Integrating M&S Representations of the Natural Environment into a C4ISR System for Decision Support

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ABSTRACT: *Models developed for Modeling and Simulation (M&S) projects can be used in a Command, Control, Communications, Computer, Intelligence, Reconnaissance, and Surveillance (C4ISR) system to compute visibility and mobility of forces under current and anticipated environmental conditions. To show this, an experimental infrastructure was developed to use models of the natural environment and its effects on military equipment, in a C4ISR system. The models are used by the C4ISR system to make predictions concerning the effects of the environment on mission outcomes. The Army Experiment 5 (AE5) scenarios, and example tactical decision aids (TDA), are used to exercise the system. The models used in this project come from the Joint Semiautomated Forces (JointSAF) system developed for the Synthetic Theater of War (STOW) ACTD. The C4ISR system is the Advanced Command and Control (AC2) decision support system. The AC2 system is a course of action (COA) development tool built as an extension to the Army's Maneuver Control System (MCS) to aid in the Military Decision Making Process (MDMP). The Common Object Request Broker Architecture (CORBA) serves as a coupling mechanism between components.*

1. Introduction

The use of Modeling and Simulation (M&S) technology in Command, Control, Communications, Computer, Intelligence, Reconnaissance, and Surveillance (C4ISR) systems for decision support has been a topic of recent study [12]. The M&S community has spent much time and effort on implementing models of the natural environment [15]. The natural environment has a profound impact on the outcome of military missions, but currently, C4ISR systems are somewhat limited in their ability to reason how the natural environment will affect military systems. Extensive work has been done by the United States Department of Defense (DoD) M&S community in modeling the natural environment and in modeling the effects of the natural environment on military equipment. These models have been largely verified and validated for accuracy and designed for speed. Recently the C2 community has recognized the need to represent the natural environment in C4ISR systems. The Integrated Weather Effects Decision Aid (IWEDA) project [10] is an example of this trend.

Our hypothesis is that environmental models developed for the M&S community can be integrated into C4ISR systems and used for environmental reasoning within the system. For this research, an experimental prototype was built to support this hypothesis.[1]

To aid in our discussion, the concept of *environmental modeling and reasoning* (EMR) is introduced. EMR considers not only terrain in the modeling of the environment but other natural phenomena as well, such as clouds, smoke, fog, precipitation, wind, temperature, tides, sun cycles, moon cycles, etc.

[1] This work was conducted as part of the MITRE Corporation's Predictive Battlefield Environments (PBE) MITRE sponsored research (MSR) project.

Environmental modeling involves models of the natural environment populated with data that are used for environmental reasoning. *Environmental reasoning* involves models of man-made systems, like vehicles and sensors, modeling their interactions with the natural environment. These models are used to answer questions in the C4ISR system. For example, a simple terrain line-of-sight computation is only useful if one is willing to assume the viewer can see infinitely far as long as the terrain does not intervene. In many cases this is not acceptable. There may be clouds, smoke, fog, or rain obscuring a target. It might be nighttime with only starlight present. The viewer may be using night vision goggles or infrared sensitive sensors. The vehicles may be emitting electromagnetic radiation. All these are factors in whether or not an object or point on the terrain can be seen by a viewer some distance off.

A C4ISR system is a form of decision support system (DSS). To define DSS, we use a similar definition to that found in [13], that is, a DSS is an information system designed to simplify and accelerate the decision making process by collecting, obtaining, providing and assessing information.

In the following sections, section 2 describes some previous work. Section 3 describes the system architecture. Section 4 discusses future work, and section 5 concludes the paper.

2. Previous Work

This section discusses IWEDA, DSS-model coupling, and the tactical decision support system (TDSS). The TDSS is most closely related to this research work.

2.1 IWEDA

The Integrated Weather Effects Decision Aid (IWEDA) [10] is a good example of the current state-of-the-art in environmental modeling and reasoning for DoD C4ISR systems. IWEDA is fielded with the Integrated Meteorological System (IMETS) and is available from most Army Battle Command System (ABCS) components, including the Maneuver Control System (MCS). IWEDA acquires gridded weather data over a 24-hour forecast period from the IMETS server at a 10-km grid resolution. A Weather Effects Matrix (WEM) is displayed to the user, indicating environmental impact on weapons systems. The IWEDA WEM displays a grid where rows correspond to particular weapon systems and columns correspond to different times. Each cell in the matrix is color coded to indicate the impact of weather on a weapon system at a particular time. Red indicates unfavorable, amber is marginal, and green is favorable. The user can query the system for a detailed description of the type of impacts indicated. For example, "freezing rain, greater than light, may freeze the missile to the chaparral launcher rails and reduces the overall system effectiveness". The user can also display a map overlay to show the distribution on impacts over an area of interest. The models used by the system consist of a set of rules derived from field manuals and other sources.

2.2 DSS-Model Coupling

The most extensive work to date, in DSS-model integration, has been in the area *of environmental management information systems* (EMIS) [6]. EMIS uses *geographic information systems* (GIS) and environmental models to support environmental management activities. Although the problem domains of command and control and environmental management are different, the fundamental issues of C4ISR DSS-model coupling and GIS-model coupling are the same.

The terms *loose coupling* and *tight coupling* [4] are used to describe different approaches to GIS-model integration. Loose coupling is a method of integration in which common files are used as the exclusive means of data exchange between otherwise independent GIS and environmental modeling systems. Using this approach, the GIS serves as a preprocessor or postprocessor to the modeling system. The advantage of this approach is simplicity. This level of integration between a GIS and modeling software is easy to achieve. Typically all that is needed is a simple interface and perhaps some common file data format conversion routines. The disadvantage is inefficiency and a lack of versatility.

The *Spatial Decision Support System* (SDSS) shell, as presented by Djokic [2], is an example of loose coupling. It is a decision support tool consisting of a collection of components. In [2], a general method of creating interfaces by linking sub-components of the system via a common command shell is presented. The shell allows the user to compose functionality of components in shell scripts, or interactively at the command line. System components consist of a GIS, an expert system (ES), and numerical models (NM). For a system (GIS, ES, or NM) to be included as a component of an SDSS shell it must meet four criteria: 1) The component should be as close to state-of-the-art as possible. 2) Each component must have an open file format for data transfer between components. 3) Each component must be controllable via standard keyboard input. 4) Components must run in a common computer environment. For systems that store data in different file formats, a common intermediate flat ASCII file format is used. This intermediate file format serves as a “data bridge” between systems. A common “command bridge” shell command interpreter must also be developed.

The SDSS shell described in [2] uses the ARC/INFO GIS, Nexpert Object expert system, and the HEC-1 rainfall runoff model as components. This particular example SDSS shell is not given a name. The purpose of the example system is to analyze watershed rain runoff. In the example, the expert system extracts parameters from the GIS and passes them to the HEC-1 numerical model. The results are then stored back into the GIS. The expert system is used to control the interaction of the GIS and NM. The GIS acts as a preprocessor to the numerical models. The expert system replaces an expert user who would otherwise be controlling this interaction. Models are not used within the GIS component itself.

The second approach, tight coupling, involves a common user interface to system components, common data structures, and GIS-model interaction through mutually accessible procedures. The primary advantages to this approach are efficient interaction between models and GIS, and versatility of model use. The GIS and modeling components of the system exchange data structures via shared memory, network communication, and shared files. Model component functionality can be invoked within the GIS at the procedure level. A disadvantage of many tight coupling approaches is the difficulty involved in modifying and integrating system components. The CLIMEX system, presented by Fedra [4], is an environmental decision support system used for global change modeling and assessment. It incorporates natural environment models such as agricultural and atmospheric models into a GIS using a tight coupling approach.

2.3 The Tactical Decision Support System

In [7] the authors describe the *tactical decision support system* (TDSS). Models of the natural environment and how the environment affects vehicles and sensors, are integrated into a GIS using a tight-coupling technique using CORBA. The purpose of the system is for *tactical decision support* (TDS). The TDSS is a decision support system for operation in a dynamic real-time setting where the decision-maker is responsible for guiding and directing deployed people and equipment.

Note the distinction between a TDS system and an EMIS. An EMIS is used in support of the decision-making process to help manage and make predictions about changes in the natural environment. The user of an EMIS is primarily concerned with how man-made or natural phenomena might affect aspects of the natural environment, such as how a new bridge will impact the ecosystem around the Chesapeake Bay, or how a longer hunting season might affect the local deer population over time. TDS, on the other hand, is concerned with managing people and their equipment. In other words, how will the natural environment impact the performance of machines? For example, how will snow affect the visual range of an aircraft, or how will rain impede the mobility of a tank? The natural environment does play a significant role in TDS, but a TDS system is not an EMIS.

In [7], a tightly coupled approach is used to integrate a GIS and environmental models. The components of the TDSS consist of a modeling component, a spatial database, and a system front end. The spatial database used is known as SAND [3]. SAND provides the fundamental storage mechanisms, access methods, data structures, and operation primitives for the system. The modeling component of the system, referred to as the *environmental model server* (EMS), was derived from JointSAF developed for the STOW'97 ACTD [15]. JointSAF implements a set of integrated models of the natural environment, vehicles, and sensors. The third component is called the Spatial Spreadsheet [8]. It serves as the TDSS front end. It is used to visualize changes in a dynamic spatial database. It also serves as a means to organize large amounts of spatial data, quickly formulate queries on data, and propagate changes in the source data to query results via a spreadsheet paradigm.

The coupling of the EMS component to the rest of the system is achieved through the *Common Object Request Broker Architecture* (CORBA) [11]. In general, the main drawback to a tightly coupled architecture is the amount of work needed to adapt new environment models to an existing system. To overcome this drawback a set of interface specifications is used for information transfer between models and the rest of the system components. The idea is to make the interface general enough so new models can be incorporated into the GIS using the same interfaces as existing models. If successful, no additional work need be done to adapt new models. The only requirement is the new models must conform to the interface specification. To make the specification useful it should be independent of the model and GIS implementation languages, and independent of computer hardware architecture. CORBA IDL [11] fulfills these requirements for a specification language. The Spatial Spreadsheet acts as a CORBA client to the EMS. The advantage of this architecture is independence between the EMS and the spatial database components. This allows for different model servers to be used in different applications to fulfill different user requirements for fidelity and efficiency.

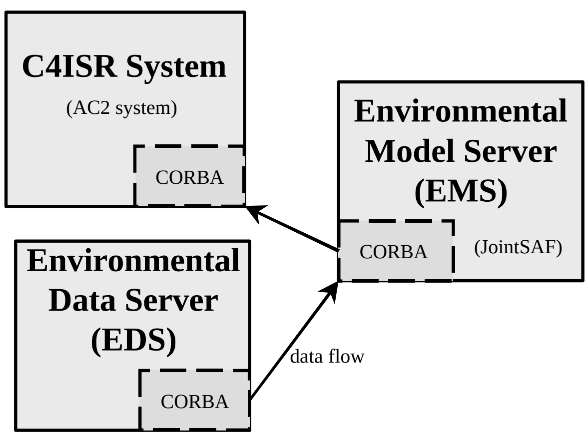

Figure 1: Architecture

3. Predictive Battlefield Environments

The Predictive Battlefield Environments MSR work is an extension of the work done in [7]. In this section we present a high-level view of the Predictive Battlefield Environments (PBE) research project system architecture, discuss the PBE system components, and describe some tactical decision aids used to drive the system.

The goal of this work is to show M&S modeling technology, as it applies to the natural environment, can be used in C4ISR systems. To do this a method to access the models from a C4ISR system is needed. In addition, applications to exercise the system to show its potential usefulness are needed.

Although this proof-of-concept demonstration is derived from specific systems, other systems can be used. For this work CORBA is used to access models from a C4ISR system; however, other means, like the HLA RTI [5], are possible. Likewise, the choice of C4ISR system need not be limited to that used here. The AC2 system extension to MCS was chosen for this work, but other systems can be used, such as systems based on the Joint Mapping Toolkit (JMTK) or other ABCS system components. For the M&S component, any system with suitably fast and accurate natural environmental modeling capabilities can be used instead of JointSAF. The choice of systems for this particular research was a matter of convenience.

3.1 System Architecture

The same approach used for DSS-model integration in [7] was also used in this research. We use a tight coupling approach using CORBA. The components of the system consist of an Environmental Model Server (EMS), an Environmental Data Server (EDS), and the C4ISR system otherwise known as the *client* (see figure 1). An MCS extension called the Advanced Command and Control System (AC2) [9] serves as the client.

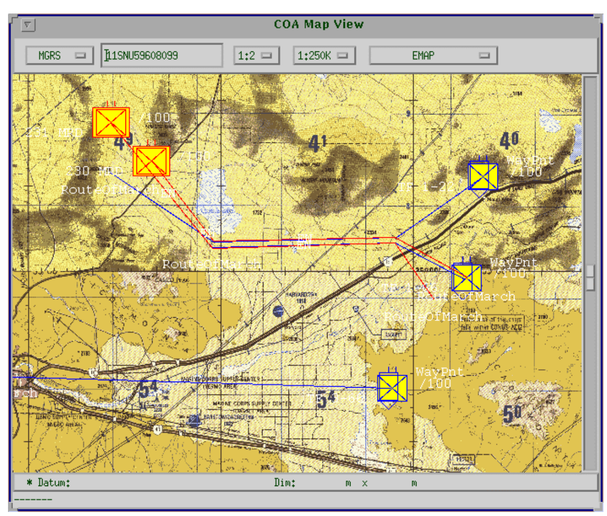

Figure 2: AE5 scenario: three friendly units on the right and two enemy units on the left

For a source of integrated models of the natural environment and military equipment, JointSAF [15] is used. JointSAF is a piece of modeling and simulation software used for military training and mission rehearsal. It provides a set of integrated models of the natural environment, vehicles, and sensors modeling their interactions with each other. These models are computationally light and have been verified and validated to be accurate representations of the real world sufficient for training and mission rehearsal.

The EDS is used to feed spatio-temporal data, consisting of gridded weather information, to the EMS. For this research a simple EDS was constructed to deliver data through a CORBA IDL interface. Other systems, such as the Integrated Meteorological System (IMETS) [10] server, could also be adapted to serve as an EDS component.

The Advanced Command and Control (AC2) system [9] is a prototype system for command and control (C2) decision support, and battlefield visualization. The objective of the AC2 effort was to augment current C2 tactical information management systems with direct support for the decision-making process.

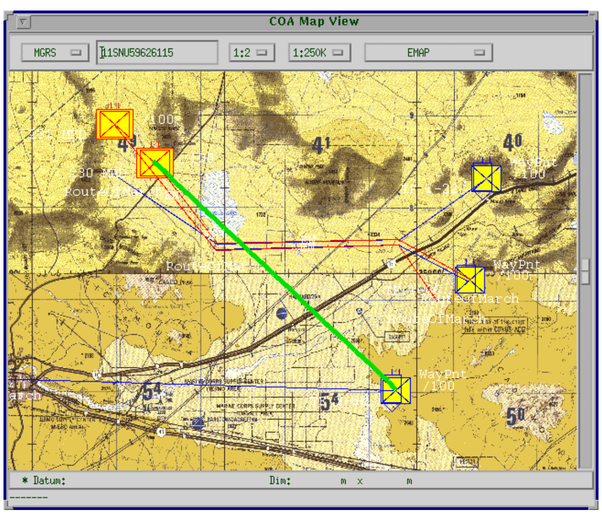

Figure 3: IV-TDA in clear weather

Researchers designed the AC2 system to help with the Military Decision Making Process (MDMP) [1] for creating and monitoring combat plans. In particular, the system supports collaborative planning between an operations officer (G3) and an intelligence officer (G2) in the course of action (COA) development and COA analysis phase of the MDMP cycle. The AC2 system is invoked as an application of the Army's Maneuver Control System (MCS). The AC2 system integrates current situation information, environment, friendly and enemy COAs into a common picture. The G2 and the G3 can access this information, create COAs, and monitor COA changes. The AC2 system consists of several applications including the Force Ratio Tool tactical decision aid, the COA Developer for collaborative planning, a wargame engine for the wargaming of COAs, and the Synchronization Matrix to monitor actual progress on the battlefield compared with current plans.

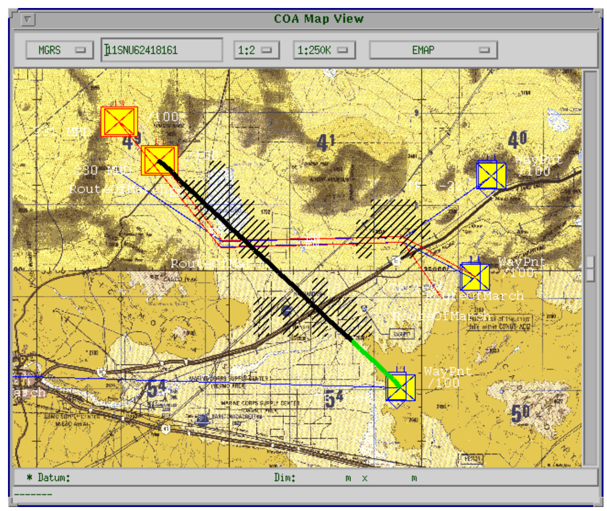

Figure 4: IV-TDA with atmospheric obscurants present

A map window can display units, control measures, overlays of terrain and other information (see figure 2). Figure 2 shows an example scenario from Army Experiment 5 (AE5) [14]. AE5 was used to test the PBE system and is used in examples throughout the remainder of this paper.

The PBE researchers developed a number of tactical decision aids (TDA) to exercise the C4ISR-model interface. The TDAs use information provided by the EMS to calculate results. The EMS in turn receives data from the EDS to instance its models (see figure 1). The EDS stores gridded weather data indexed by time. A system clock keeps track of the current time of interest defined by the user. When the clock changes, the EDS feeds data to the EMS to update environmental models and keep them consistent with the new time of interest. This is one major difference between [7] and this work. The TDSS in [7] does not support temporal data.

3.2 Tactical Decision Aids

The primary purpose of the tactical decision aids developed for this research is to provide an example of how environmental modeling and reasoning may be used in a C4ISR system. The TDAs hide the details from the user. The user need not be an expert in meteorology, or have any special training in the use of models. The TDAs are also used to test and demonstrate the system.

Part of the MDMP is *intelligence preparation of the battlefield* (IPB). This includes gathering all relevant information in the area of interest about the battlefield environment. To aid in this task the PBE system has a number of IPB TDAs. The simplest IPB TDA is the point query tool. This tool allows the user to click on a point in the map window, and display information about the environment for that location at the terrain surface.

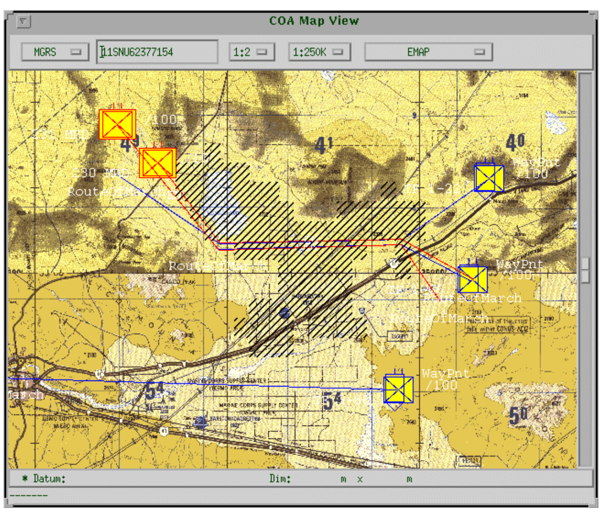

Figure 5: Fog bank at time H0

Another TDA is the point-to-point intervisibility TDA (IV-TDA). It calculates how visible a target is from a given point. The IV-TDA can use terrain or atmospheric obscurants, or both, to calculate visibility. Atmospheric obscurants include clouds, smoke, dust, precipitation, etc. The IV-TDA renders a shaded line on the map window from an observer location to a target location. The darker the shading the less visible are targets on the terrain along the line segment. Figure 3 shows visibility, from a friendly unit on the right to an enemy unit on the left, in clear weather. Figure 4 shows visibility in foggy weather. The IV-TDA uses algorithms supplied by the JointSAF EMS. The C4ISR system invokes a CORBA interface, passing an observer location and a target location to the EMS. The EMS calculates the result and returns it to the C4ISR system. The C4ISR system then renders the result in the map window.

Other IPB TDAs are used to visualize spatio-temporal gridded weather information. These TDAs create overlays on the map window reflecting the current state of the environment or some state in the future. Figure 5 shows a fog bank overlaid on the map window at time H0. Figure 6 shows the fog bank partially dissipated at time H1. The future environmental data can be derived using predictive weather models. Some currently fielded systems, like the IMETS for the Army Battle Command System (ABCS) [10], provide spatio-temporal data derived from predictive weather models.

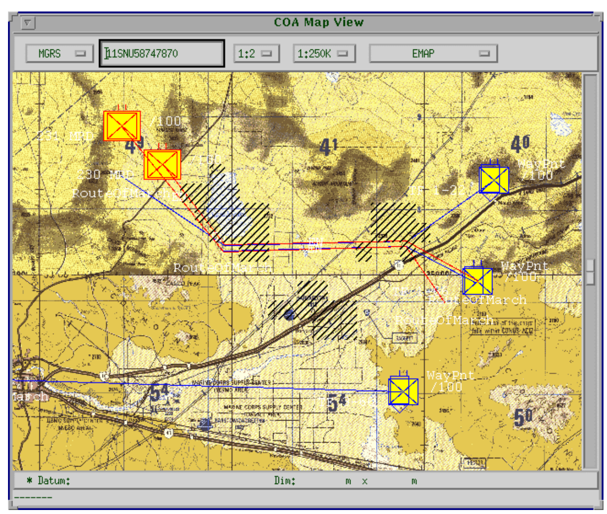

Figure 6: Fog bank at time H1

Many of the tactical decision aids, used to exercise the C4ISR-model interface, produce spatial data as output. The output is displayed graphically as overlays in the map window. When the time of interest changes, the map window overlays are updated to show changes in TDA output as a result of new environmental states. The clock can also be cycled to animate changes over time in map overlays.

The mobility TDA (M-TDA) computes trafficability for a given vehicle type over an area of interest. The M-TDA can take terrain, environmental conditions, or both into account when computing mobility. Figure 7 shows an advancing storm. Figure 8 shows an area of slow-go mobility as a result of the storm. Colors in the overlay indicate varying degrees of mobility for the region. Yellow indicates slow-go areas, red indicates no-go areas, and green are go areas.

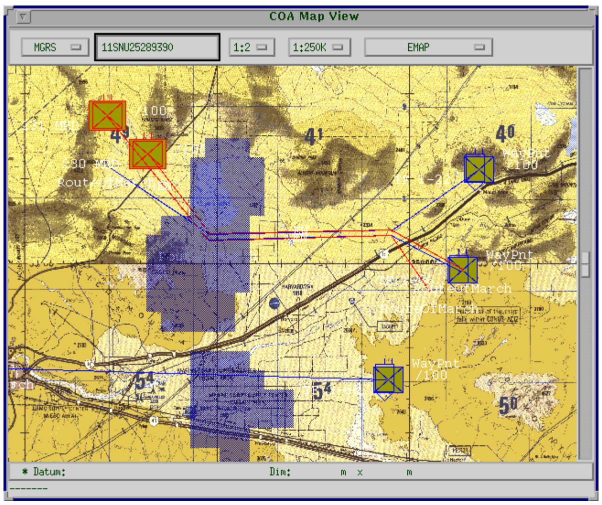

Figure 7: Advancing storm

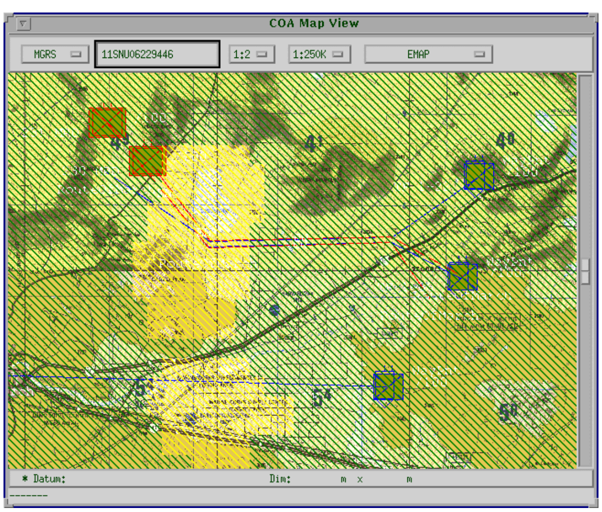

Figure 8: Yellow or lightly shaded area shows decreased mobility zones

There are many other possible TDAs that can use environmental models in their calculations. For example, a masked area plot map overlay computes visibility over an area. An average visibility range calculator shows average visibility distance for a given sensor type. A TDA can show the areas of terrain visible from an aircraft, or show the minimum altitude to keep a particular point on the terrain in view. A TDA can show how long it might take to get from one location to another, compute trafficability corridors, or view sheds. These are all examples of TDAs that can use environmental modeling and reasoning to consider environmental conditions in their calculations.

4 Future Work

We plan to extend the set of TDAs to more fully exercise the available models. For instance, the IV-TDA takes into account only some of the possible atmospheric obscurants. This TDA will be expanded to consider other atmospheric phenomena like precipitation rate and precipitation type.

5 Conclusion

The approach presented here for extending C4ISR decision support systems with existing M&S models of the natural environment, can be used to enhance capabilities of existing C4ISR tactical decision aids, or for developing entirely new ones.

Many models exist. It’s only a matter of integrating them. This work is a step in that direction. We have successfully developed an infrastructure by which models can be applied to generate environmental reasoning capabilities within a C4ISR system.

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