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Situation Awareness of Commanders: A Cognitive Model

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ABSTRACT: *This paper discusses a computational model of situation awareness (SA) for military command and control in complex battle situations.*

Cognitive modeling is a research method that does not forgive vagueness. How do military commanders create awareness in a highly complex and uncertain world? The model described in this paper simulates computationally some of the cognitive operations performed by commanders during the evaluation of a complex battle situation.

Although the set of cognitive processes that support SA are still not well understood, we have hypothesized a meta-architecture involving: information gathering, assessment, and alternative generation. The cognitive model reported here paves the road towards a more complete and valid representation.

The model was implemented using ACT-R, a cognitive architecture, and tested with scenarios running in OTB, a simulation tool for war scenarios.

1. Introduction

This paper discusses a computational model of situation awareness (SA) for military command and control. Situation awareness (SA) has been defined as the process of perceiving the elements in the environment, understanding the elements in the environment, and the projection of their status into the near future [1].

Military decision making (MDM) is a complex process achieved by teams with incomplete, uncertain information and often under time constraints. MDM can be seen as a process where commanders continuously assess the situation, set goals, and plan actions to achieve the goals. This process requires gathering and analyzing large quantities of information about the battlefield. Commanders make decisions often based on their experience and their training. MDM is both art and science because while some operations, such as movement routes, fuel consumption and weapons effects, are quantifiable; other factors, such as the complexity of the operations and uncertainty regarding the enemy intentions, are difficult to quantify [2].

The military decision making process (MDMP) is defined to help commanders and their staff in the

process of analysis and decision making. The traditional MDMP consists of seven steps: mission reception, mission analysis, development of the course of action (COA), COA analysis (war game), COA comparison, COA approval, and production of orders. As the commander follows these steps, he is made aware of certain factors that need to be considered in making a decision. Another information source that enriches the awareness of commanders is the intelligence preparation of the battlefield (IPB), which is a continuous process of analyzing the threat and the environment [3].

In this paper, we introduce a cognitive model that reproduces the commander's behavior during the execution of a battle. The cognitive model is supported by ACT-R, a cognitive architecture that has a broad history of research and accounts for many empirical results from experimental psychology [4] [5]. It is hybrid architecture of cognition, which combines a production system to capture the sequential, symbolic structure of cognition, together with a sub-symbolic, statistical layer to capture the adaptive nature of cognition. ACT-R researchers build integrated cognitive models to demonstrate how different components of the mind work together [5].

The cognitive model described here is different from the previous SA models. While it simulates the

commander's SA in different environments and scenarios, it also produces quantitative data to evaluate situation awareness in its different levels. The fact that the cognitive model can answer SA questions makes it possible to compare data produced by the model with empirical data obtained from human subjects interacting with the system. Another difference from the previous models is that this model consists of several software components to simulate commander's interaction with a team to understand a situation. The software components that act as team members can be manipulated using parameters such as, the number of intelligent agents, their positions, or the scenarios.

This paper has the following organization: (1) we describe previous SA models in command and control; (2) we enumerate the requirements for a SA model, (3) we describe our model (4) we give an example session with the system, and (5) we describe how the system evaluates the SA model.

2. Existing Cognitive Models of Command and Control

Many research projects have attempted to model cognitive aspects of commanders' decision making in complex battles. For example, the project "training critical thinking for the battlefield" aimed to develop a theory of cognitive skills that allow one to function in uncertain domains; develop methods for training those skills in the context of Army battlefield; and develop an architecture to support adaptive instruction and feedback in critical thinking training [6]. The project studied how training affected the use of critical thinking. After being trained, the commanders used more proactive strategies than they used before. Using interviews from commanders, researchers developed the cognitive structure and possible strategies used by commanders during an execution of a battle. Then, researchers developed a computer architecture to support adaptive feedback in critical thinking.

Another similar example is the work on modeling situation awareness for command decision making by Kreckler [7]. Kreckler, Gilmer and Knox (1995) presented a model of situation awareness that simulates how a commander integrates information from observations, sensors, orders, and reports with their knowledge of doctrine and tactics to develop an individual understanding of the situation. The model of SA consists of battlefield state (units and environment objects) and operation structure (roles, relationships, and phases of operations).

A cognitive framework for battlefield commanders' SA was also developed by Cohen, Adelman, Tolcott, Bresnick and Marvin (1993) [8]. The framework has three components: memory structures, value/action structures, and meta-cognition or executive processes. The model of situation assessment is defined in terms

of limited space in working memory, errors in retrieval from long-term memory, and the cognitive effort required by the executive process. They also distinguish between two models of processing: procedural and knowledge-based. In addition they also distinguish between many long-term structures, such as plan structure, enemy goals, strengths and opportunities, among others.

The model described here is different from previous commanders' models because it addresses the complete situation awareness processes instead of only situation assessment. A particular characteristic of this research is the computational implementation of the model that is based on a cognitive architecture that interacts in real-time with realistic war scenarios in a complex simulation. More intuitive ways to perform decision-making will be explored with this model.

3. Requirements for Modeling

This section presents a list of requirements for the cognitive model that simulates commander's decision making.

Although it is almost impossible to model the full spectrum of cognitive processes that must be going on while a commander directs a battle, a computational model can simulate some of the cognitive processes used by commanders in real life. There are several challenges in doing this. First, given the technology limitations, it is hard to encode the commander's experience accumulated in military universities and in the battlefield. Second, it is challenging to encode "common sense" knowledge that often develops with experience and plays an important role in decision making. Third, the complex representation requirements for battle scenarios include terrain knowledge and reasoning, units' formations and strategies, doctrinal and situation templates, events and courses of action planning, among others. Fourth, the process of decision making is performed usually in collaboration with staff teams, often with diverse expertise and skills. Finally, additional challenges include the appropriateness and realism of the tools, used to simulate scenarios that could interact in real-time with the cognitive architecture.

Previously, we have presented these requirements for a cognitive model of SA in a meta-architecture [9]. Figure 3.1, summarizes the requirements for the cognitive model of SA. The model of SA requires the support of sub-models shown in Figure 3.1, such as control, memory structures, situation assessment, information gathering, planning, plan recognition, and learning.

Next, we describe the design goals and research requirements for the cognitive model.



Figure 3.1: Requirements for the Cognitive Model of SA

3.1 Goals

A cognitive model of SA might be used to study issues such as:

- The impact of memory in the process of situation awareness
- The process of information gathering and fusion in situation awareness
- The influence of situation representation in situation awareness
- The influence of doctrinal templates reasoning in SA
- The relationship between situation representation and course of action selected in the process of learning
- The process of course of action (COA) generation that includes temporal reasoning analysis
- The process of reasoning in situation assessment for SA
- The process of plan recognition to predict events in SA

3.2 Research Requirements

The research platform of a cognitive model must be flexible, adaptable, and with capabilities to customize data reports to study interactions between model parameters and SA performance. Some of the requirements are:

- The system must produce data that can then be validated with empirical data. It is not enough to implement a model that simulates a commander making decisions, it is also necessary to have methods to validate the model with data obtained from human subjects.
- The simulation platform must allow an easy aggregation of new software elements for the simulation platform. For example, adding new staff agents such as a logistics agent or a fire and support agent should be transparent for the simulation.

- The simulation elements must have parameters that can be manipulated to change their behavior. For example, accuracy, and omission errors might be defined different for each software agent to study the impact of these parameters in the SA performance.
- Finally, the model must be adaptable to simulate the particular style of commander. For example, the system might simulate a commander that delegates tasks to the staff while another model might simulate a commander that centralizes decisions.

4. Commander's Cognitive Model

The cognitive model was implemented in ACT-R, however, given that an individual cannot manage the complete information gathered from the battle field, we also used software agents that process some information before it is processed by the cognitive model. This model uses intelligence and terrain agents to assist the commander.

Figure 4.1 shows the architecture used to study commander's SA. This diagram demonstrates that the agents are intermediaries between the commander's model and the battle simulation. The system components are described in the following paragraphs.

4.1 Cognitive Model

ACT-R is a cognitive architecture that simulates human cognitive processes. Models implemented in ACT-R encode declarative knowledge using memory chunks, and procedural knowledge using production rules. Figure 4.1 shows the cognitive model and its interactions with software agents such as intelligence agents, the terrain agent, and the friendly staff agent.

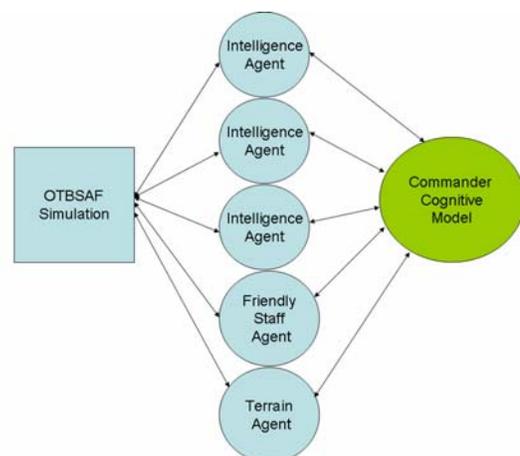


Figure 4.1: Cognitive Model Interacting with the Staff

4.2 Control

The control component decides how the multiple tasks will be performed by the simulated human. In this task it is assumed that the reactive behaviors are not available and instead the decisions must be planned after doing detailed analysis of the situation.

Figure 4.2 shows four processes executed by the cognitive model in a loop until the model finishes or fails to achieve the mission. The goals in a model are presented as memory chunks with multiple attributes, for example, the model's mission is a set of goals in ACT-R. The model first runs the different sub-models that monitor the environment. After that, the model evaluates the situation by firing production rules. It then analyzes possible threats based on doctrinal templates and data obtained from the battlefield. Finally, the model fires rules to generate a course of action based on the situation assessment. The model repeats this cycle until the mission is achieved or it fails.

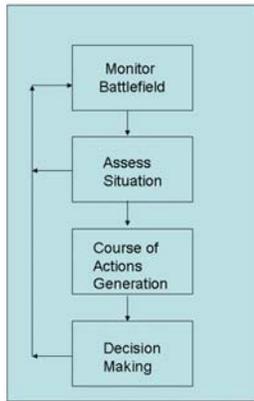


Figure 4.2: Cognitive Model Flow Diagram

The model monitors the battlefield following a checklist (METT-T) that allows a commander to estimate the situation. METT-T is an acronym that stands for Mission, Enemy, Troops (friendly) Terrain/Weather, and Time available. METT-T is a method used by the military to perform situation analyses. Those factors are checked by the commander model every time [10].

Figure 4.3 shows how the information is collected by the model in order to have a situation representation.

4.3 Memory Structures

The model encodes static and dynamic knowledge. The static knowledge consists of war principles, doctrinal templates, knowledge related to the battlefield.

The dynamic knowledge encoded in the model includes the terrain representation, the situation at a specific time, courses of action generated, the plans followed by the friendly and opposition forces. What

follows is the detailed description of the components of dynamic knowledge encoded in the model.

1. Mission Information. The mission information was implemented as a memory chunk and describes the mission in the ACT-R architecture. Some of the fields in the memory chunk contain information with uncertainty such as the estimation of mission progress. The slots that compose the mission chunk consist of: type of mission (offensive or defensive), the main goal or intent, action places specified by lines of phase and control points, the list of direct tasks, the list of implied tasks, the list of modifications to the mission, the progress field that contains the percentage of progress of the mission, list of opposition units, and a list of friendly units, and a set of bounding boxes to control where the action is taking place.
2. Terrain Information. The terrain information is stored in matrixes of different resolution which we assume in reality are maps that can be consulted by the commander to understand the situation. The chunk created in ACT-R contains a high level of abstraction view of the terrain. For example, the memory chunk contains the troop's positions, obstacles, and types of soils. The model can query for specific detail about roads, rivers, bridges, and trees. For the terrain the model considers: fields of fire, cover and concealment, obstacles, key terrain, and avenues of approach.

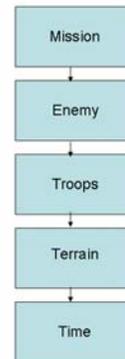


Figure 4.3: Monitoring Control Flow

3. Enemy and Friendly Troops Information. The information about the troops is represented by a chunk containing information about the troops at an aggregate level, i.e. the chunk only stores large groups of friendly and enemy units, a measure of their strength, their physical status. Additionally, the model can

query a list of units with detailed information assuming that the commander receives a document that saves the model the necessity of memorizing the detailed data.

For the enemy, the model analyses the disposition and composition, strength, recent activities, weaknesses, possible courses of actions (COAs), probable COAs, and reinforcement abilities. For the available friendly troops the factors considered are: disposition, composition, strength, activities, weaknesses, morale, maintenance level, and combat service support [10].

4. Commander's Experience. The commander's experience is represented in procedural knowledge encoding the war principles. These are production rules and declarative knowledge including some strategies. The war principles are divided in categories that include offensive, defensive, troops and terrain [11]. Also, some doctrinal templates for the opposition forces are stored as memory chunks. Although the experience used to model the commander is very simple compared to the experience of a real commander, it is complex enough to support our model and to study its impact in the performance.

4.4 Information Gathering

The process of information gathering is performed using different mechanisms. The system gathers information about the enemy, about the friendly forces, the terrain, and the mission.

The process of gathering information is simulated by the process of obtaining summaries of information coming from staff agents that collect and integrate the information coming from the battlefield.

The decision of using agents to obtain information for the commanders was made to avoid an unrealistic model of a commander processing the whole data set coming from the battlefield. The agents that collaborate with the commander are shown in Figure 4.1 and they are described in paragraphs following below.

4.5 Assessment

The assessment of the situation is performed using the doctrinal templates which contain the composition and the layout of opposition forces. The assessment is performed using belief networks to identify possible threats while the system is obtaining uncertain information. The system contains a set of Bayesian sub-networks used to compose belief networks that fuse the information obtained. Some of the employed networks contain information about units and doctrinal

templates. For example, a sub-net might link the detection of a class of a unit in front of an adversary to several doctrinal template classes with different probabilities. Those types of relationships are stored in a database and later they are recovered to be attached to other sub-nets in order to obtain a complete belief network that explains a situation.

1. Plan Recognition. This module simulates how humans recognize enemy plans in order to predict future actions from some opposition units.

To recognize an enemy plan the model uses the intelligence data collected by the system agents, the doctrinal templates retrieved based on the battlefield information, the type of enemy doctrine, the enemy location, the enemy goal, the enemy and friend capabilities and strengths, the terrain, the objectives and the weather.

2. Enemy COAs. An enemy's course of action (COA) is defined based on the enemy's plan in memory, the enemy's intent, the terrain, the enemy's goals, and enemy's strengths. The COAs are generated using the war principles stored in memory. Combining rules in the usage of terrain, troops, offensive, and defensive strategies, the commander model generates COAs that are analyzed before they are allocated to combat units in the simulation.

4.6 Planning

Planning is a task that is performed by the model after the situation has been assessed. Planning uses the knowledge generated about the mission, enemy and friendly forces, terrain, and military doctrines to assemble a set of tasks to be performed by the force. In this case planning requires the management of material and human resources as well as scheduling activities.

The planning process includes several courses of action that are evaluated by the war-gaming module that select the best course of action.

The planning module receives a situation template as input and produces a course of actions and plans as outputs.

4.7 COAs Selection

This module takes the courses of action generated by the planning module and compares the different courses of action in the context of the information available for the mission. In the future, the system will have a mechanism to mentally simulate the different COAs but the present prototype only compares the different COAs generated based on a utility function.

4.8 Simulation Environment

The battle simulations run in OTB (Onesaf Testbed Baseline). OTB is a simulation system that lets the user to create and to control entities on a simulated battlefield [12].

OTB allows users the creation of scenarios by selecting the terrain, creating the units for the friendly and opposition forces, and assigning tasks to every entity. The simulation platform allows users the manipulation of many parameters, including those of weather conditions, creation of obstacles, control points, and lines.

This simulation system has been used as a training tool and for experimentation with real commanders and their staff.

4.9 Staff Agents

Several agents have been developed to support the tasks of gathering information from the battlefield. The existing prototype does not have one agent for each staff member like in the real world. However, the team of agents can be extended to complete the commander's staff. The agents implemented are described in the following paragraphs.

4.9.1 Intelligence Agents

To obtain information about the enemy troops, the model communicates with intelligence agents that provide information about enemy units and their locations. The model must discriminate and integrate the information coming from different agents with the information obtained from his/her interaction with the environment.

The agents are software entities deployed by the model to specific points in the terrain and based on visibility they obtain information from the battlefield. The commander request information from the agents and the agents send information to the model using XML messages. The messages contain information about the enemy units, location, types, and status.

Our current prototype considers 3 intelligence agents. Those agents are running with some parameters to add errors of accuracy and omission in order to produce a cognitive model that makes decisions based on imperfect information. The model integrates the information coming from the three intelligence agents.

4.9.2 Terrain agent

This agent answers queries about the terrain used in the system. He uses the library provided by OTB to respond to questions about the terrain used in the scenario.

Some of the questions include elevations in the terrain, types of soil in specific points, and the visibility between two points. The terrain agent also can locate objects in the terrain such as points, lines, roads, trees, and rivers.

The agent also provides information grids with different resolution levels to explore different regions in the map.

4.9.3 Friendly Staff Agents

This agent provides information to the model about the friendly units. Also it provides a plan executed by every unit in the friendly forces.

This agent also allocates tasks to units in the simulation based on the commander's (cognitive model's) allocation decisions.

5. A Running Example

This section shows an example of the cognitive model running.

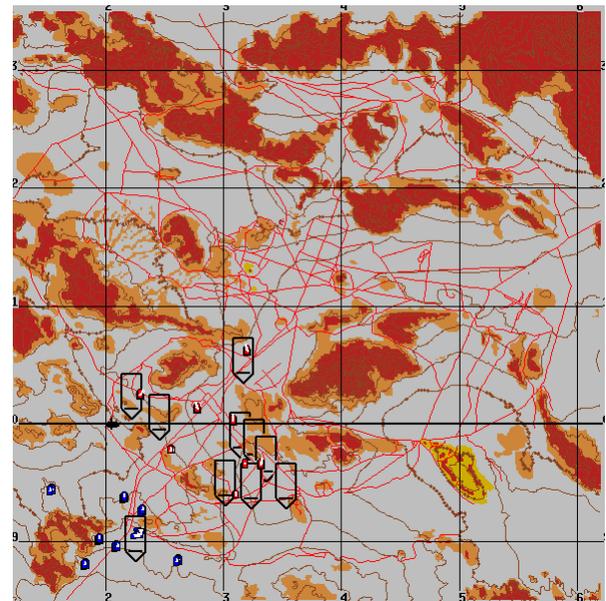


Figure 5.1: The OTBSAF scenario

The scenario used is shown in the Figure 5.1. The blue forces are controlled by the cognitive model and they are located in the bottom left corner. The mission for the friendly or blue forces is to eliminate every red unit without allowing them to withdraw to another area.

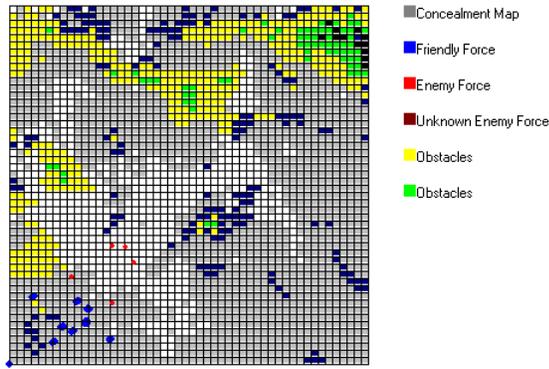


Figure 5.2: The initial sketch received

First the cognitive model evaluates the mission. To do so it requires information from the intelligence staff. The simulated commander receives an aggregated view with information about the locations of friendly and enemy forces. The system also receives information from the terrain agent about the location of obstacles, water, and concealment areas. Figure 5.2 shows the sketch that was compiled by the commander with the information obtained in order to achieve the situation assessment and to plan the course of actions (COAs).

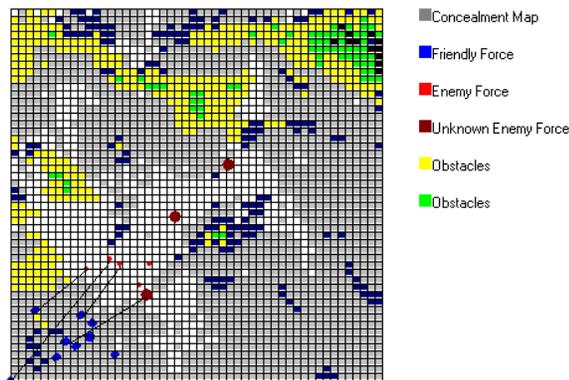


Figure 5.3: The sketch after analyzing the information

After the cognitive model has the initial sketch, it starts the process of information understanding. Based on the enemy information it determines the doctrinal template that the enemy may be using. Once the template is selected, the model predicts the locations of other units that may not have been reported by the intelligence agents. Figure 5.3 shows the view that includes the units that were not located by the intelligence agents, but they were identified based on the template that the model predicted was used by the enemy. Figure 5.3 shows also possible routes that can be employed by the friendly forces. After this set of operations the cognitive model has a prediction about the enemy plans.

The model selects course of actions based on the enemy's data and the commander's experience. The commander creates a plan and then allocates tasks to the units in the battlefield.

The system may then "sleep" for some minutes and then monitor the mission again, query the agents in the battlefield. If everything goes well, it will "sleep" again. However, if the model receives information about events, such as detonations and fire, it will analyze the information again and will re-plan the mission if necessary.

If the model detects that the enemy is using a different doctrinal template, or that the enemy is following a different plan, or that the number of threats is increasing, the model will analyze the information and re-plan if necessary. The model stops running when the goal was reached or when it is no longer possible to achieve it.

6. Experimental Platform for SA

Our model is an experimental platform that allows experimenters to study the relationships among the model parameters and the SA performance. The parameters that we can change in the current prototype to evaluate their impact in SA consists of: scenario complexity, number of intelligence agents, omission error in agents, accuracy error in agents, agents position, commander experience, and ACT-R parameters.

6.1 Scenario Complexity

It is possible to study two or three scenarios of different complexity and the impact of this change on the SA performance, because the system uses OTB, which allows experimenters the creation of diverse scenarios,

6.2 ACT-R Parameters

ACT-R provides many parameters to evaluate specific cognitive issues. Some of those parameters include activation noise and latency factor.

6.3 ACT-R Model

The comparison of different SA models is made possible in ACT-R by changing some of the sub-models in ACT-R. For example, it is possible to compare two commanders by using two models with different sets of chunks that represent experience so as to study the impact of experience on SA.

6.4 Agent Parameters

The software agents have standard parameters for information accuracy and omission. These parameters determine the probability that an agent may have an omission error in his report. Another parameter is the degree of inaccuracy committed by an agent.

6.5 Learning

We will use the cognitive model to perform experiments based on the instance based learning theory (IBLT). IBLT is a theory about learning based on the accumulation and refinement of instances, containing the decision-making situation, action, and utility of decisions [13].

6.6 Scenarios with two Commanders

The model can easily be adapted to support two cognitive models acting as commanders, one for the opposition forces and one for the friendly forces. The same scenario might be played by two humans in order to validate the computational model.

6.7 Team Organization and Communication

Another parameter that can be manipulated is the number of agents and the communication paths in the organization to study its impact on SA.

6.8 Hybrid Staff Members

Although the existing prototype only has software agents to support the process of information gathering, it can be adapted to have humans acting as staff members interacting with the cognitive model and software agents.

7. Measuring Performance on Situation Awareness

We designed a software tool to evaluate SA. We were inspired by a software tool created by Endsley to evaluate commander's SA in military exercises performed by a group of commanders interacting with OTBSAF. This tool uses the Situation Awareness Global Assessment Technique (SAGAT) also created by Endsley to evaluate SA [14]. This technique stops the simulation and administrates queries to evaluate the subject's awareness.

7.1 SAGAT Agent

Figure 7.1 shows the SAGAT agent that administrates questions to the cognitive model. The Figure 7.1 shows some points in the terrain and those points are the answer of the model to a query.

7.2 SAGAT Questions

The SAGAT agent asks the model two blocks of 4 questions. The questions reflect only the levels 1 and 2 of SA. A level is composed of questions about the situation perception and other questions about situation understanding.

The current prototype sends the following questions to the model:

- Locations of friendly units
- Locations of friendly armor units
- Strength of friendly forces
- Doctrinal template used by the enemy
- Location of enemy forces
- Location of friendly units destroyed
- Location of enemy units destroyed
- Location of enemy threats

7.3 Model Configuration

The model configuration used to run the SAGAT experiments used the following components: three intelligence agents, one terrain agent, one executive agent, and one friendly staff agent.

The parameters manipulated were the following: agents' position, omission error, accuracy error, and amount error.

7.4 SAGAT Results

Next we present the results obtained from the two experiments in which we manipulated these parameters.

7.4.1 Experiment One

The parameters for this experiment are shown in the Tables 7.1 and 7.2.

Table 7.1. Agents' Locations Experiment 1

Agent	XLocation	YLocation
8866	17237	12279
8868	12501	12449
8870	18759	7205

Table 7.2. Agents' Parameters Experiment 1

Agent	Omission	Accuracy	Amount
8866	0.35	0.25	0.05
8868	0.35	0.25	0.05
8870	0.35	0.25	0.05

With those parameters we got a situation awareness of 7 points out of 8 points for situation awareness.

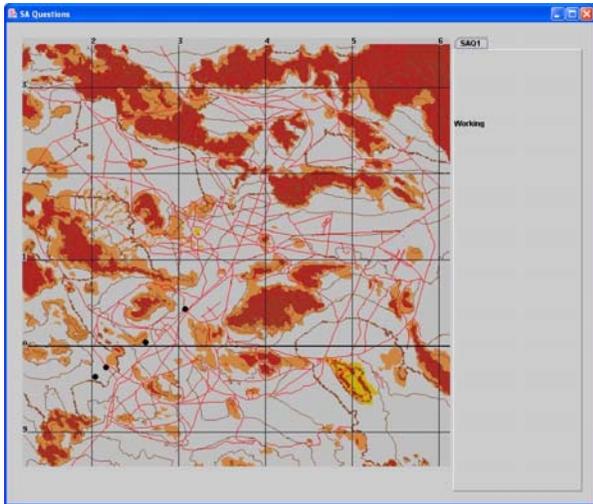


Figure 7.1: Software tool to evaluate SA

7.4.2 Experiment Two

The parameters for this experiment are shown in Tables 7.3 and 7.4.

Table 7.3. Agents' Locations Experiment 2

Agent	XLocation	YLocation
8866	23500	31300
8868	24400	32000
8870	26500	29450

Table 7.4. Agents' Parameters Experiment 2

Agent	Omission	Accuracy	Amount
8866	0.8	0.6	0.4
8868	0.8	0.6	0.4
8870	0.8	0.6	0.4

With these parameter values the SA measure is 5.8 points out of 8 points. Figure 7.2 shows a chart with the relationship between omission errors and SA performance.

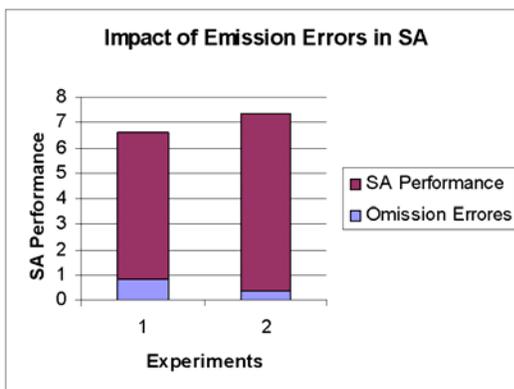


Figure 7.2: Omission Errors and SA

8. Summary and Future Research

This paper describes the design and implementation of a cognitive model of Situation Awareness (SA) that works in a very complex domain, such as a war scenario.

Although our model is very simple compared to the abilities of a real commander, it is complex enough to understand some aspects of the commander's cognitive system such as the relationship between memory and performance in war-gaming scenarios.

The existing model interacts with simulation scenarios running in OTB. In the near future, we will perform empirical studies to evaluate the cognitive model as a predictor of performance of human commanders. The model will be refined based on the data obtained in the empirical studies.

A separate experiment might model the capabilities of recognizing doctrinal templates based on partial and continuous information obtained from the battlefield.

A more realistic simulation should include a complete support staff that is composed of humans and software agents that collaborate with the cognitive model to make decisions that support the mission's achievement. However, this type of configurations adds more complexity to the simulation. The model of complete staff implemented with humans and software agents must include the creation of ontology and languages to support the team communication. Also a distributed team model must include collaboration, coordination, and planning models to simulate the work of large staff teams.

To make the model more realistic one might include a hierarchy of teams where each staff leader has a team to perform the tasks. For example, the commander gets information from the intelligence commander who also gets and integrates the information obtained by the intelligence agents. However, these types of models increase the complexity for coordination and planning in teams. Every staff member might be a human, a software agent or a cognitive model.

The model will be gradually transformed into a team model where the commander interacts with a set of staff members who simplify his work by processing the information. Reasoning about battlefield sketch will be an important component for the cognitive model with a larger staff team. The study of sketch representation and reasoning is included because there will be a language proposed to communicate with the staff members to achieve a mission.

Finally, the model will be transformed to better study the SA connection with the decision making process. This will require the current model to be augmented with more highly specialized staff agents to reflect the staff of a real world commander. For example a space intelligence officer will perform tasks related to the terrain information, a staff member assigned to

planning will elaborate the plan which will be evaluated and corrected by the commander. This modification is necessary because in the real-world a commander performs his/her tasks while supported by a highly specialized staff.

Acknowledgments

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