI) [MS98]). A great deal more work is needed for this task before a fully operational system can be fielded.

B.4. Task 2 FAGAN Functional Concept Development

Military cross-country movement is intellectually demanding with competing requirements – complete mission, survive, minimize noise, reduce wear and tear on equipment and personnel, and so on. Using requirements from Task 1, we have developed a mixed-initiative concept for the planning and execution, as well as analysis for training and rehearsal, using multi-agent architecture to provide operational services, over-the-shoulder help, and tutoring for a human operator, in the context of guided route planning and execution. It will overlay situational data over terrain analysis displays and recommend routes or other information that would be needed to complete the routing plan. The functional architecture is detailed in a following section. To begin, the operator using mission orders initiates the system with top level plan. Using a variety of data sources, FAGAN will compare new information with the current plan that might enhance or threaten the plan. The analysis will consider, as appropriate, cross-country movement (CMM) variables such as trafficability and maneuvering. The functional architecture is the same for training and operation; the difference being the source of data and agent awareness of which mode the system is in.

The recommendations are output and simple overlays are made over the terrain data. It employs assistance to the operator in the form of queries relative to the terrain analysis with information received over the networks and internal knowledge – as limited by the hardware/software implementation. A dismounted Soldier with a hand-held computer is less powerful than a vehicle-mounted system. One obvious attribute for movement is *stealth*; for a tactical mission, it is to be able to move undetected to the objective. For example, a candidate route may have a critical path (e.g., bridge data) that needs updating or enemy occupied downtown area with tall buildings and rubble in the street choking movement and creating exposure to enemy snipers.

We designed and developed intelligent software agents that can participate as passive or active members for the operator. The intelligent agents assimilate the terrain analysis data feeds given to them and, working with the operator, adapt and improvise to many different types of problems. An enemy spot report causes a divert from the primary route. Later due to more re-routing the hydrology data is needed near a bridge since spring runoff may negate the route. During mission execution the agents interact with the human; the human providing guidance and FAGAN providing low level analysis and recommending other information from higher echelon or adjacent forces. Prior to a mission, the agents can tutor the operator through a mission rehearsal for a more complex mission task.

As far as performance is concerned, it should be noted that the fidelity of the functions is critically dependent upon the host computational ability – whether in a mounted or dismounted version. Furthermore, many times an 80% accurate solution provided in a timely manner is more useful than a 99% accurate solution given too late.

B.5. Task 3 Generalized 4D Route Planning and Navigation Concept

The route planning and execution of the task is, in general, a 4D spatiotemporal problem. Even though the current discussion is limited to a ground-based mission where the maneuver is typically in 2D, the overall mission may entail synchronization with airborne and spaceborne sensors and platforms. As noted earlier, we seek to develop tools and techniques for aided route planning and execution. The idea is to provide feedback and guidance to the operator to help plan and execute the task using intelligent agent-based interactive terrain and situational awareness. The aided route planning assumes that a human operator will provide an initial route taking into consideration all information and overlays available to (and accessed by) the operator at a given time. The proposed set of intelligent agents will analyze the route for its feasibility, provide detailed plan if the route is feasible and track the progress of the task if the plan is operational. If the plan is found to be infeasible (due to terrain and/or operational constraints) the same is indicated to the operator along with the reasons for the failure. The operator provides a new route and the sequence is repeated until a suitable plan is found. Note that, while the operator may have only limited information/overlays on his/her interface, the agent-based software tool will be able to assess and evaluate all available terrain and intelligence information available through the networked battlespace at a given time. In an operational battlefield environment, these intelligent agents will be able to sift through all relevant available information and provide guidance and help for better planning and execution. If operated in training mode, information actually used by the agent for evaluation of the plan can be cross referenced with the information overlaid by the operator on his/her interface and suitable training feedback can be provided.

We developed and implemented three types of higher-level FAGAN intelligent agents for aided planning and execution. For the demonstration of the concept, these higher-level agents are prototyped using 21CSI's lower-level AEDGE® agents discussed in Task 2. The three behavior-based intelligent agents are (1) analysis agents (2) planning agents and (3) navigation agents. For a given task, there is more than one of each of these three types of intelligent agents. These intelligent agents are populated along the proposed or the executed route and are referenced by their spatial location. Each of the agents works on and has access to only spatially local information. This spatial referencing and local characteristics of these agents significantly reduces the computational need for the agents. Also sharing of information between the three types of agents avoids the duplication of computation.

Each of the agents of any given type is virtually located (referenced to) at a specified position (x, y) on the terrain and represents a specified region of interest (*ROI*) of the terrain in the neighborhood of the specified location. Each agent of a given type can cooperate and communicate with the agent of same type in the immediate neighborhood. A given agent can cooperate and communicate with other types of agents falling within its area of interest. Each of these agents subscribe to information and events occurring within their region of influence (or those having potential to influence behavior in their region of interest). This set of information may include topological information, geospatial intelligence information, and specific mission intent. Each agent can provide analysis and control output dictated by their specified behavior and purpose. In a following section we discuss these three types of intelligent agents proposed for interactive terrain analysis in more detail.

B.6. Task 4 FAGAN Phase I Single Vehicle Demonstration in Open Terrain

Implementation of the proposed software prototype should be reasonably straightforward. FAGAN will be an extension to AEDGE®. Class and object hierarchies (inheritance) will be employed. We will support active entities (agents of different types, simulation objects as well as functional objects) communicating over a software bus, cooperating and so on. Services and libraries to support various analyses will be provided. The system will be implemented in Java™, with Java Database Connectivity™ for DB access, Java AWT and possibly 3D for interfaces, JFC for common objects and so on. While Java remains a somewhat peculiar language with some idiosyncrasies (e.g., single inheritance with interfaces instead of multiple inheritance), our overall experience with it is positive and we do expect the language to grow and to be used universally quite soon.

A prototype for intelligent agent-based route planning and navigation system in 2D will be developed and implemented as a demonstration case. This demonstration case will be limited to aided and interactive route planning for a standalone manned ground vehicle. In particular a simplified version of the analysis agents, planning agents and navigation agents will be developed and implemented as proof of concept. This exercise will also provide opportunity to demonstrate implementation architecture and interactions between the lower-level agents and higher level intelligent agents. The work on this is well underway and is expected to be ready around the beginning of March 2005. Screen shots of the user interface are shown at the end of the functional description.

C. Scenario Description

FAGAN is a system which provides feedback and guidance to the operator to help plan and execute the mission using intelligent agent based interactive terrain analysis and situational awareness. A particular scenario is explained in more detail. This scenario is for illustrative purposes. The figures shown below are a 2-D representation of a possible situation. In the upper right-hand corner of each figure is a block diagram of the FAGAN architecture (discussed in detail in section D). The highlighted blocks represent the activated components of the architecture. Refer to the functional description in section 4 for details on the components.

The initial screen is the where the operator is asked to enter the departure point, destination and the initial route. Once the route is entered, FAGAN checks whether there are any overlays in the terrain which were missed initially. Here, high rate flow of stream in spring and also the mine field area were missed. This data is fetched from the memory and is displayed to the operator as warnings. This feedback to the user from FAGAN acts as a reminder that these data sources should be looked at before a route is planned. The details of the missed information/overlays are recorded in the log and can be used for evaluation or for After Action Review (AAR). Figure 1, shows the current situation.

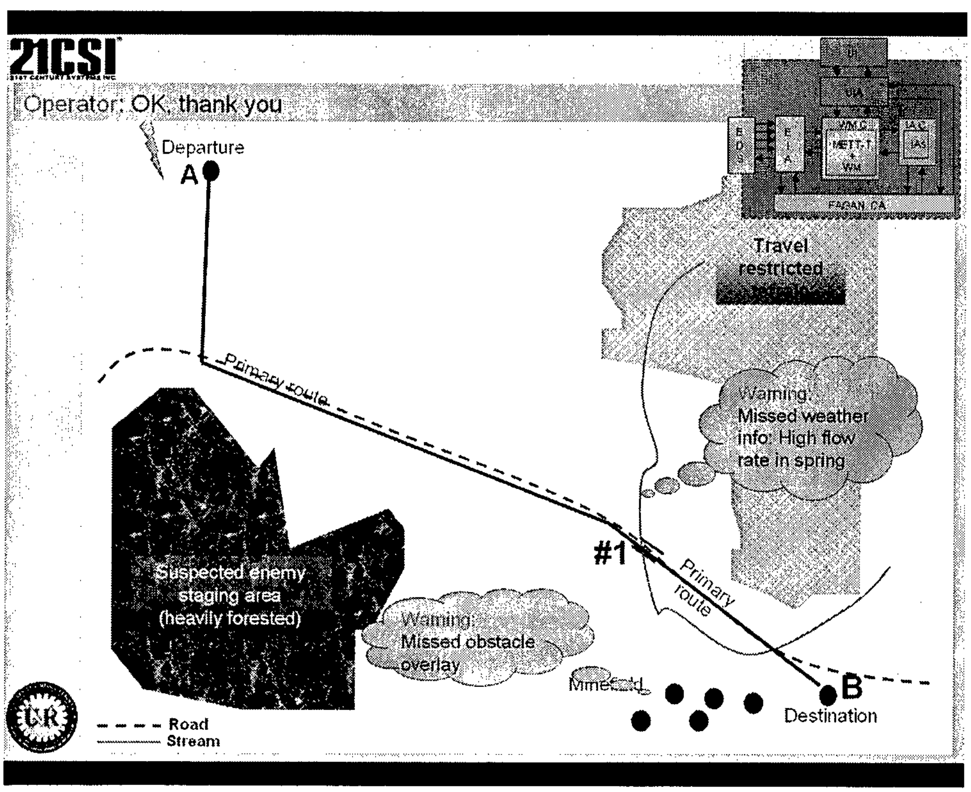

Figure 1. FAGAN accepts a new route from the operator, and evaluates the overlays and indicate the missed information.

The operator responds by giving 'OK' for the route analysis to start. The intelligent agent coordinator populates analysis agents along the route provided by the operator initially. The purpose of the analysis agent is to evaluate and investigate local terrain/topological information and relevant intelligence information such as maneuverability of the vehicle in the terrain, and presence of an obstacle in the area. In particular the analysis agents evaluate the local terrain with respect to the Observation, Cover and concealment, Obstacles, Key terrain, and Avenue of approach (OCOKA) factors applicable to the current mission. Once the analysis agents are populated, each agent evaluates the local path along its circular region of interest using the appropriate factors.

The second analysis agent observes a possible ambush area due to the thick forest nearby the route. The situation is displayed to the operator. FAGAN asks the operator to provide a new path since the initial route is unfeasible. The situation is shown in Figure 2.

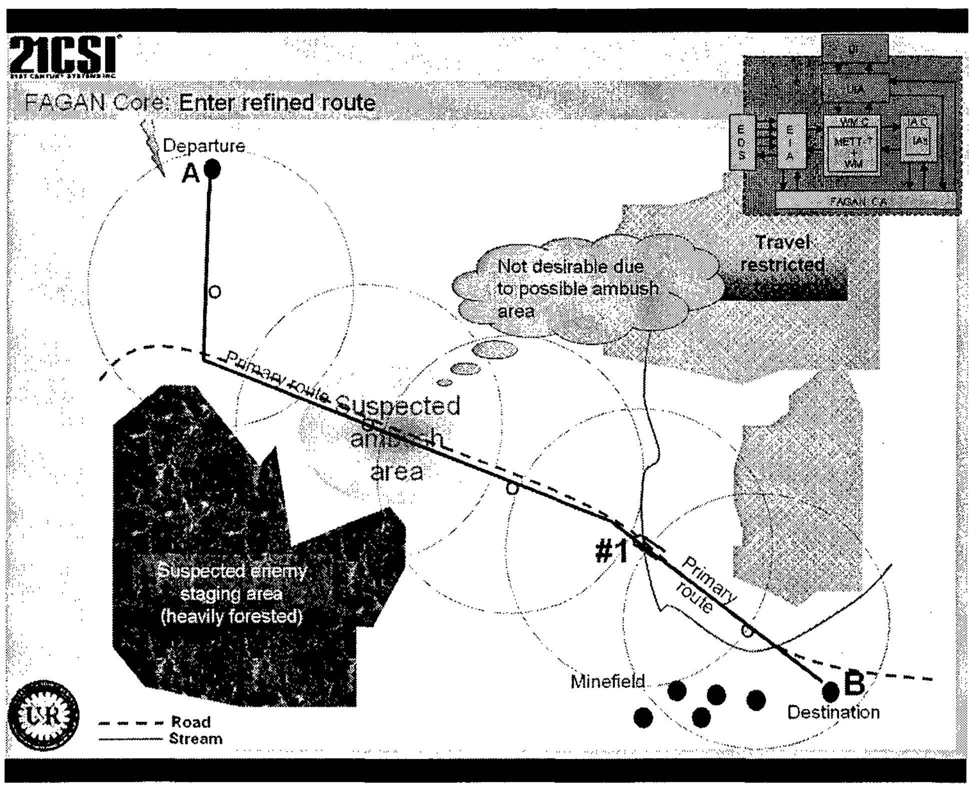

Figure 2. Local terrain analysis along the route indicates possible ambush area so FAGAN suggest a change in route.

The operator provides a new path avoiding the suspected ambush area. This is done the same way as the initial route was drawn. The FAGAN Coordinator activates the Intelligent Agent Coordinator (IAC) to populate the analysis agents over the new path. Each agent again evaluates its local region of interest. The path was found feasible as there were no obstacles in the new path and 'Route ready for planning' is displayed to the operator for him to respond. Once the operator says 'OK', the IAC populates the planning agents along the route.

The planning agent seeks to find a refined detailed plan. The analysis information provided by the analysis agent that was updated in the working memory once the analysis was done is accessed by the planning agents for constrained minimization of an appropriate objective cost function. The cost function would be mission dependent and may include factors such as fuel consumption, speed etc.

In the current scenario, the planning agents provide the detailed plan. It sees a steep uphill along the path and this particular mission, minimum fuel consumption was required and so the planning agents suggest a slight detour to minimize fuel consumption. The reason for deviation from the suggested plan is displayed to the user. Once the calculation is done the optimal path is displayed to the operator for his approval. The operator says 'OK' and the detailed route is updated in the memory. The situation is shown in Figure 3. The mission is now ready to execute.

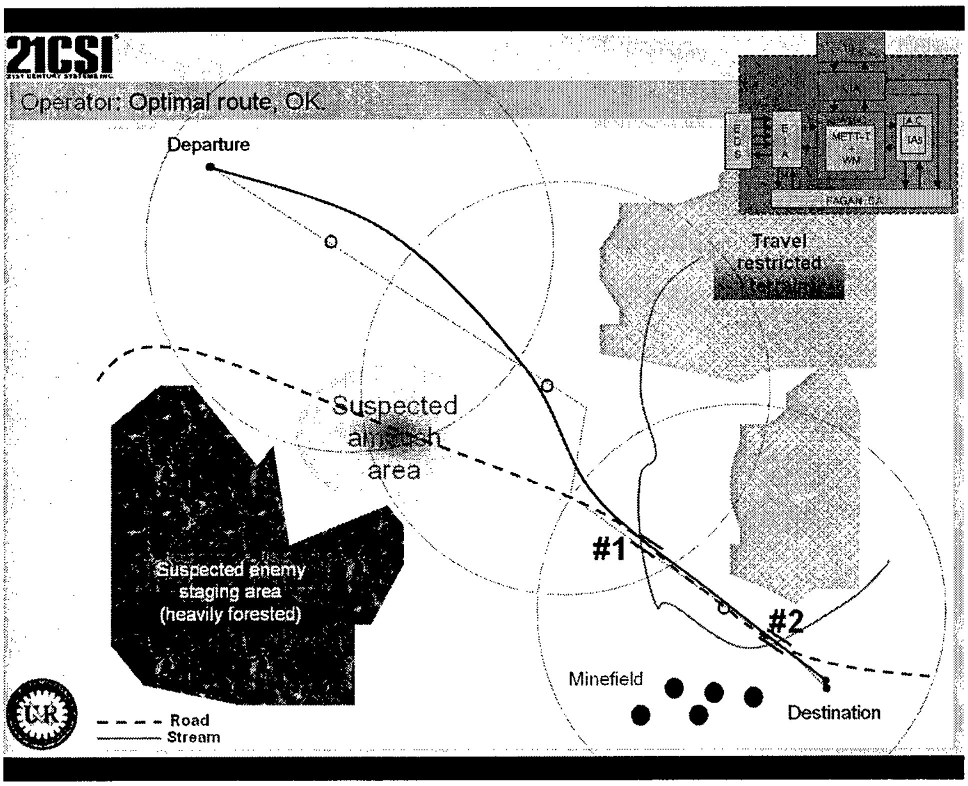

Figure 3. FAGAN provides refined path and detailed mission plan.

Once the operator gives a go ahead for the execution of the plan, the IAC populates the navigation agents along the current plan. Navigation agents work towards the verification and validation of the current plan. Given the path and the information used to create this path (terrain analysis from analysis agents and planning constraints and cost evaluation from planning agent), navigation agents look for any relevant emerging information which may be in variation with the information used during the planning phase, and may have bearing on the viability of the plan.

Once the navigation agents are populated, FAGAN core alerts the user that the system is ready for mission execution. If the operator says 'OK' and starts moving along the path, the navigation agents wait for any change in parameters. When new real time information is available at the external data source, the FAGAN coordinator triggers the navigation agents to fetch the new data from the memory. Now it evaluates the dependency of the change, in the route. It is found that enemy paratroopers have landed nearby and the warning is popped up to the operator for his response. The operator chooses to continue through the path with caution. Operator traverses through the suspected ambush area slowly. The navigation agents continue to monitor for further change in parameters.

Once again a change in parameters is received by the external data source which triggers the navigation agents. Navigation agents fetch this data from the memory and calculate its dependency. A high rate flow of stream collapsed the bridges which were in the current path. The navigation agents find the current path to be unusable because there was no way of passing through the bridge. So instead of passing this information as a warning to the operator, the FAGAN Core directly prompts for a new path. The current situation is also displayed to the user. Figure 4 shows the situation.

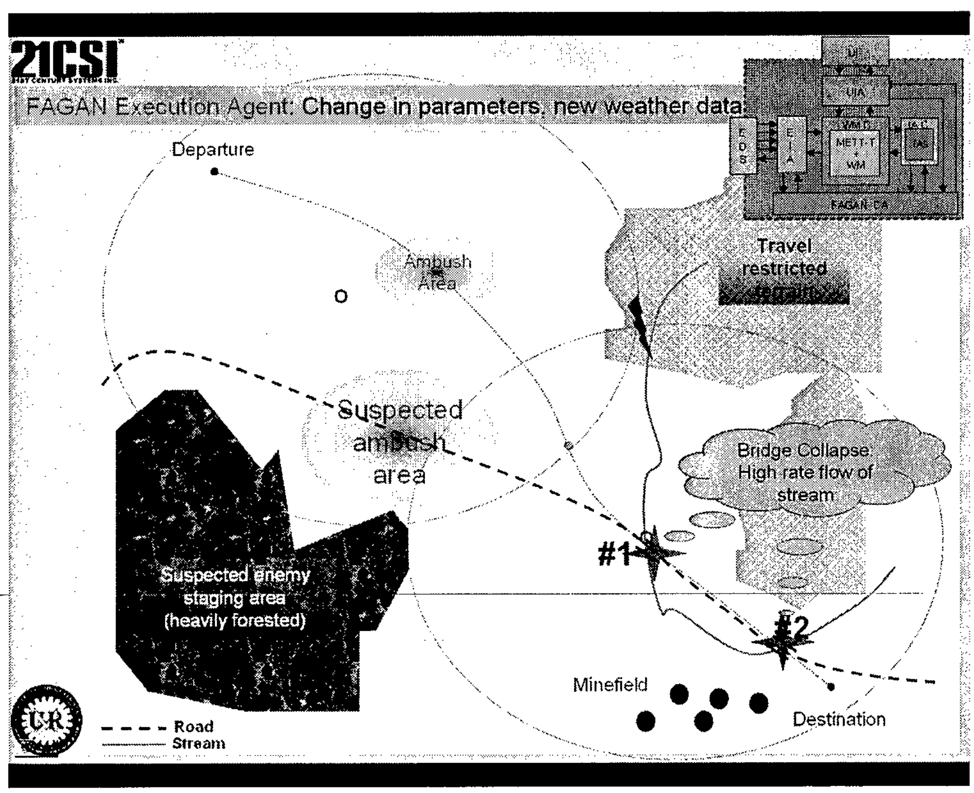

Figure 4. During execution, FAGAN indicated a possible ambush area due to enemy paratroopers and advise caution. FAGAN later indicated collapsed bridge on the path ahead.

The blue dot along the path represents the operator's current position. The user enters the new path avoiding the bridge and the stream. This path is updated in the memory and the IAC populates the analysis agents along the new path. Each agent evaluates the local region of interest by accessing the working memory. FAGAN Core displays that the route is OK for planning phase to begin. Once 'OK' is received from the operator the IAC populates the planning agents along the route. After the population of the agents the planning agents calculates and evaluates the detailed optimal plan. It is displayed to the user and the FAGAN core waits for the user's approval. The situation is shown in the Figure 5.

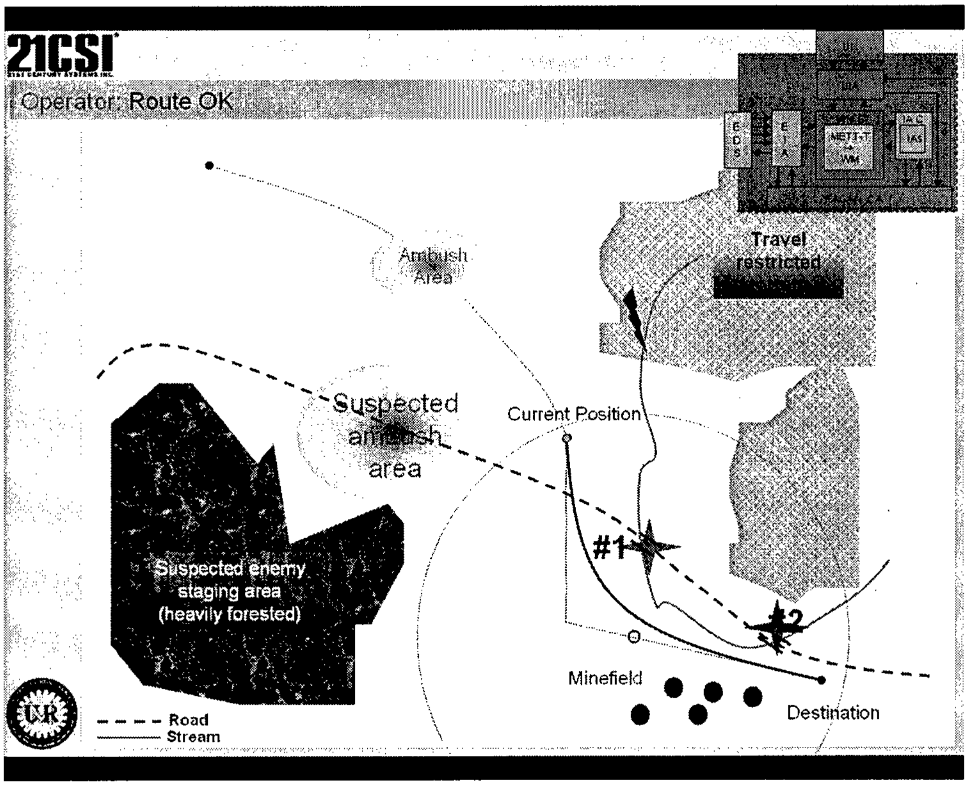

Figure 5. New refined path avoiding the collapsed bridge is obtained interactively between the operator and the FAGAN intelligent agents.

Once the detailed optimal route is approved by the user, the FAGAN core triggers the IAC to populate the navigation agents. The navigation agents are populated along the route and then the user is told that the system is ready for mission execution along the new route. The operator decides to start from the new position by saying 'OK'. This will trigger the navigation agents which will monitor the progress as he traverses through the path. When he reaches the minefield area, the navigation agents evaluate the threat and gives a warning pop-up to the operator that there is a minefield and suggests him to go slow as shown in Figure 6.

The operator says 'OK' and decides to move cautiously to avoid the minefields and finally reaches the destination. The navigation agents stop and the information is displayed in the operator display. Once the destination is achieved, the system goes to the initial state for selecting a new mission.

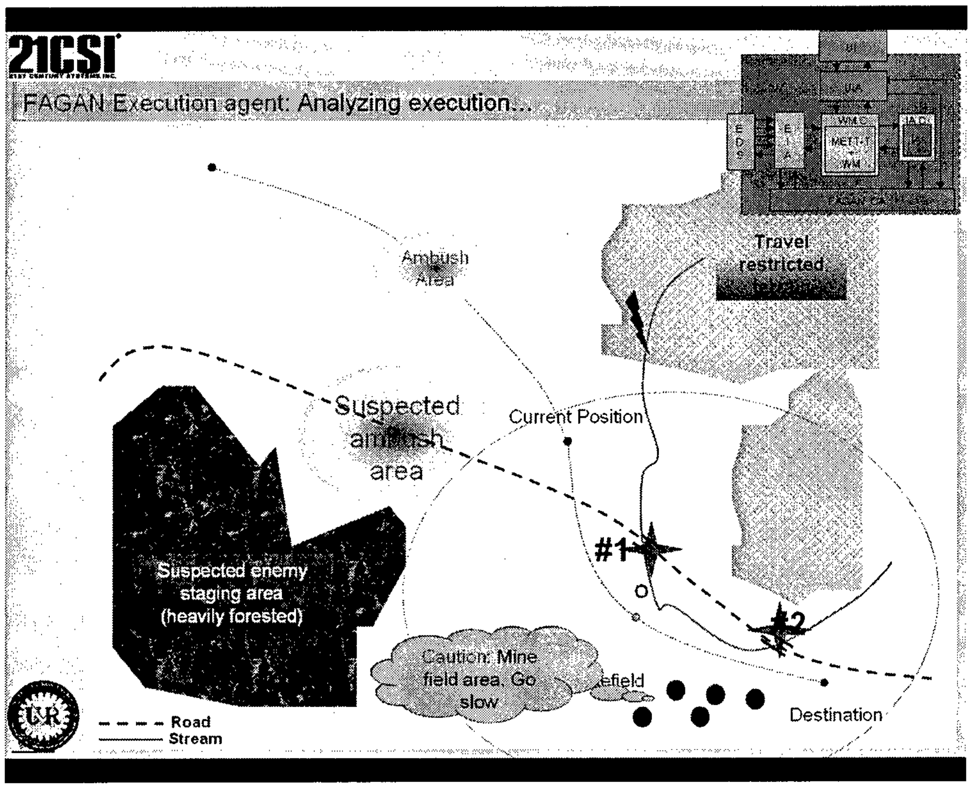

Figure 6. FAGAN reminds the operator of the presence of old minefield area and suggests caution.

D. FAGAN Functional Description

D.1. FAGAN Top Level Architecture

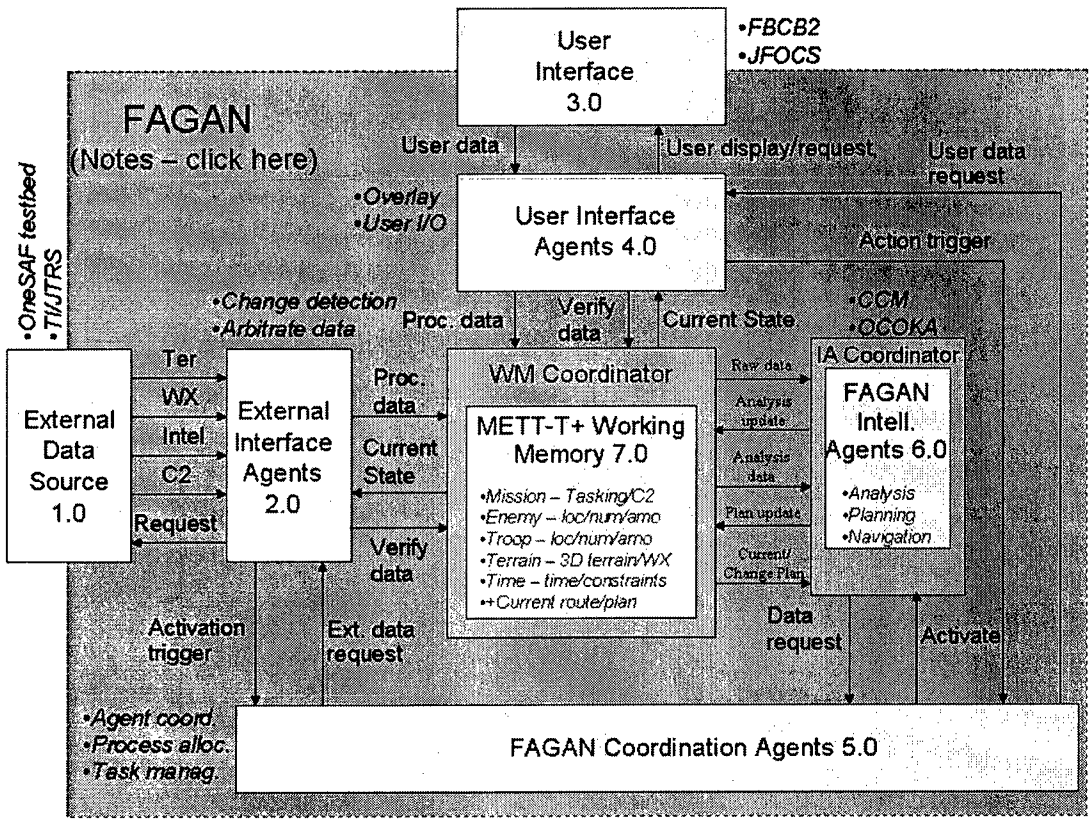

Figure 7. Top level of the FAGAN architecture.

The top level shows the overall flow of the information. The concept is that the user will initiate the system by supplying information as to the nature (real/rehearsal/training) of the mission. FAGAN will then determine what data sources it has available. If the mission data is available from the external sources the system will begin processing. If the mission data isn't available, FAGAN will query the user to supply the necessary mission data.

The processing begins with FAGAN requesting the user enter an initial path. This may be way-point entry, or possibly screen interactive with the user using a stylus or touch screen to draw a line on the displayed map. The system primarily interacts with the user via overlay displays. The basic background will be the topo-map of the terrain. Alerts for hazards, weather conditions, enemy activity, etc. will then be displayed on top of the topo-map. The user interface will be customizable to show the user the information he/she requests.

D.2. FAGAN External Data Source

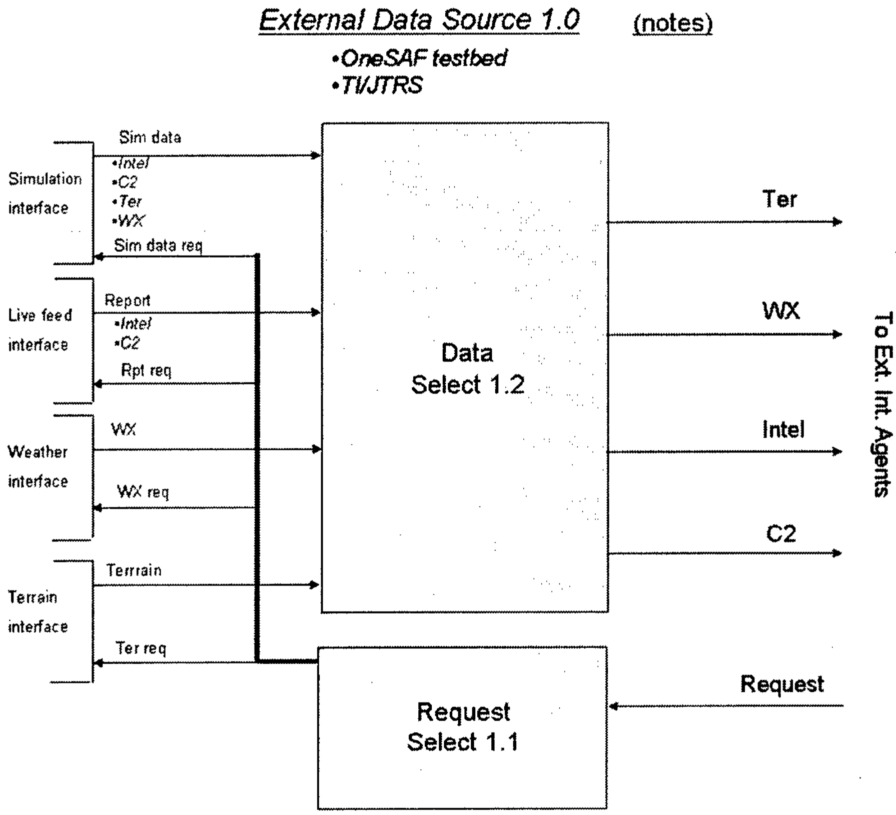

Figure 8. External data source interface.

D.2.1. Purpose

The purpose of the function is to request and retrieve data from external data sources.

D.2.2. Functional Description

The data may either be accessed in response to a request or may be accessed unsolicited.

D.2.2.1. Requested data

FAGAN will request data that it needs for processing. For example, the terrain database may contain more data than what is needed by the mission. FAGAN will take the mission statement and extract the region of the terrain data it needs. FAGAN will then request this data from the terrain database.

The data request is initiated by the Request signal into the Request Select block. The Request signal will tell the select block which data to use and what parameters to send to the data source. The Request Select block then routes the parameters to the appropriate data source.

The returned data is then detected by the Data Select block. The Data Select block will determine the type of data that is being received (terrain, weather, intelligence, or command and control) and then route the data to the associated agent for the type of data.

D.2.2.2. Asynchronous (unsolicited) data

A feature of the system is that when new data is made available the system can bring the new data in without the need to request it. For example, spotter reports may come during the operation. The report will be unknown to FAGAN, but will be available over the tactical internet. The Data Select block can detect activity on the data source line and bring in the information.

Since the Data Select block already has the duty of determining the type of data being received the same function works for both requested and asynchronous data. FAGAN makes no distinction between requested and asynchronous data such that the data structures remain consistent for analysis processing. To the internal agents of FAGAN, all the data received is one of the four data types listed above (Ter, WX, Intel, or C2).

D.3. FAGAN External Interface Agents

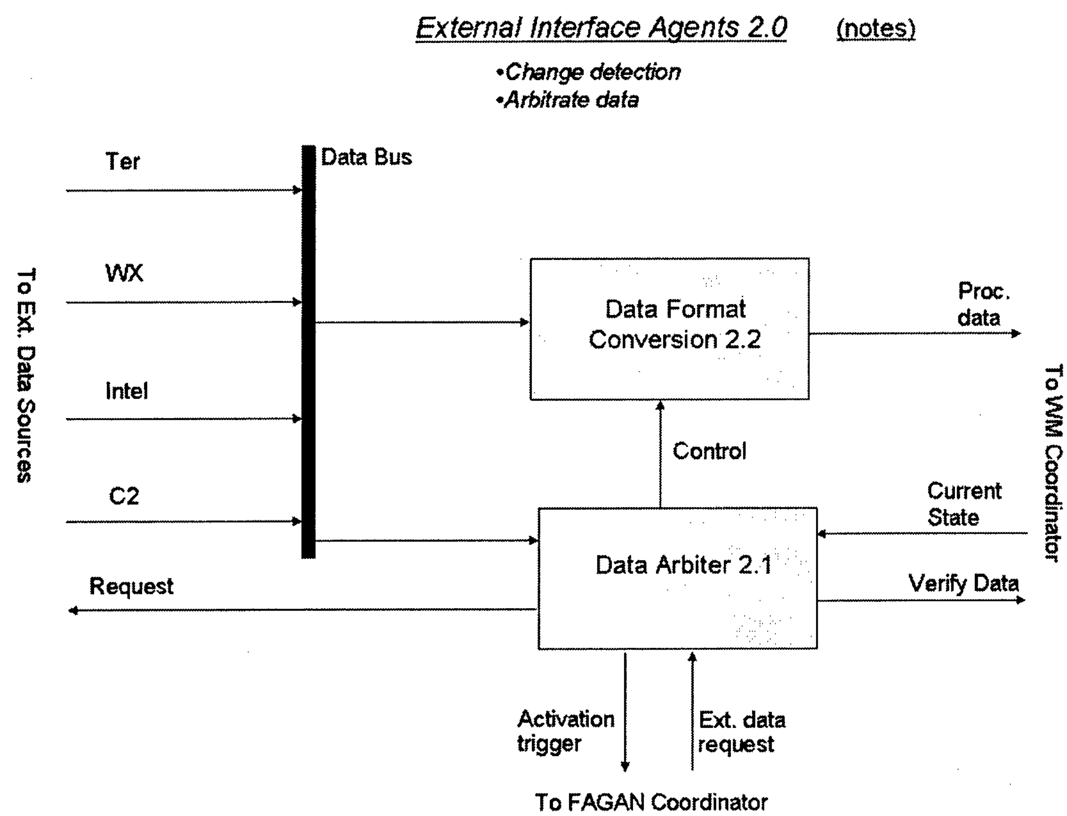

Figure 9. External data source interface agents.

D.3.1. Purpose

The purpose of the function is to convert the raw data into the data structure needed by the system, initiate data requests to the external data sources, and verify the need of new data with the working memory.

D.3.2. Functional Description

Two agent types will be utilized, the conversion agent and the arbiter agent.

D.3.2.1. Data conversion agents

The data conversion agents will be programmed with the raw data structures from the source data and will convert the data to the FAGAN data structure. The conversion is, however, controlled by the data arbiter.

D.3.2.2. Data arbiter agents

The data arbiter agent will have two roles, request verification of the data and activate the data conversion agent. Additionally, there are two methods by which the arbiter may be activated. The first method is via the external data request line. If other agents in the system request external data, the request is processed by the data arbiter. The arbiter will verify with working memory that the requested data is in fact not available. This is to reduce unnecessary external network traffic. If the data is needed the request is passed to the external interface. The arbiter then goes back to waiting for the data bus to become active with new data.

The second method for activating the data arbiter is through the data bus itself. Unsolicited data, such as spotter reports, may come across the external interface asynchronous to the activity of FAGAN. This data must be first detected, then verified, and then processed. The same mechanism is used to detect unsolicited data and requested data. The arbiter will again query the working memory to verify if the data is new. This may also be where the data is verified against malicious attack or corrupted data. If the working memory verifies the need for the data, arbiter will activate the control signal to begin conversion of the data.

D.4. FAGAN User Interface

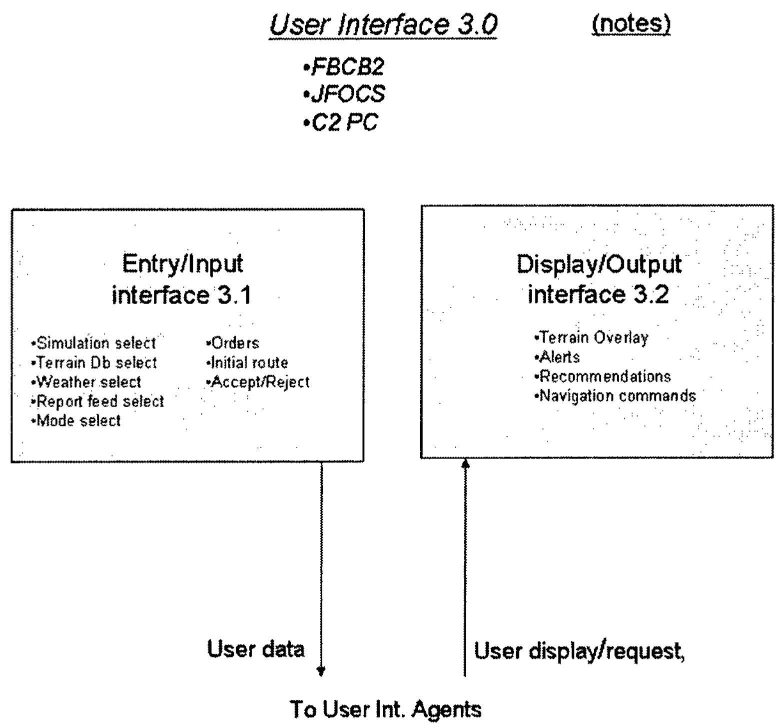

Figure 10. User interface.

D.4.1. Purpose

The purpose of the function is to request and retrieve data from the user as well as display the current state to the user in the form of overlays.

D.4.2. Functional Description

User data must be able to be entered into the system, the user will need to query the system, and data must be displayed to the user. The data input are handled by the input interface; the data output are handled output interface.

D.4.2.1. Data Input

The mixed-initiative approach we are taking requires interaction with the user. The user may be asked to provide any of the following:

- Simulation select
- Terrain Db select
- Weather select
- Report feed select
- Mode select

- Orders
- Initial route
- Accept/Reject

The first four listed above relate to where the input to the system will be taken from. The user may then asked to select if the mission is real, training, or a rehearsal. Orders may be manually entered or may be taken from the external interface. Finally, the user will interact with the system during operation by selecting routes and accepting or rejecting suggestions from FAGAN.

Additionally, the user may probe the system for information. This may take the form of asking the rationale behind selecting one route over another during real missions or rehearsals. During training, the user may ask FAGAN as to what potential obstacles are in a particular location.

D.4.2.2. Data Output

Data output is much less complex than the input. The base display is a topographic map of the terrain. Then on top of the map will be the following:

- Terrain Overlay
- Alerts
- Recommendations
- Navigation commands

Terrain overlays will be in the form of weather patterns, restricted areas, viable routes, etc. Alerts may be in the form of visual flashes to draw the attention to a particular location, audio tones, haptic actuators, etc. All the alerts are aimed at aiding the user to focus on the problem or avoid a dangerous situation. Recommendations may be in the form of overlays, or they may be text messages. The navigation commands are primarily for robotic users, but may also be incorporated on an overlay or as audio messages to give directions to the user.

The interface will communicate with simulation packages and external systems. For instance the FBCB2 system is being investigated as well as the possibility of the C2 PC system. For simulation purposes, the OneSAF Testbed Baseline (OTB) is being investigated. Initial development is being performed on the Joint Force Open Component Simulator (JFOCS).

D.5. FAGAN User Interface Agents

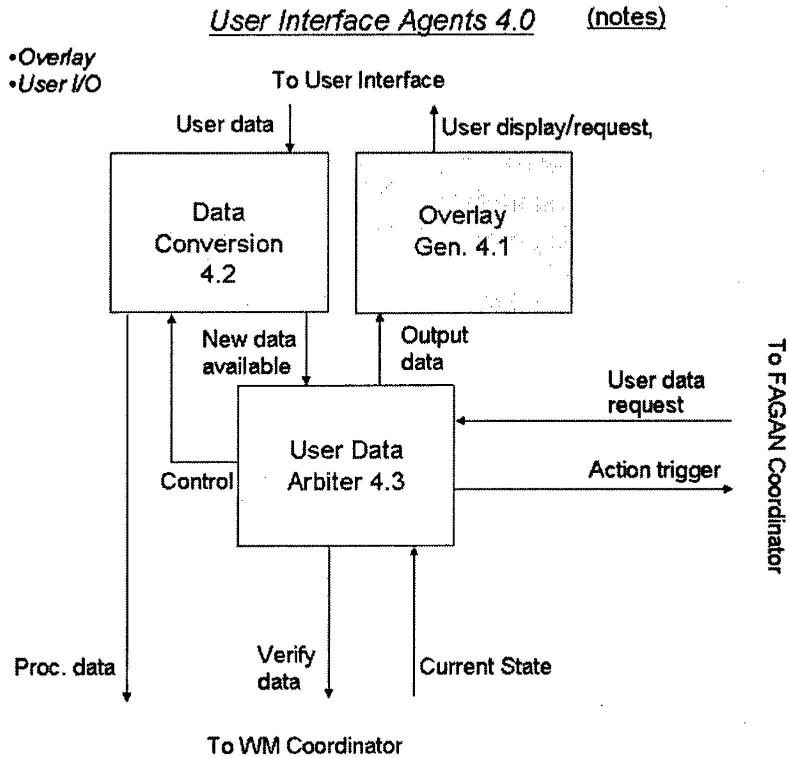

Figure 11. User interface agents.

D.5.1. Purpose

The purposes of the function are to convert user data requests and entered data into the data structure needed by the system, initiate data requests to the user interface, and verify the need of the new data with the working memory. Additionally, the user agents generate the data to be displayed in the overlays, alerts, and recommendations.

D.5.2. Functional Description

The main function of the user interface agents is to control the flow of data to and from the user. Three blocks are used to perform the control: The overlay generation block, the data conversion block, and the data arbiter are used.

D.5.2.1. Overlay Generation

Data from the current system state is passed to the overlay engine through the data arbiter. The overlay agent may be configured to display the data to the users liking. The overlay generator keeps track of what overlays have been requested (either by the user or by FAGAN) and the time length that they are to be displayed. Any new overlay must be processed by the data arbiter as needing to be displayed.

D.5.2.2. Data Conversion

The data conversion agents will be programmed with the raw data structures from the user data and will convert the data to the FAGAN data structure. The conversion is, however, controlled by the data arbiter. The data conversion agents will also inform the data arbiter if potentially new data has been entered in by the user.

D.5.2.3. Data Arbiter

The data arbiter for the user has basically the same task as the external data arbiter (2.1) with the additional task of verifying what data needs to be displayed. The tasks that the arbiter does are: Process data requests to and from the user, activate the conversion control signal, and process data to be displayed by the overlay generator. The arbiter will process the data requests by verifying the need for the request. The data request may be from the user or from another FAGAN component. The need will be verified by requesting the state from the working memory and checking if the data is missing or not.

If the data is in fact needed, the arbiter will send the needed request to the appropriate location. For example, if FAGAN would need a path update from the user, and the arbiter concluded that it was a needed request, the arbiter would send a message to the overlay generator that a course update was needed. Another example would be if the user wanted to know the reason for avoiding a location, the request would be processed by the arbiter to see if the data was available. The request would then be sent to working memory via the verification channel. The subsequent state data would then be routed to the overlay generator to be displayed to the user.

The overlay generator only gets its information through the arbiter. To reduce the amount of data displayed to the user, only that data that the arbiter processes is displayed. The request mechanism determines the data to be displayed.

D.6. FAGAN Coordination Agents

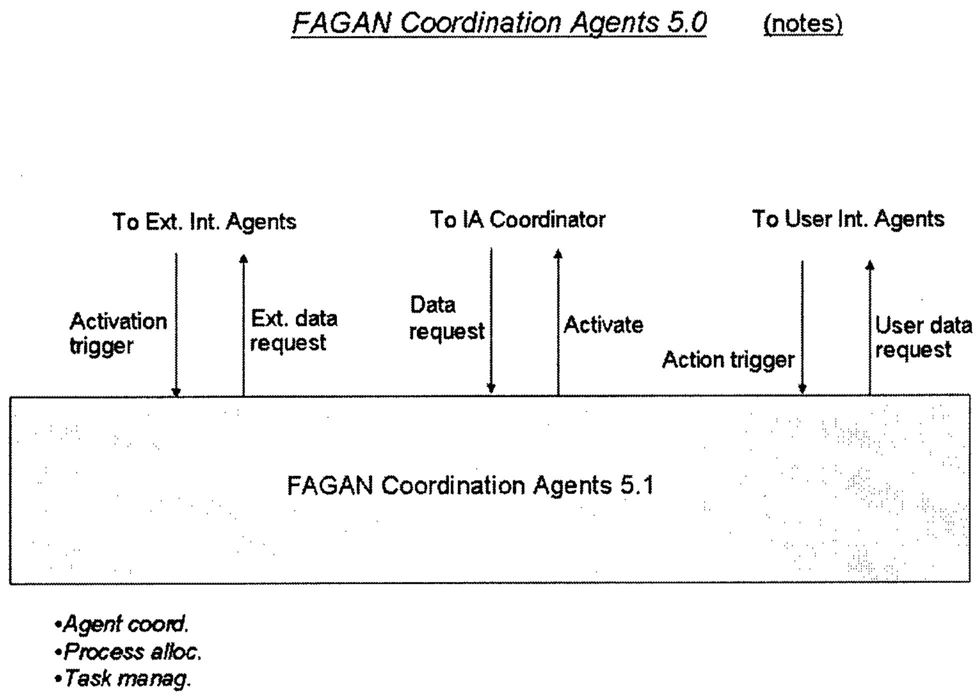

Figure 12. FAGAN coordination agents.

D.6.1. Purpose

The purposes of the function are to send data requests to the appropriate agent and activate the agent when the request is made. Additionally, agents in the coordination function will have to control system resources such as CPU usage, memory allocation, memory access (disk access), and monitor network availability.

D.6.2. Functional Description

The main function of the agent coordination is to be the communication layer between the functions. When data is missing or new, the request to process a request passes through the coordination block. The coordination block will route the request to the appropriate function for processing. The coordination block will send necessary activation signals such that the agents in the receiving block will be up and ready to process the data when the request is made. Additionally, any system level need will also be allocated by the coordination agents.

D.6.2.1. Data Request Signals

The data request signals contain the coordinates and the request type. The requests will be made to fill in the information for a particular location. Therefore, only the source that covers the particular location need be activated. The data type needed is also requested, terrain data for example.

D.6.2.2. Activation Signals

The activation signals also contain three parameters. In order to speed processing, the coordinator will send out the longitude and latitude (if applicable) coordinates so that the any data request or activation can be targeted. The responding agents, being coordinate centric, will only respond if the particular activation signal is in their area of coverage. The signal will then also contain the data type of the activation. For example, if a new weather report is received, the external agents signal the coordinator that new data is available. The coordinator then sends out to the agents that new weather data is available for a particular latitude and longitude. Only the agents that handle the weather need respond, and only the agents that cover the coordinates need respond. This will greatly reduce the amount of agent activation.

D.7. FAGAN IA Agents

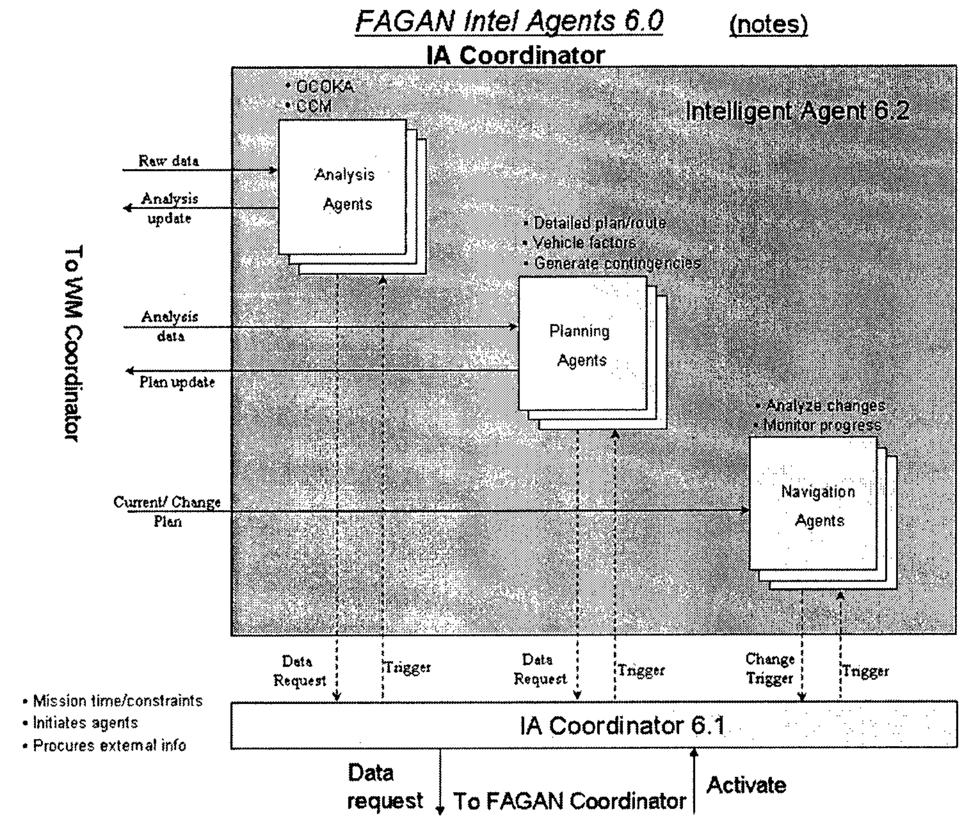

Figure 13. Intelligent agents and the Intelligent Agent Coordinator (IAC).

D.7.1. Purpose

The purpose of the intelligent agents is to analyze the route provided by the user for its feasibility, provide a detailed plan if the route is feasible and track the progress of the mission if the plan is operational. It also indicates the reason for the failure if the plan was not feasible.

The architecture for Phase I was designed around two key points. First, the system is interactive with the user. The final decision as to the route that is taken lies with the operator. FAGAN will provide the information that the operator needs to make the decision in the form of an integrated picture of the known hazards, strategic locations, and goals of the mission. FAGAN will also analyze the route, provide suggestions on areas to avoid/achieve, and evaluate the performance of the mission as the mission proceeds. The second key point is that FAGAN is not a global search engine. FAGAN will not provide an indication on the optimality, nor try to find the optimal route. Route selection lies with the user. In this way, we avoid the no solution/too many solution problem since the operator is the final judge as to the route to take.

D.7.2. Functional Description

There are three types of intelligent agents which are activated in a sequence when need arises. The agents are the analysis agents, planning agents and navigation agents. Each agent is triggered in the required sequence by the intelligent agent coordinator.

D.7.2.1. Analysis Agents

This agent helps to evaluate and investigate local terrain/topological information along its circular area of coverage. This agent gets all the local, raw data it needs from the working memory when it is triggered by the intelligent agent coordinator. The information is processed by considering several factors like Observation, Cover and concealment, Obstacles, Key terrain, and Avenue of approach (OCOKA) and Cross Country Movement (CCM). After processing the analysis update is fed back to the working memory. Some missions might need only certain data from the working memory and may also need some updates such as weather information. In such cases the data request from the analysis agents will ask for the particular data through the intelligent agent coordinator and the FAGAN agent coordinator. If the analysis agents encounter any considerable problems in the user's route it asks for a new route by sending in a new data request.

D.7.2.2. Planning agents

Once a feasible path is obtained, planning agents are triggered by the intelligent agent coordinator. Planning agents evaluate the analysis data from the working memory and comes up with an optimal route to reach the destination. It evaluates a minimal cost function which would be mission dependant and may include factors such as minimum time, stealth, minimum fuel, and minimum risk. The detailed plan is again fed into the working memory. This agent also gets the data required by sending data requests through the intelligent agent coordinator.

D.7.2.3. Navigation agents

Once the detailed route plan is there in the working memory, the navigation agents are triggered to monitor the execution of the detailed plan. The purpose of the navigation agents is to analyze changes and monitor progress as the mission is being executed. If any actionable change is encountered, it is either displayed to the user for a decision or a change in route is suggested. The navigation agent does this through the intelligent agent coordinator and FAGAN agent coordinator which will activate the data arbiter agent to send messages to the overlay generator.

D.8. FAGAN WM Agents

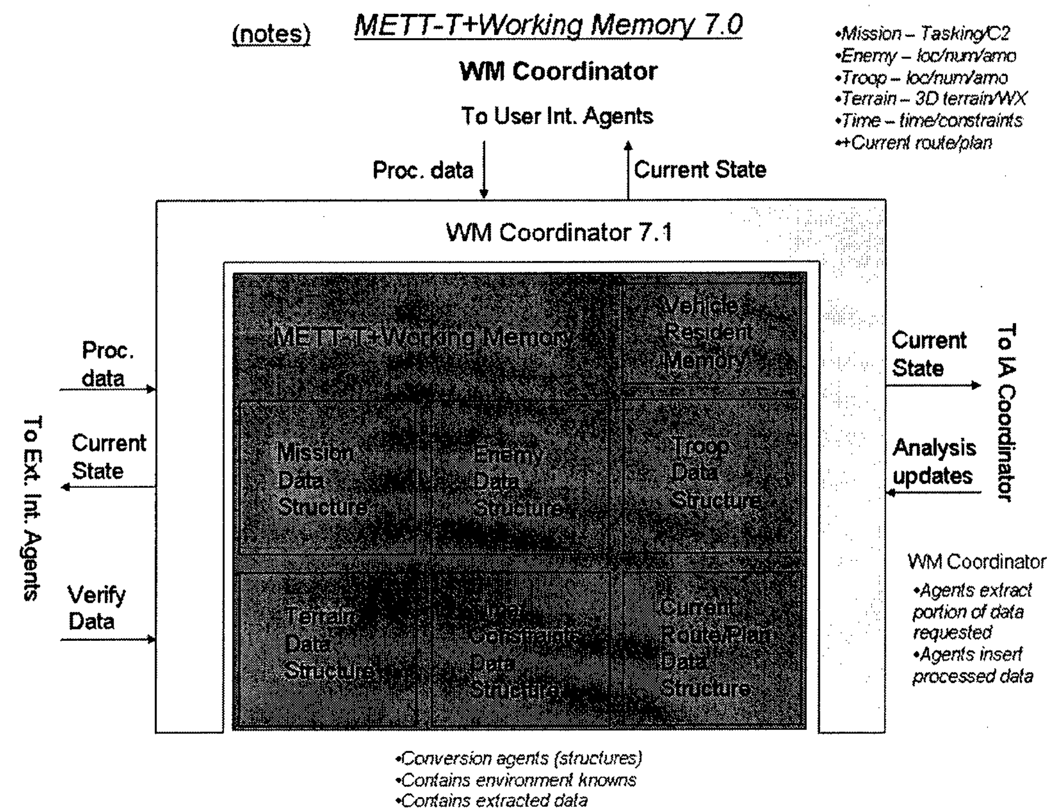

Figure 14. Working Memory (WM) and working memory coordinator.

D.8.1. Purpose

The Working Memory (WM) block is the central unit to the system. The purpose of the block is to store the information for the system based on Mission, Enemy, Troops, Terrain, and Time (METT-T). Agents contained in the WM Coordinator place and retrieve data in the WM.

D.8.2. Functional Description

The key aspect of the WM will be the data structures used. The data must be structured such that temporal and spatial dependencies between data types are preserved. For example, the WX data will be spatially located, but the duration is limited, and will move in time. However, a mine field is fixed in space, but is there for all time.

D.8.2.1. Resident Vehicle Memory

The first data type is on the specific vehicle that contains FAGAN. The data stored here will be speed, fuel consumption, grade limits, range, capacity, terrain crossing ability (i.e. water fording capability), weapons, armor, etc. All the data that will be used by the analysis agent must be stored here.

D.8.2.2. Mission Data

The mission data will store the a priori information about the mission. The data here will be mission target, stealth requirements, and speed.

D.8.2.3. Enemy Data

The enemy data will contain the information about enemy capabilities. Any enemy activity is contained here. The data here will be enemy movement, suspected objectives, weapons, armor, location, ambush areas, mine fields, etc.

D.8.2.4. Troop Data

The troop data contains the information on friendly troops. The data here would be information on the other vehicles in a convoy, supporting units (fire capability), etc.

D.8.2.5. Terrain Data

The terrain data contains the terrain information on the area of activity. Only the area of operation need be known. The data will be slope, condition (dry/wet), vegetation, soil type (rocky/sandy/grassy…), and weather data will be stored here as well.

D.8.2.6. Time and Constraints Data

Time and constraints are all the limitations placed on the movement. The data here would be available mission time, logistics, network accessibility, etc.

D.8.2.7. Current Route Plan

The current route plan is the known plan of action. The spatial and temporal planned movements are stored here. This is the end goal of FAGAN to create the route plan that meets all mission requirements.

In addition, the current route plan may be used to store additional route plans and their associated viability for history keeping. FAGAN will be able to use this history to provide further feedback to the user. The user could use this feature to create several alternatives and the select which one is best.

All the data structures listed in the next section are able to be stored and downloaded for After Action Review (AAR). The data stored can be used to evaluate the operator's performance. For example, during a training scenario, FAGAN will record the actions and decisions that the user enters into FAGAN. During the AAR, the evaluator judging the performance can look at what information was provided to the user and what decisions were made by the user. From this, the evaluator can run the trainee through the mission to show what mistakes were made. The history data can also be downloaded for real missions in the event of a mishap to discover the source of the problem.

D.8.3. Data Structures

D.8.3.1. Base structure

The base structure used to reference most other data classes is the latitude and longitude. Appended to the base structure is the ground elevation, grade, and terrain feature. The terrain feature will be in the form of properties such as vegetation, soil condition, etc. The terrain feature will primarily be used for cover and concealment calculations.

D.8.3.2. Base Reference in Time

Time data is stored in the data class structure after being referenced by the base structure. For example weather data will be referenced by location as well as start and end time of the event at the location (possibly predicted data).

D.8.3.3. Non-base Referenced Classes

There are some data classes that can not be referenced in space (or not efficiently stored by special reference). At this point, there are five data types: Mission, vehicle data, route plan, date and time, and RF connection.

D.8.3.4. Known Data Types

Table 1. Data types and descriptions.

Data Type	Description
Terrain	latitude, longitude, elevation, grade, feature
Weather	latitude, longitude, extent, t_0, t_f, condition
Static Obstacles	latitude, longitude, height, extent, disposition(friend, enemy, unknown, none)
Moving Obstacle	latitude, longitude, speed, type, disposition
Troop Type	latitude, longitude, size, type, disposition, readiness, resources(weapons)
Navigation Plan	latitude, longitude, objectives, critical issues
Mission	type(offense, defense, recon), objective, time constraints, mission constraints
Vehicle Data	max speed, max grade, payload, condition, armor, weapons, fuel
RF Connection	signal strength, frequency, type
Route	waypoints, time constraints
Date and Time	Seasonal data, time related data

D.9. Implementation Details

FAGAN uses the Agent Enhanced Decision Guide Environment (AEDGE®) from 21CSI which lets agents communicate efficiently and effectively amongst each other. The AEDGE® Agent Environment is a subscription network where agents may subscribe to different topics. As an example, when the External Interface Agent receives new entity information about a given region, it will signal interested agents on the topic "Entity Updates". This saves processing time, since the agents are only awake when they need to be.

FAGAN maintains a central storage component, the working memory, which contains all the information needed for the intelligent agents to make decisions. The working memory maintains a spatial index, specifically a Quad Tree, of all the entities in the system, reducing the overall search time per request. Terrain is stored in a list of nodes, which allows slope calculation between adjacent nodes to be performed efficiently. The working memory also stores analysis results of the different regions in the current path, allowing a simple interface to determine path feasibility.

Upon startup, the external interface agent will gather information about the current mission, constraints, and the current route for the entity. It will send out the event "New Plan Set", which will awaken the Intelligent Agent Coordinator (IAC). The IAC will check the data, and then send out multiple requests for terrain, entities, weather, and other information it needs.

When an update is received from the external interface agent, it will send out an event to the agent environment, which will then wake up any subscribers to that topic. The subscribed intelligent agent coordinator will start up, and tell the analysis agent to start execution within its own thread context, allowing the system to remain responsive while the agent works. The planning agent will be started, and will wait until the analysis agent has completed a large enough region to allow the planning agent to work. When the agents finish, the working memory is updated with the new plan.

An event will be sent out after this on the topic "Plan Update". Subscribers to this topic, commonly the external interface agent, will respond and interface with the data source.

FAGAN currently interfaces with the AEDGE® Simulator, a framework driven simulation service that models real life activities. The simulator can handle many different situations, from avoiding threat areas, high priority zones, to refueling capabilities. The AEDGE® Simulator is highly configurable, allowing scenarios to be read in through a configuration file, which contains information about entities, zones, commanders, and even orders for specific entities. The simulator is capable of providing a sensor-specific view of the region, as well as terrain and weather information.

The current implementation is geared for the single, human user. The human user will enter the initial plan via the interface screen. FAGAN will indicate the viability of the route and provide information on possible hazards. The final decision on the route lies with the user; FAGAN only recommends and advises. Future work will include the addition of commander level FAGAN where a commander can use a FAGAN variant to advise a group of FAGAN units. This then will have a natural extension into the autonomous realm where the FAGAN group would be robotic units taking instruction from the command FAGAN.

D.9.1. Overview

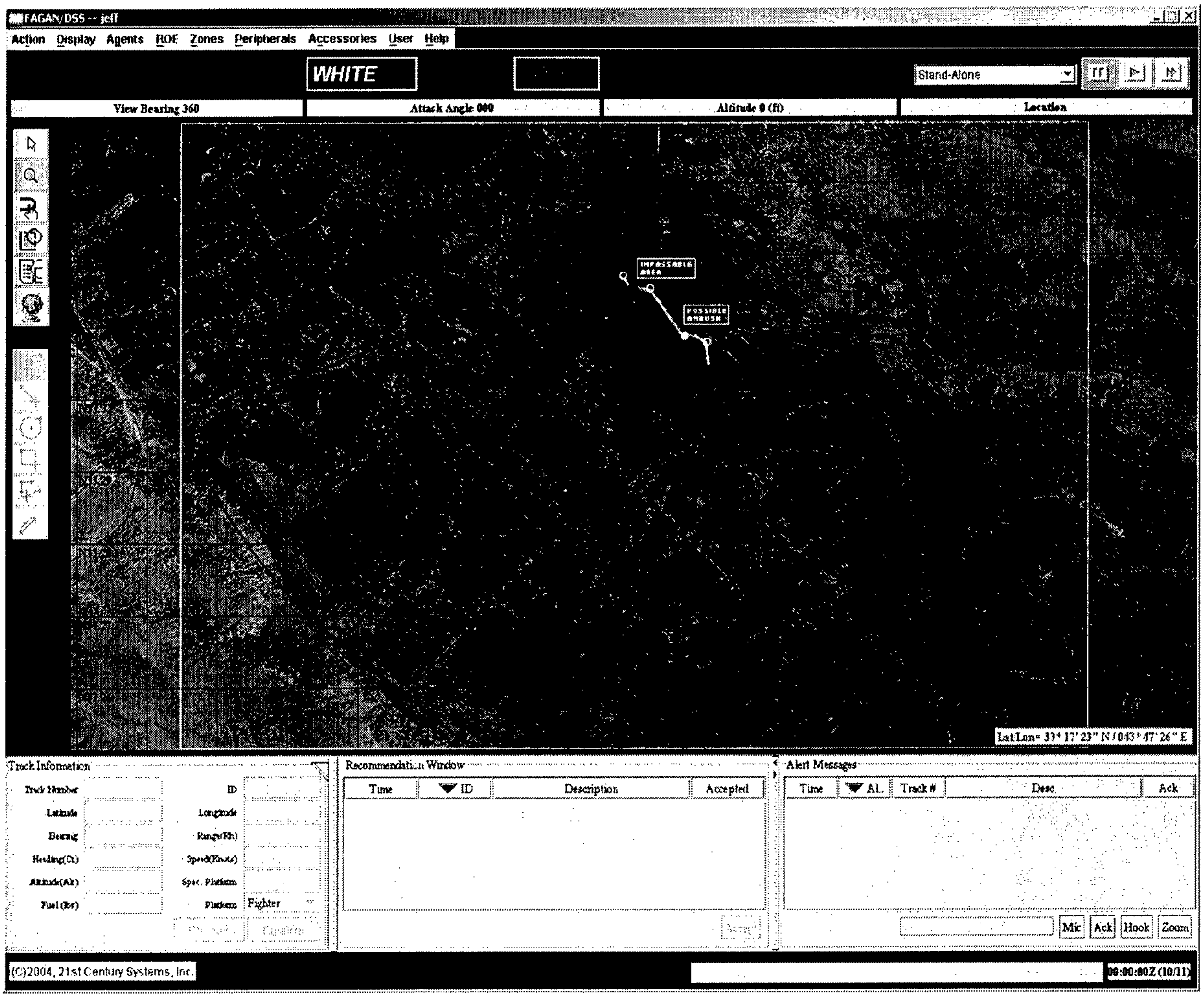

Figure 15. Overview of possible scenario (screen shot).

The screen shot above shows a large view of a possible operational area for the FAGAN project. The screen shot was developed using the Joint Force Open Component Simulator (JFOCS). This simulates the type of input screen that the user will encounter. This is an actual screen shot of the system where the user has entered the initial path for analysis. Two situational zones indicated on the screen are detailed in the following sections. The analysis portion was not ready for this screen shot. A working prototype will be completed around the beginning of March.

D.9.2. Ambush Detail

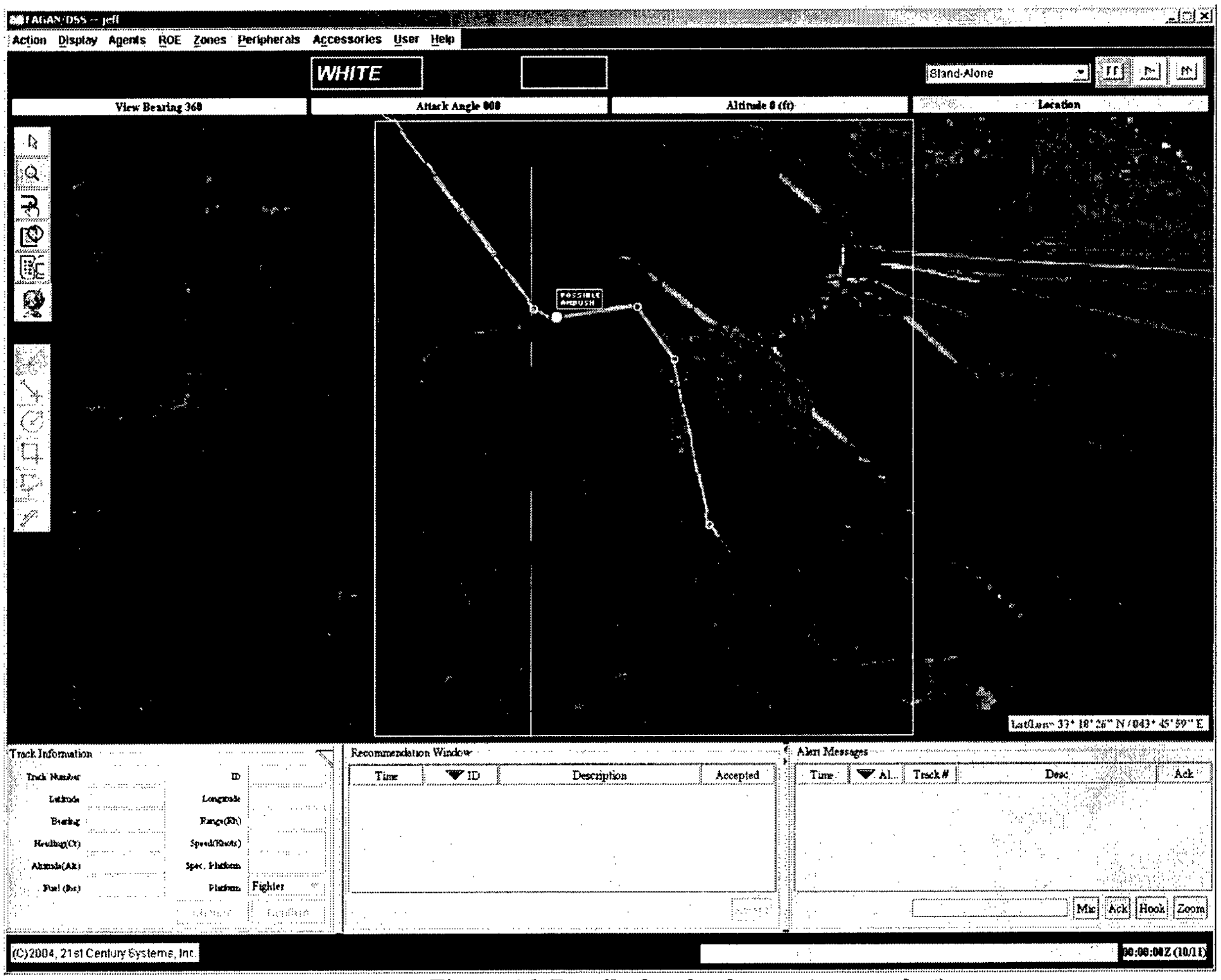

Figure 16. Detail of ambush area (screen shot).

The above screen shot shows a blow up of the ambush area that is indicated by FAGAN. The ambush area was pre-programmed into the memory for the screen shot. Normally, the analysis agents will recognize the existence of the ambush area from the tactical information being received and then alert the user interface agent. But for this demonstration, the user interface was given the information directly.

D.9.3. Impassable Area Detail

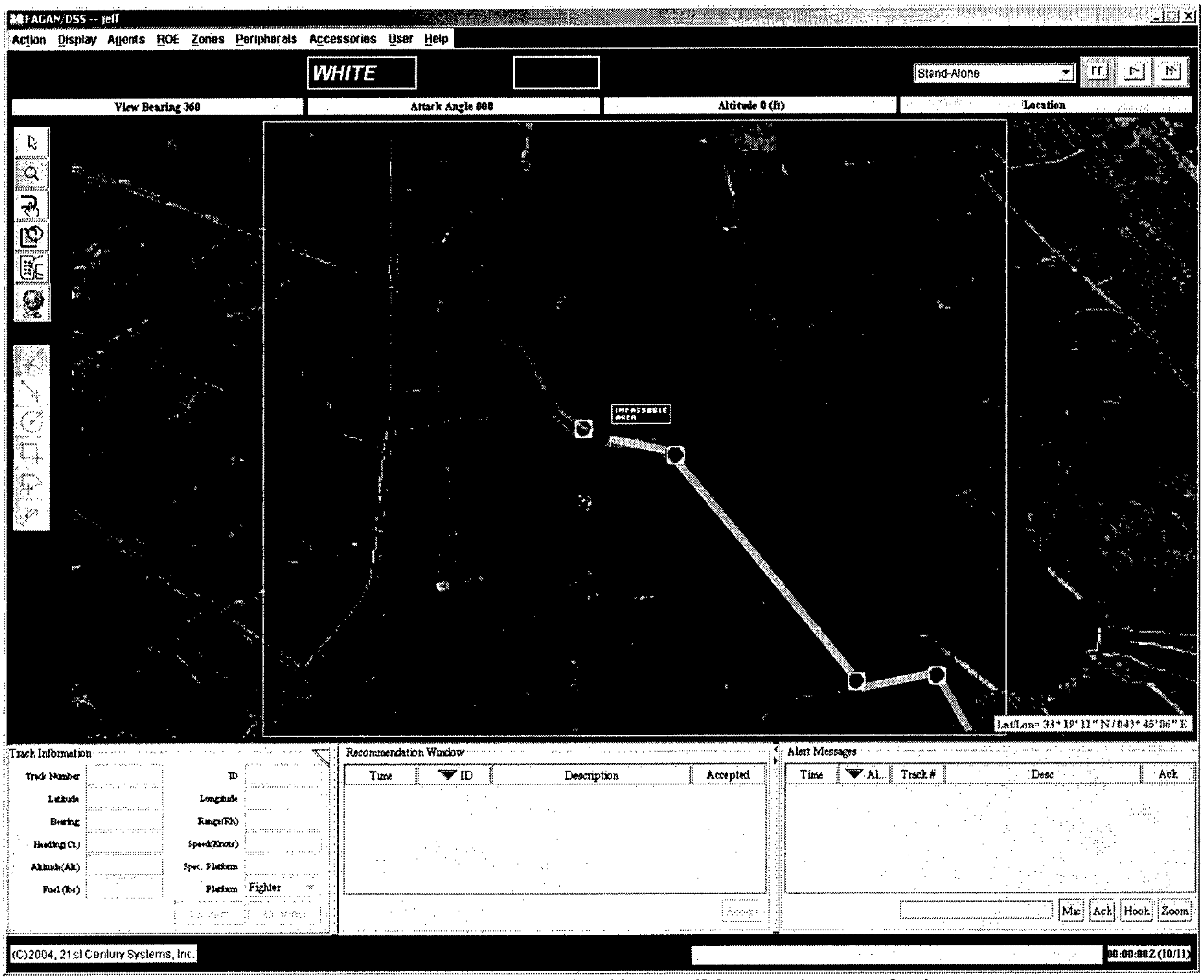

Figure 17. Detail of impassible area (screen shot).

The above screen shot shows a blow up of the impassible area that is indicated by FAGAN. The impassible area could be due to a flooded out bridge. The impassible area was pre-programmed into the memory for the screen shot. Normally, the analysis agents will recognize the existence of the impassible area from the tactical information being received and then alert the user interface agent. But for this demonstration, the user interface was given the information directly.

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