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OPERATIONAL-LEVEL NAVAL PLANNING USING AGENT-BASED SIMULATION

by

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This thesis uses agent-based modeling techniques to develop a simulation of the operational-level naval planning process. The simulation serves as an initial exploratory laboratory for analyzing the consequences of the force allocation, force deployment, and force movement decisions made by operational-level naval commanders during times of conflict or crisis. This model will hopefully help decision-makers in gaining insight into the naval planning process and enable them to make more informed decisions in the future.

The agents in the model represent the opponent operational-level naval commanders. These agents perform force allocation, force deployment, and force movement tasks based on their perceived environment, attributes, and movement personalities. There are seven naval platform types represented in the model by default, but any type of naval platform can be added to the simulation. An integrated graphical user interface enables the user to instantiate agent and platform attributes, set simulation parameters, and analyze statistical output.

The resulting model demonstrates the ability of the agent-based modeling to capture many dynamic aspects of the operational-level naval planning process. It establishes an initial simulation tool to further explore the operational-level naval planning process.

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OPERATIONAL-LEVEL NAVAL PLANNING USING AGENT-BASED SIMULATION

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I. INTRODUCTION

A. THESIS STATEMENT

Agent-based simulation techniques can be used to model and simulate naval combat in order to assist operational-level decision-makers in understanding the potential consequences of their force allocation and force management decisions.

B. MOTIVATION

The three basic roles of a Navy of any nation are peacetime engagement, deterrence or conflict prevention, and fight and win. In order to accomplish these goals, a capable Navy should be fully operational at all times. This requires carefully studied plans at every level of procurement, maintenance and operation cycles of naval platforms. All of these plans fall under a single name, "Naval planning process."

The naval planning process consists of three tightly related sub-processes. The first sub-process is strategic planning that basically aims at developing top level naval war plans and procuring naval platforms that are capable of achieving these plans. Navy's top leaders, in coordination with the top military and government leaders, conduct the strategic planning process. The second sub-process is operational planning, which focuses on delivering the maximum impact from naval force capabilities to achieve operational objectives by supporting the combatant commanders. A wide spectrum of naval commanders can conduct the operational planning process, depending on the organization of the Navy and the nature of the operational plans needed. A person responsible for this process is called the operational commander. The last sub-process is

tactical planning, which considers the employment and the maneuvers of individual units in relation to each other and the enemy. The immediate commanders of the unit commanders in the operational area conduct the tactical planning process. A person responsible for this process is called the tactical commander.

Operational planning, described briefly in the previous paragraph, is the key process of the naval planning. Generally, the outcome of naval battles not only depends on superiority in numbers but also on superiority in operational plans. A carefully studied operational plan supported by precise intelligence greatly enhances the effectiveness of tactical commanders in the field. Presently, operational commanders are regularly making key decisions with neither the time nor the ability to fully model how these decisions might effect the outcome of the naval combat. A model of naval operations that captures important decision-making aspects of a real battle can assist commanders in gaining insight into this operational planning process. This insight would help those commanders make more informed decisions in the future.

Both entertainment and military organizations have used conventional modeling and simulation techniques for a long time to reach their objectives in their respective applications. However, these techniques have not allowed them to model and simulate complex adaptive systems like naval combat. This was true because everything was hard-coded in these conventional models at the beginning of the simulation and so exploring the causes of dynamic change was impossible. Complex adaptive system techniques provide the analyst with an explicit way to control the dynamics of the model, usually by adjusting a set of variables. (Casti, 1997).

Over the past several decades, the entertainment industry has used a new modeling and simulation technology called "agent-based simulation" in their computer games that in most ways surpassed the technologies used by military training facilities. Ill-defined problems and complex adaptive systems like naval combat can be effectively modeled by using agent-based simulation techniques (Arthur, 1994). The military has used this technology for the last five years. ISAAC (Irreducible Semi-Autonomous Adaptive Combat) was one of the first military research studies that modeled land combat by using agent-based simulation techniques (Ilachinsky, 1997). Likewise, agent-based simulation techniques can also be used to model naval combat in order to provide decision-makers insight into the dynamics of naval combat.

An ill-defined problem can be described as a problem that does not have any of the three following properties: a well-defined initial state, a well-defined and small number of solutions that can be evaluated easily, and a well-defined goal state. In this respect, operational-level naval combat is an ill-defined problem because the initial state is not well defined (the actual opponent force level and their plans are not known) and there are several interactions within and between opponent forces that cannot be evaluated easily. Even the goals of the opponents may be unclear to each other.

C. THESIS GOALS

The overall goals of this thesis are:

- Develop an Operational Planning Laboratory, a model that demonstrates the successful implementation of a non-situated, and low-resolution operational-level naval combat through agent-based simulation techniques.

- Prove usefulness of the model through the output and analyses of summary statistics gathered from experimental simulation scenarios.

D. THESIS ORGANIZATION

Six chapters that comprise this research:

- *Chapter I – Introduction*: Identifies the purpose and motivation behind conducting this research. Establishes the goals for the thesis.
- *Chapter II - Agent-Based Modeling*: Provides information on agent-based modeling and simulation.
- *Chapter III – Operational-Level Naval Planning*: Introduces basic concepts for the operational-level naval planning.
- *Chapter IV - Model Development*: Describes the process and methodology employed during the development of the simulation to model the operational-level naval combat.
- *Chapter V - Model Analysis and Results*: An analysis of selected cases comprises this section.
- *Chapter VI - Future Work and Conclusion*: As research is far from complete, this section discusses the possible directions that this research can take.

II. AGENT-BASED MODELING

A. INTRODUCTION

Computers are not good at deciding what to do next in the midst of an undefined problem and uncertainty. In traditional programs, every situation that a computer may encounter must be explicitly anticipated and coded by a programmer. In most cases, people happily accept computers as obedient, literal and unimaginative servants. However, for an increasingly number of applications, we need systems that can decide what to do on their own in order to satisfy their design objectives. Such systems can be built with the help of agents. (Weiss, 1999) These agents are the core entities of agent-based models. They populate and interact with each other and the environment in these models. (Axelrod, 1997) Agents are adaptive software devices. When combined in moderate to large numbers, these agents can produce decisions and behaviors that are rational, even in ill-defined or dynamically changing complex situations. These rational decisions and behaviors advance the agent toward the achieving of its goals or intentions.

The study of complex systems that have many actors and their interactions often becomes too complex for a mathematical model. Agent-based modeling is a tool to study this kind of system. The tricky part of this modeling tool is to specify the environment, agent-knowledge model and the interactions between the agents. (Axelrod, 1997)

Section B of this Chapter clarifies some of the important terms for agent-based modeling and simulation. A number of agent-based applications are introduced in Section C. In section D, a short discussion of the similarities and differences between the current

study and other multi-agent system (MAS) simulations is presented. Section D summarizes the important points in the Chapter.

B. IMPORTANT TERMS

1. Agents

There is no universally accepted definition of the term "agent." The lack of such a definition is primarily because various attributes associated with agency are of differing importance for different domains. For some domains, learning is the most important aspect of an agent, yet it may be not only unimportant but also undesired for other domains. The only concept present in almost all definitions of agents is "autonomy." (Weiss, 1999) Agents have autonomy. This means that their actions are the result of commands obtained from a user, and the result of a set of goals and tendencies embedded in them. (Ferber, 1999)

An agent can be any type of physical or software entity that fulfills the basic concepts of agency. Ferber defines the properties of an agent as follows:

- An agent is capable of acting and modifying its environment.
- An agent can communicate with other agents in the environment.
- An agent has intentions.
- An agent controls some local resources.
- An agent is capable of perceiving its environment (but to a limited extent).
- An agent has only a partial representation of its environment (a reactive agent may not have any representation of its environment).
- An agent possesses skills and can offer services.

- An agent may be able to reproduce itself.

Examples of what an agent can represent include living beings, organizations, vehicles, or nations. Agents have the ability to perceive their environment and act upon the stimulus from this environment. The actions of agents modify the environment, which in turn affects the agent's decision process. These actions are embedded in the agent structure generally as weighted-rule sets. The weights of these rules are updated continuously according to their performances in the past. The rule with the highest weight determines the next movement of an agent. Some ineffective rules can even be replaced with new ones. This property allows agents to adapt to their environment more rapidly.

The ability to adapt to their environment is one of the most important properties of agents that distinguish agent-based modeling techniques from other conventional modeling techniques. From the agent's point of view, adaptation means changing the rules of actions based on what the agent has learned from previous interactions. The adaptation capability of an agent allows a simulation to imitate the behaviors of increasingly complex systems.

An agent's internal mechanism for achieving intelligent behavior can range from quite simple (in the case of a reactive agent) to exceedingly complex (in the case of a cognitive agent). Cognitive agents have some internal representation of the environment that they are operating in. The sensory information from outside the agent is processed in this representation before taking a new action. Thus, cognitive agents can operate in a relatively independent way. By contrast, reactive agents do not have an internal representation of the environment. As a result, they take an action according to the

information directly sensed from the environment or according to the internal motivations that prods them toward accomplishing a task. Since reactive agents are incapable of performing complex tasks individually, they are often deployed in large numbers to overcome this limitation. Figure 1 depicts the difference between cognitive and reactive agents.

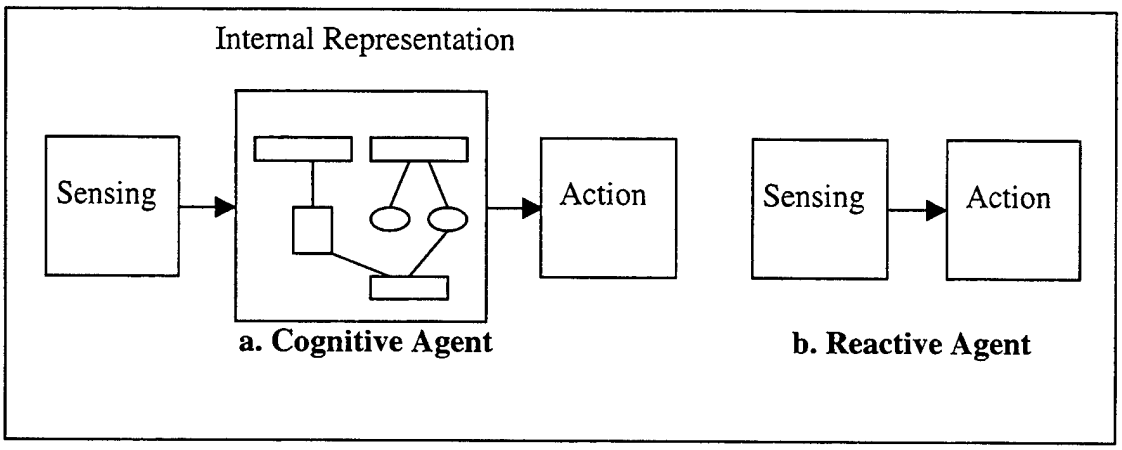

Figure 1. The Difference Between Cognitive and Reactive Agents

2. Multi-Agent Systems (MAS)

Just like the term agent, finding a widely accepted definition of MAS is difficult. Weiss (1999) gives the following characteristics of multi-agent environments: They provide a basis for specifying interaction and communication protocols; they are mostly open and have no centralized designer; they contain autonomous and distributed agents that may be cooperative or self-interested. Instead of defining MAS characteristics, Ferber (1999) reports elements that comprise a MAS. These elements are environment, objects, agents, relations, operations, and operators. Environment is a space in which every object of the MAS resides. Everything in the environment is an object. An agent is also an object in the environment that satisfies agency requirements. Relations link

objects to each other in the environment. Operations are the actions that agents can perform in order to modify the environment and to achieve their goals. Operators can be described as the laws of the environment. Operators are basically the reactions of the environment to the actions taken by agents. Constructing a MAS requires detailed models of these elements.

Moreover, Ferber defines four type of MAS according to the communication ability and physical existence of the agents in the environment. These are:

- Communicating MAS: A MAS in which agents are situated and have an ability to communicate with each other.
- Purely Communicating MAS: A MAS in which agents are not situated but can communicate with each other.
- Situated MAS: A MAS in which agents are situated and can communicate.
- Purely Situated MAS: A MAS in which agents are situated but cannot communicate with each other.

Ferber describes three levels of organizations studied in multi-agent systems:

- Micro-Social Level: Interactions between agents and the various forms of links between agents are considered for this level.
- Group Level: Intermediary structures are considered for this level.
- Population Level: Dynamics of a large number of agents, together with the general structure of the system and its evolution are considered for this level.

3. MAS Simulations

Computer simulation imitates selected properties of reality, usually to predict the future or to practice and to rehearse problem-solving skills (Thinking Tools, 1999). The phrase "imitation of selected properties of reality" implies the model of the system under

investigation. In most modern simulations, these models are based on either mathematical or rule-based relationships between system variables, which can be measured in reality. The most frequently used modeling methods are transition matrices, differential equations, and rule-based "if-then" systems. These models are either deterministic or stochastic depending on the nature of the system under study.

"Lanchaster Equations," or LEs, introduced by F.W.Lanchaster in 1914, uses a set of coupled ordinary differential equations as models of attrition in modern combat. Conventional combat models have primarily been based upon these equations even though they lacked some of the basic properties of modern combat. Ilachinski (1997) identified the following shortcomings of the LEs:

- LEs did not account for any spatial variation of forces, that is, no link established between attrition and movement.
- Human factors issues were completely discarded in these equations.

Therefore, Ilachinski concluded that LEs are inadequate for modeling land combat and used agent-based simulation techniques for ISAAC (Ilachinski, 1997).

Ferber (1999) also discussed some of the problems of conventional models. These problems are listed below:

- These models contain a large number of parameters that are challenging to estimate.
- In these models, observing the effects of individuals to the state of the system is difficult.
- These models cannot consider qualitative parameters of the system under study.

All of the conventional models described above lacked the evolving and adapting characteristics of the real systems, particularly because most of these real systems consist of elements that adapt or modify their behaviors and internal structure in order to use the environment more efficiently. Obviously, models based solely on formulae cannot effectively imitate complex, adaptive systems.

MAS simulation is a new solution to the problem of imitating complex adaptive systems. Axelrod (1997) describes MAS simulation as "a way of doing thought experiments," the goal of which is to enrich our understanding of fundamental systems. He contents that the goal of MAS simulation is not to find solutions to real world problems, but rather to provide insight into complex systems that conventional approaches cannot model. Therefore, modeling every aspect of the system is unnecessary. Axelrod (1997) proposes the famous army slogan, "Keep it simple, stupid" to the MAS simulation designers. Otherwise, the change in the outcome of the simulation cannot be linked to any particular variant in the simulation and hence makes simulation useless. However, one should also be very careful in deciding which aspect of the real world should not be included in the simulation. Omitting a key component of a system from the simulation may result in meaningless, undesired outcomes.

C. NOTABLE MAS SIMULATIONS

MAS simulations have been used to analyze a broad range of systems. Some of these systems are biological systems, organizational systems, and military systems. Even some commercial computer games like *SimCity* are thought to employ MAS simulation techniques, although the exact technology for these games has not been published (Hiles,

1999). The following MAS simulations have been produced by some of the pioneers in this domain.

1. Boids

Reynolds (1986) designed boids to demonstrate that fully reactive agents acting only on local information can generate complex group behaviors. He managed to create a flock of birds by equipping them with simple movement rule sets and letting them interact with each other in the environment. Boids follow three rules to control their actions:

- Steer to avoid crowding local flockmates (separation rule).
- Steer toward the average heading of local flockmates (alignment goal).
- Steer to move toward the average position of local flockmates (cohesion rule).

With this fairly simple rule set, Reynolds demonstrated that his boids exhibit an emergent behavior: flocking similar to that of birds without leadership. This study proved that using reactive agents with simple rule sets and acting only on local information could perform complex tasks.

2. El Farol Bar Problem

Brian Arthur introduced the El Farol bar problem to demonstrate the limitations of deductive reasoning for solving complex and ill-defined problems and to prove the usefulness of agent-based simulation in such cases (Arthur, 1994). The problem is actually quite simple. There is a bar named "El Farol" in Santa Fe, New Mexico, that offers Irish music on Thursday nights. The bar has limited space, and if less than 60% of the patrons are present, the bar is enjoyable. Otherwise, the bar is too crowded to be an

enjoyable place. Every Thursday night, each patron has to decide either to go to the bar or to stay at home. A patron decides to go if he expects less than 60% of the patrons to show up, or stays at home if he expects more than 60% to go. Communication between the patrons is not allowed prior to deciding on attending the bar or not, meaning that there is no way of knowing how many patrons will be at the bar before one decides to go or to stay at home. The choices are unaffected by previous visits and the only information available to the patrons is the number of attendance in previous weeks.

Deductive reasoning fails to solve this problem because there is no obvious model that the patrons can use to forecast attendance and to base their decisions on. In his solution to the problem, Arthur creates an "alphabet soup" of mathematical predictors and randomly ladles out a small number of them to each of the agents. Agents use these predictors while deciding to go or not. If the predictor forecasts attendance to be more than 60%, the agent stays at home. At the end of each week, the agents update the weights of the predictors according to their accuracy for that particular night. This is in fact the adaptive property of the agent's behavior in El Farol. The agents are constantly looking for better rules to predict the bar attendance so that they can enjoy their night either at home or at the bar. Figure 2 shows the outcome of Arthur's solution. Note that the number of agents is 100 in this solution. The mean number of attendance always converges to 60 as depicted in Figure 2. This is because the predictors are self-organizing into equilibrium in which, on average, 40% of the active predictors is forecasting an attendance of above 60 and 60% of the active predictors are forecasting an attendance of below 60. Note that these active predictors are not always the same

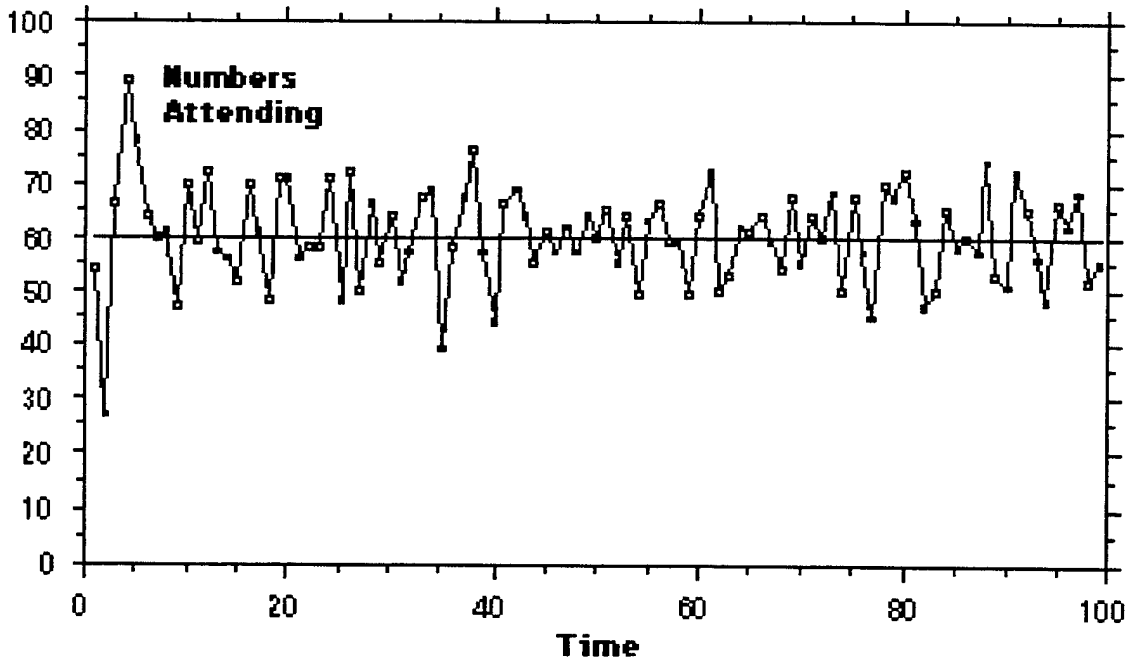

Figure 2. Bar Attendance in the First 100 Weeks (Arthur, 1994)

predictors. The equilibrium is not changing although the active predictors are changing from week to week for each agent.

3. Iterated Prisoner's Dilemma

In 1984, Robert Axelrod used multi-agent simulation techniques to solve the problem widely known as Two-Person Prisoner's Dilemma. This was the first application of genetic algorithms to evolve strategies in interactive environments. (Axelrod, 1984)

Before discussing the Iterated Prisoner's Dilemma, one should understand the basics of genetic algorithms. Genetic algorithms were developed by John Holland, a computer scientist at the University of Michigan, to explain the adaptive process of natural systems and to design computer systems that retain the important mechanisms of natural systems (Goldberg, 1999). They have been used in several applications as search

algorithms, where the search space is quite large and complicated. Genetic algorithms are composed of three operators: reproduction, crossover, and mutation. For more information on genetic algorithms, the reader is directed to (Goldberg, 1999)

The Prisoner's Dilemma problem is actually very simple. Two people are arrested for a crime and put in separate interrogation rooms in a jail. Before the interrogation, they are told that they will receive a reduced sentence if they testify against the other. If they testify, the other will receive a worse sentence. A prisoner can either cooperate by not implicating the other, or defect, by testifying against his accomplice. If this process is iterated, the prisoners try to develop a strategy to estimate the next movement of each other by evaluating the results of the previous iterations and then act accordingly. Finding a strategy in such a case is a complicated problem. This is the place where agent-based simulation comes into the play with genetic algorithms to find an effective strategy in a huge set of possible strategies. Axelrod used genetic algorithms to solve this problem by letting the strategy sets of individuals evolve throughout the iterations. Between iterations, effective strategy sets were chosen to create offspring strategies by way of reproduction, crossover, and mutation. After about ten or twenty generations, effective strategies filled the strategy sets of the individuals, and the individuals did better with these strategies. The evolving social environment led to a pattern of increased cooperation based upon an evolved ability to discriminate between those who will reciprocate cooperation and those who will not. As the reciprocators do well, they spread in the population, resulting in more cooperation and greater effectiveness. For more information on Iterated Prisoner's Dilemma, the reader is directed to (Axelrod, 1997).

4. Irreducible Semi-Autonomous Adaptive Combat (ISAAC)

Lanchester Equations (LEs) have been commonly used in military studies as models of attrition in modern combat. However, LEs have two serious shortcomings that make them inadequate for assessing advanced war fighting concepts. These equations do not take spatial components of a combat into account, and they totally disregard human factors. (Ilachinski, 1997)

The goal of the ISAAC was to assess the general applicability of "new sciences" to land warfare. Andrew Ilachinski viewed land combat as a dynamic, nonlinear system in which many agents interact and try to adapt to a rapidly changing environment. Consequently, he used agent-based simulation techniques to develop ISAAC for Commanding General, Marine Corps Combat Development Command (MCCDC).

A blue or red agent in ISAAC is called an ISAACA (ISAAC Agent). ISAACAs represent individual infantrymen in the simulation, and they are situated in a battlefield consisting of a two-dimensional grid system. See Figure 3 for a depiction of the battlefield.

The overall goal of the ISAACAs is to capture the enemy's flag in the opposite corner. An ISAACA can be in one of the three states in a simulation run. These states are alive, injured, and dead. The state of an ISAACA effects its capabilities in the battlefield. Additionally, ISAACAs are equipped with various range characteristics for their sensors, weapons, movements, and communications.

The personality of each ISAACA consists of six separate movement propensities. These propensities drive ISAACA to move toward the following directions: alive friendly, alive enemy, injured friendly, injured enemy, blue flag and red flag. In the

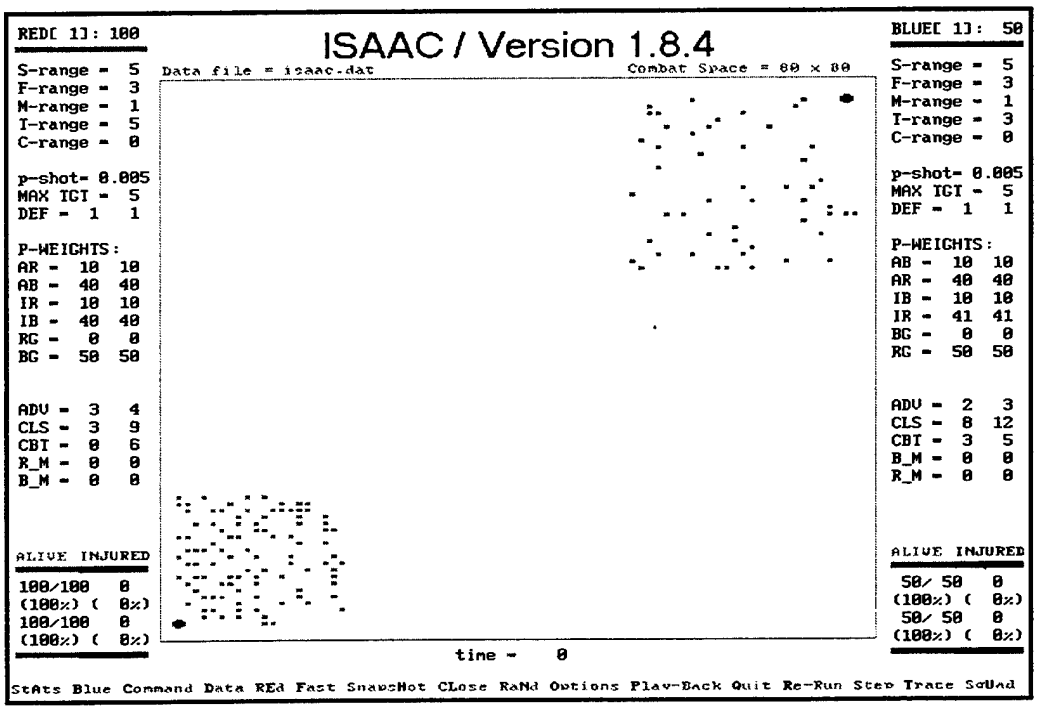

Figure 3. Main ISAAC Screen From Ref.[Ilachinski, 1997]

battlefield, each ISAACA occupies a grid position. The movement of an ISAACA is driven by its personal propensities and sensed environment. A penalty function is used by each ISAACA to determine the next movement. This function is calculated for each grid that can be reached in the next step, and then the grid with the smallest penalty function is visited in the next run.

D. CURRENT APPLICATION IN TERMS OF MAS

The multi-agent system under investigation for the current study is operational-level naval combat. This MAS consists of commander agents, conflict zones and

platforms. There are two agents in the environment that represents operational-level naval commanders. Unlike ISAACAs, these agents are not situated in the environment. Instead of being in a geographical space, they are in a problem space like the agents in the El Farol Bar and Iterated Prisoner's Dilemma simulations. These agents have certain personality factors that drive them to their global goal of deterring aggression or defeating the opponent. They are cognitive agents, which means that they have internal representations of their environment. They keep track of the operational information in conflict zones and act according to their internal models of the environment. They interact with each other through the interactions of the platforms that they manage. Conflict zones and platforms are the objects in the environment. Platforms are situated in the conflict zones and managed by commander agents.

E. SUMMARY

This Chapter introduced the basics of multi-agent systems and simulations. The inefficiency of the conventional modeling techniques in modeling complex adaptive systems has been stated and agent-based modeling and simulation approach proposed for such cases. The important terms like agent, MAS and MAS simulation have been discussed to construct a basic understanding, although there were no commonly accepted definitions for these terms in the literature. A review of significant MAS simulations that effectively modeled different systems with different approaches was also included. The Chapter concluded with a short discussion of the similarities and differences between the current study and presented MAS simulations. The next Chapter presents the key concepts in operational-level naval planning.

III. OPERATIONAL-LEVEL NAVAL PLANNING

A. INTRODUCTION

Planning is the act of preparing for future decisions. In this respect, we can think of a plan as a practical scheme for solving a problem. A plan helps us to make decision at the necessary time and place. Planning is a fundamental part of professional leadership. Effective plans link the members and activities of an organization, and help the organization react to changing circumstances.

Military organizations possess complicated structures and deal with diverse types of missions, ranging from non-combat missions, from disaster relief to combat missions. Planning should be central to all military training and operations. Carefully designed plans in peacetime facilitate the decision making during times of crisis, when parameters change so rapidly and in ways that are difficult to estimate. Planning leads to faster and more accurate decision making, which, in turn, increases the effectiveness of military operations.

Section B of this Chapter clarifies the basics of the military planning process. It introduces the principles of the military planning and presents the military planning logic. Joint operation and force planning processes for the U.S. Armed Forces are discussed in Section C to provide a basic understanding of where naval operation planning fits into the whole military-operation planning process. Section D presents the naval-operation planning process in detail. The relevance of the naval operation planning process to the current study is discussed in Section E. Section F presents a brief summary of this Chapter.

B. BASICS OF MILITARY PLANNING

1. Principles of the Military Planning Process

The main purpose of the military planning process is to facilitate decision-making at all levels of the command chain that enables the successful execution of military operations. Effective military plans always result from applying sound planning principles. These principles form the conceptual framework in which military decision-makers evaluate military issues. A brief summary of these principles is given in the following paragraphs. Unless otherwise noted, all the information in this section was drawn from Ref. (NDP 5, 1996).

a. Relevance

Military plans prepared at each level of command must support goals of higher authority and must be achievable using available resources. Plans that do not support higher-level plans are irrelevant and waste resources or interfere with more critical missions. Likewise, unrealistic plans are also irrelevant and misleading for higher authorities.

b. Clarity

Military plans should be as clear and simple as possible. In this sense, common terminology is critical and must be clearly understood at all levels, especially in the context of joint operations. A superior plan is useless if the executing units do not completely understand it.

c. Timeliness

Plans must be completed and distributed as early as possible in the planning process to allow subordinate commanders enough time to prepare their own plans. Plans prepared by subordinate commanders under time pressure may not reflect the intentions of the superior commander, or they may be impossible to implement. Moreover, time pressure hinders coordination between executing units.

d. Flexibility

A military plan should clearly state all objectives and avoid unnecessarily detailed directions. This allows subordinate commanders to make better use of their forces and help them adapt to changing circumstances rapidly. A good plan should state what to do and should avoid giving highly detailed directions as much as possible. However, the plan should be more detailed at times when the planner suspects that the executing units may not know how to implement the plan, or when only one of many possible ways to execute the plan will satisfy all of the plan's requirements.

e. Participation

Plans must be distributed widely as early as possible to allow the assigned commanders to participate and to facilitate their planning efforts. Early awareness of responsibilities allows for better integration and coordination of participating units and ensures that the plans prepared by subordinate commanders support both plans of the superior commander and plans of the other subordinate commanders.

f. Economy of Resources

Military plans should make sure that the operation will be as economical as possible. Unnecessary assignments and movements of the forces should be avoided. Limited resources should be controlled at the lowest possible level at which their capabilities are best known and can be effectively managed and coordinated for the overall benefit of the force.

g. Security

Plans should be kept and distributed carefully to prevent an adversary from accessing them and then preparing effective counter-plans. This security can be achieved in a variety of ways including: limiting distribution, isolating one's own forces with detailed knowledge, and practicing effective communication security.

h. Coordination

In most of the military operations, diverse military units act independently to support common objectives of the superior commanders. In such cases, military plans should provide sufficient coordination directives to synchronize the efforts of these forces. The coordination principle ensures that separate operations and military units avoid interference and provide support where and when it is needed.

2. Military Planning Logic

The application of the military planning principles discussed in the previous section follows a logical sequence and framework known as "the military planning logic." While military problems vary tremendously in character, scope, and time available, this logic is common to most military problem solving. Figure 4 depicts the

flow of military planning logic. According to this logic, the resolution of a military problem is divided into four phases. These phases are the *commander's estimate of the situation*, the *development of detailed plans*, the *preparation of the directive*, and the *supervision of the planned mission*. All of these phases should follow the military planning principles discussed early in the Chapter. These phases will briefly be discussed in the following section.

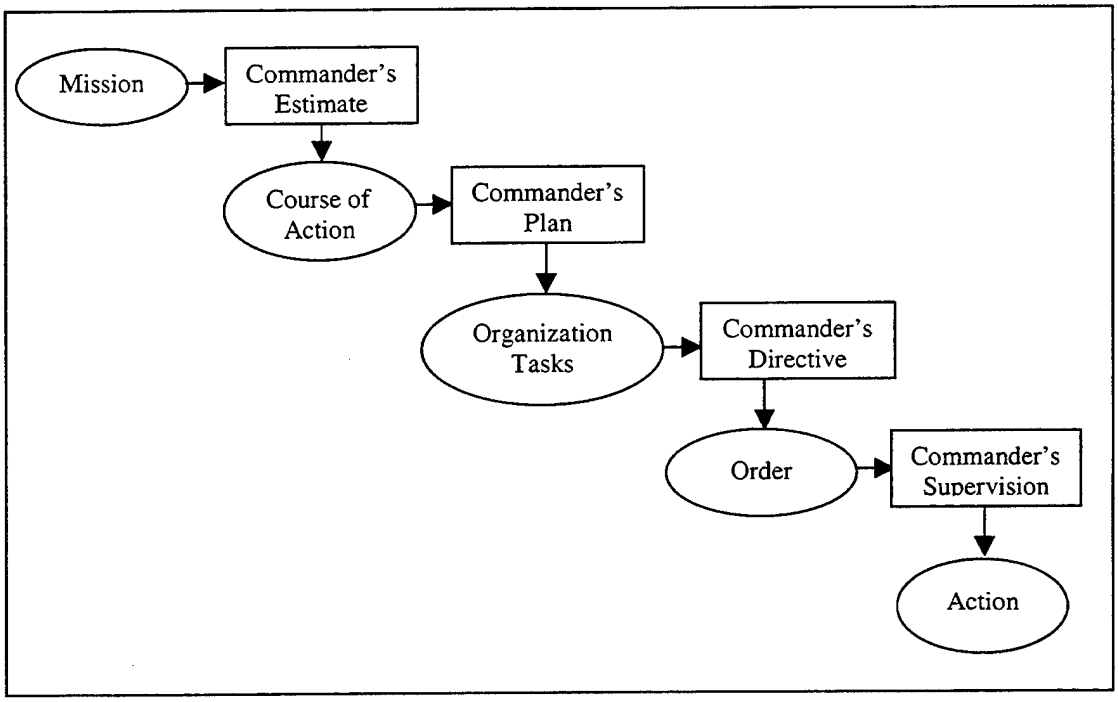

Figure 4. Military Planning Logic (NDP 5, 1996)

a. Commander's Estimate of the Situation

In this phase, the decision-maker analyzes the situation, evaluating the threat and perceiving the mission. The commander looks at the vulnerabilities of his own and the opponent's forces and prepares a Course of Action (COA).

b. Development of Detailed Plans

The selected COA is distributed to the subordinate commanders for the preparation of detailed plans. Subordinate commanders who probably know the environment, possible threats, and capabilities better than the commander prepare detailed plans. Detailed plans include the allocation, deployment, and employment of the forces in the operational area. The commander then evaluates and approves these plans.

c. Preparation and Distribution of Directive

After deciding the COA and creating a detailed plan for it, the commander prepares and distributes a directive to execute the plan. This directive should be as clean and simple as possible, and it should allow subordinate commanders to take initiative where and when necessary.

d. Supervision of the Planned Mission

In this phase, the execution of the plan is supervised and adjusted as necessary. Time pressure is higher and the environment is very dynamic throughout this phase. The control of forces in the operational area falls under this phase in a military planning cycle.

C. MILITARY PLANNING

Military planning includes two broad categories of planning; force planning and operation planning. Both are integral and mutually supporting parts of military planning. Unless otherwise noted, all the information in this section was drawn from Ref. (AFSC Pub 1, 1997). The definitions of the terms mentioned in the following sections are provided in Appendix-B.

1. Force Planning

Force planning can be described as a military planning process that aims at creating and maintaining military capabilities. Military Departments and Services are the primary organizations responsible for smoothly executing this process. The force planning process is conducted under the administrative control that runs from the Secretary of Defense to the military departments and services. The goal of this process is to have the necessary military capabilities to conduct the operations planned through the operation planning process. In order to achieve this goal, the military services recruit, organize, train, equip, and provide forces for assignment to combatant commands and then administer and support these forces. (Joint Pub 5-0, 1995)

The force planning process is not directly related to this thesis, so, it will not be discussed in detail. For more information on this process, the reader is directed to (Joint Pub 5-0, 1995) and (AFSC Pub 1, 1997).

2. Joint Operation Planning

Even though this thesis focuses on the operational-level naval planning, knowing at which level of the whole military planning process operational-level naval planning occurs is crucial. Therefore, the joint operation planning process for the U.S. military will be introduced first, and then the operational-level naval planning will be discussed in detail.

Joint military operations are planned by using two distinct processes: the *deliberate-planning process* and *crisis-action planning process*. The following

paragraphs will introduce these processes, and clarify the similarities and the differences between them.

a. The Deliberate Planning Process

The deliberate-planning process is conducted in peacetime to prepare for conflicts and crises. This process develops plans that address many potential operations. These plans, based on several assumptions, require revisions when used for an actual crisis or operation. The Office of the Secretary of Defense (OSD) generates and maintains the Contingency Planning Guidance (CPG) which is translated into guidance and tasking in the Joint-Strategic Capabilities Plan (JSCP). The deliberate-planning cycle usually begins with the publication of the JSCP and terminates at the end of the period to which the JSCP applies. This planning cycle is accomplished in five phases: initiation, concept development, plan development, plan review, and supporting plans. Figure 5 depicts the flow of the deliberate-planning process. (Joint Pub 5-0, 1995)

This thesis focuses more on the crisis-action planning process than the deliberate-planning process. Therefore, phases of the deliberate-planning process will not be discussed here. For detailed information on the deliberate-planning process, the reader is directed to (Joint Pub 5-0, 1995) and (AFSC Pub 1, 1997).

b. Crisis-Action Planning Process

The deliberate-planning process can take from 18 to 24 months to complete. However, at times there may be only a few days to plan a military operation. In such situations, the crisis-action planning process provides for a rapid transition from

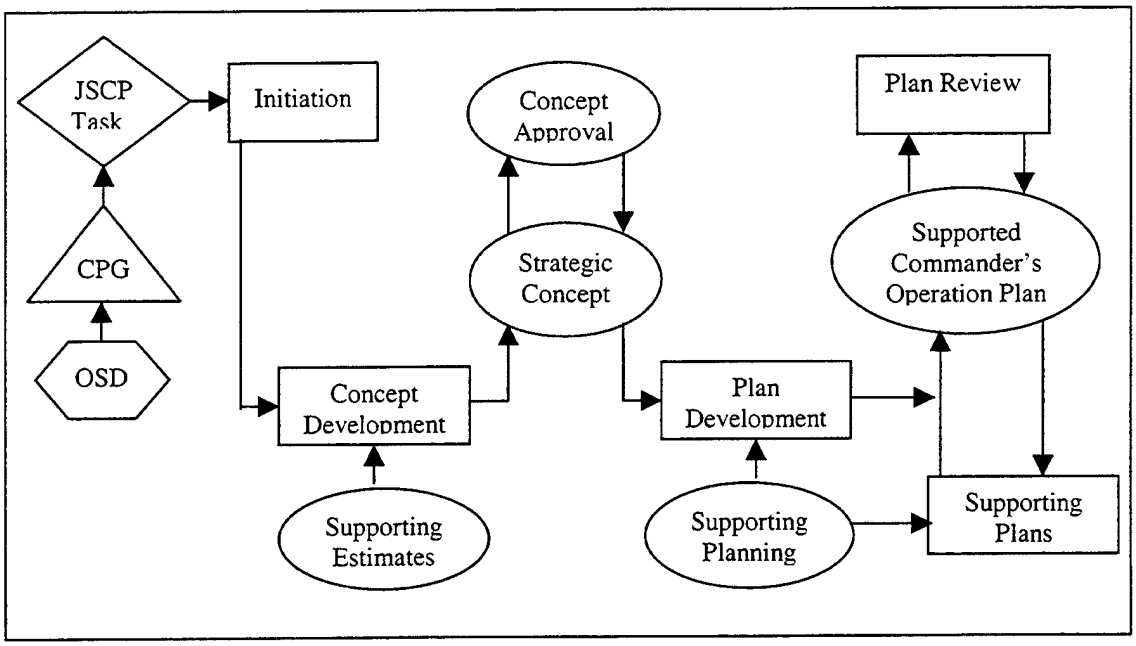

Figure 5. Deliberate Planning Process (NDP 5, 1996)

peace to crisis or war. The deliberate-planning process supports this process by anticipating Obviously, every crisis situation cannot be anticipated. However, as the crisis develops and the assumptions are replaced with facts and reality, the planning accomplished in deliberate-planning process can facilitate effective decision-making and execution planning during time-sensitive periods. Crisis-action procedures are designed to plan and to initiate a response within whatever time is allowed by the crisis, regardless of whether there has been previous contingency planning for this particular scenario. If there has been prior deliberate planning, it is considered and exploited whenever possible.

A crisis has been defined as "an incident or situation involving a threat to the United States, its territories, citizens, military forces, and possessions, or vital interests that develops rapidly and creates a condition of such diplomatic, political, or

military importance that commitment of U.S. military forces and resources is contemplated to achieve national objectives." (Joint Pub 5-0, 1995)

The crisis-action planning process is initiated when an event having possible national security implications is recognized. Normally, a unified commander reports the event, but any unit can report it. Then the geographic combatant commander informs the affected component commander of the estimate of the situation and directs him to initiate a detailed analysis. In this case, the affected component commander can be thought of as a naval operational commander. The initial evaluation includes the determining the opponent's strength and one's own available forces in the theater. Intelligence and communication capabilities play a vital role in determining the opponent's strength in the operational area.

Crisis-action planning uses previously developed plans (if available) by adapting them to current situations and makes the most effective use of the limited time available. Crisis-action planning and execution is accomplished within a flexible framework of six phases. These phases are *situation development*, *crisis assessment*, *course of action development*, *COA selection*, *execution planning*, and *execution*. Figure 6 depicts the flow of the cisis-action planning process. The phases of this process will be discussed in detail in the following sections.

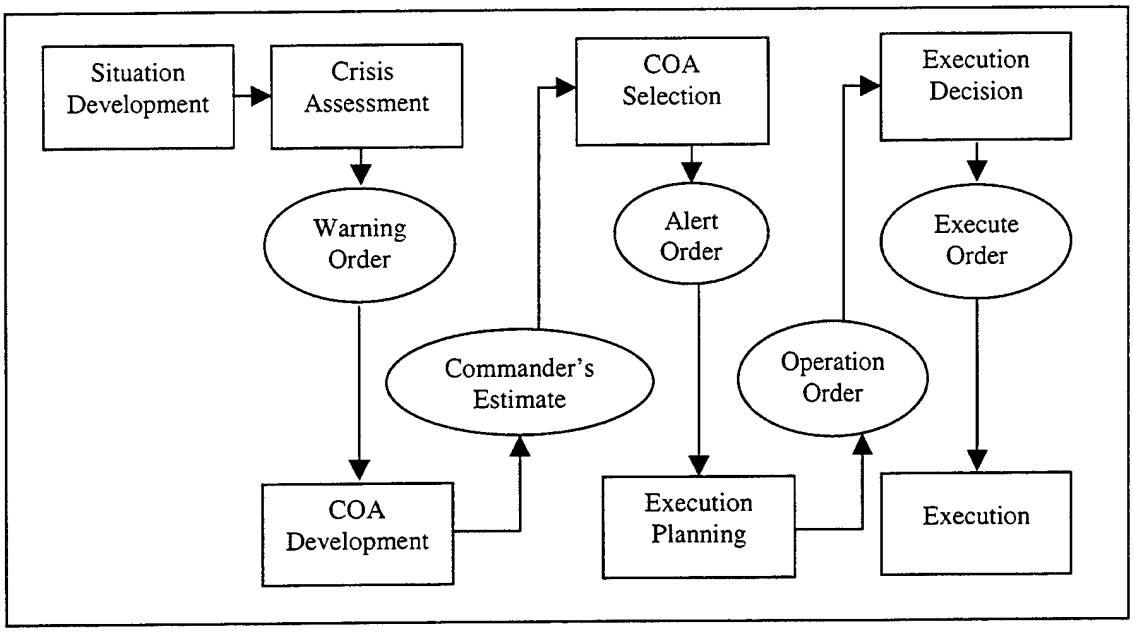

Figure 6. Crisis Action Planning Process (NDP 5, 1996)

(1) *Situation Development Phase.* By observing the routine world situation, intelligent resources detect and report events with potential national security implications to the National Command Authorities (NCA). Then the NCA, in coordination with the Joint Chiefs of Staff (JCS), determines whether a military response is required. The combatant commander responsible for the area in which the event occurs becomes the supported commander.

This phase ends when the supported commander submits his assessment to the Chairman, Joint Chiefs of Staff (CJCS), and the NCA. If the situation is so urgent that normal crisis- action planning procedures cannot be followed, the commander's assessment may also include a recommended COA, which may serve as the commander's estimate (normally prepared in a subsequent phase).

(2) *Crisis Assessment Phase.* During this phase, the NCA, the Chairman, and other members of the JCS analyze the situation to determine the need for preparing a military option to deal with the evolving problem. At the end of this phase, one of the following decisions is made:

- to remain in this phase and continue to gather information
- to return to the pre-crisis posture
- to progress to the next phase of the crisis-action planning process

(3) *Course of Action Development Phase.* With the decision having been made by the NCA to develop military options, the CJCS issues a Warning Order directing the development of the COA. If time permits, the supported commander will then assign component commanders (an operational-level naval commander is one of them) the task of identifying the forces and the supplies necessary to support the COAs under consideration. At the end of this phase, the supported commander submits his recommended COA to the NCA and CJCS, in the form of an estimate of the situation. If the nature and timing of the crisis mandate accelerated planning, the CJCS may proceed directly to the COA selection or execution phase.

(4) *Course of Action Selection Phase.* The CJCS, in coordination with the Joint Chiefs, reviews and evaluates the COA provided in the supported commander's estimate. They prepare recommendation and advice for the NCA to consider. The NCA selects a COA and initiates the execution planning. The CJCS then issues an alert order to the supported commander advising him of the COA selected. This

is the formal crisis-action planning process method of notifying the supported commander of the selected COA and initiating execution planning.

(5) *Execution Planning Phase.* This phase is similar in function to the plan-development phase of deliberate planning, in that the necessary detailed planning is performed. This allows COA to be executed when directed by the NCA. The supported commander, with the help of his component commanders, identifies the actual forces, sustainment and strategic deployment resources, and describes the concept of operations in an operation order format.

The emphasis during this phase is on the supported commander and its component commanders (operational-level naval commander). They review the alert order to get the latest guidance on forces, timing, constraints, etc. The planning done during the COA development phase is adjusted and updated for any new forces or sustainment requirements, and the sourcing of forces. This phase ends with a NCA decision to implement the operation order.

(6) *Execution Phase.* The NCA decision to choose the military option and to execute the operation order opens the execution phase. The Secretary of Defense authorizes the CJCS to issue an Execute Order, which directs the supported commander to implement the operation order. The supported commander then issues an Execute Order to the component commanders to initiate the execution of the operation.

At this point, changes to the original plan may be necessary due to strategical, operational, or tactical considerations. This phase continues until the crisis is terminated or the mission is terminated and force re-deployment has been completed. If

the crisis is prolonged, the process may be repeated continuously as circumstances change and the missions are revised.

D. NAVAL OPERATION PLANNING

The previous section described the flow of two different and supplementary joint military operation-planning processes. In both of these processes, the supported commander is the key personnel since operational plans are prepared and executed under his responsibility. During the operation planning and execution phases, the supported commander uses his component commanders who are most familiar with the capabilities and limitations of their service forces and specific warfare types, like land warfare or naval warfare. If the operation needs a joint-force structure, the supported commander focuses on integrating and coordinating the operation and execution plans, which the component commanders prepare.

If only one type of service force, like the naval force considered in this study, is needed for a particular operation, the specific component commander becomes the key personnel in the whole planning process as the operational-level commander. In this case, the supported commander generally relies on the assessments and plans generated by the operational-level commander and acts as a communication bridge to higher authorities. In a crisis-action planning cycle, the naval component commander conducts three basic responsibilities. These are *preparation of the Commander's Estimate of the Situation*, *preparation of naval operation plans*, and *coordination of the plan execution*. These responsibilities are discussed briefly in the following. Unless otherwise noted, all the information in this section was drawn from Ref. (NDP 5, 1996).

1. Commander's Estimate of the Situation

The component commander prepares the *Estimate of the Situation* document, which evaluates and summarizes the potential COAs. This document includes a mission statement, a description of the situation, an analysis of enemy capabilities, and a comparison of the potential COAs.

The intelligence capability of the component commander significantly affects his estimate, which in turn affects the COA that higher authorities will select. If the component commander does not know the force level and disposition of the adversary precisely, the COA and the forces allocated to this operation will most likely be inadequate.

2. Preparation of Naval Operation Plans

Naval operation plans are the basic tools for coordinating the naval actions at the operational or tactical level. This phase basically consists of two important sub-phases. These are *operation planning* and *force planning*. The component commander develops these plans according to the estimate of the situation that was prepared in the previous phase. Therefore, this estimate greatly influences the outcomes of both of these planning processes. Misleading intelligence may cause the component commander to select an unsuitable COA.

Likewise, the experience level of the component commander affects the outcomes of these planning processes. A commander that is comfortable with a particular type of warfare (anti-air warfare, anti-surface warfare, etc.), a type of platform (fast patrol boat, destroyer, etc.), and a type of tactic (concentration of forces, disposition of forces, etc.)

will most likely develop plans accordingly, and this will eventually affect the composition and disposition of the forces allocated to the operation.

3. Coordination of the Plan Execution

During the execution of the operation plan, the naval component commander is responsible for coordinating the naval tactical commanders in the operation area. This guarantees the maximum impact from naval force capabilities to achieve the operational and strategic objectives. The naval component commander continuously monitors the movements of the forces in the operational area. During this phase, changes to the original plans will most likely be needed due to tactical considerations (adversary force movements, one's own force needs, etc.). At this point, the naval component commander makes sure that the tactical commanders have necessary forces where and when they need them.

E. CURRENT STUDY IN TERMS OF NAVAL PLANNING

As discussed in the previous section, in times of crisis, the responsibilities of a component commander, or operation-level naval commander are to allocate, initially deploy, and manage the task force in the operational area to obtain the desired results. This thesis explores the outcomes of decisions made by operational commanders who have the three basic responsibilities mentioned above.

Before discussing how the operational commander makes these decisions in this particular simulation, one should know the following information about the simulation. The blue commander agent in the current simulation represents the operational-level naval commander under investigation. The red commander agent is the opponent who

creates the crisis situation. The simulation consists of three consecutive multi-agent systems that model the force allocation, the initial force deployment, and the force management responsibilities of the opponent commanders. In the beginning of the simulation, the user determines the properties of the red commander and the initial red force level in the operational area. The user also defines the inventory, the available budget, and the properties of the blue commander that affects his decisions in the simulation. Moreover, the user defines the properties of the platforms that are employed by the commanders in the operational area. Some of these properties are *combat power*, *speed*, *endurance*, and *cost of the platform*.

Allocating platforms from available inventory to the task force is the primary task of an operational-level naval commander at the beginning of a crisis. At this point, the most important information the operational commander needs is the opponent's force level in the crisis area. In the real world, this information is obtained from varying intelligence sources. The accuracy of the intelligence directly depends on the reliability of these sources. In this study, the user provides the initial intelligence capability of the blue operational commander at the beginning of the simulation. This capability is defined as a number between zero and one. An intelligence level of *one* means that the blue commander knows the exact force level and disposition of the red force in the operational area. As this level decreases, the difference between the actual opponent force and the perceived opponent force increases. Once the blue commander has a limited knowledge of the red commander's force level according to his intelligence capability, he initiates the platform allocation process. Besides perceived opponent-force level, the personality and the warfare usage tendency of the blue commander, the budget allocated for the

success of the operation, and the available inventory are the key factors that affect the blue commander's force allocation decisions. In the simulation, the blue commander has an allocation goal for each platform type that prods him to allocate that particular platform type from the inventory to the task force. Within the constraints of the budget, the platforms that have the highest goal weights are allocated to the task fprce. These goal weights are the functions of the number of red platforms in the operational area, the number of blue platforms already allocated to the task force, and the number of available platforms in the inventory.

Once the blue commander allocates platforms to the task force, he needs to employ these platforms in different locations in the operational area. The perceived disposition of the opponent force in the operational area, and the strategic importance of the theaters of the operational area affect the employment decisions. In the simulation, the blue commander has a platform deployment goal for each theater that prods him to deploy platforms to that particular theater. The blue commander deploys platforms to the theaters that have the highest goal weights.

After the allocation and the deployment of the blue task force, the red and the blue operational commanders are responsible for moving and the coordinating the forces in different theaters of the operational area. In order to achieve this task, the commanders continuously monitor the theaters and decide which force level is needed in each theater. In the simulation, both of the commanders have some goals associated with moving the platforms in the operational area. They both manage the maneuvers of their platforms by choosing the highest weighted goals.

The combat resolution between the opponent forces is conducted in a simple way. If both forces are in the same theater and one of them decides to attack the other because he thinks that he has the attrition advantage, simple mathematical calculations are used to resolve the battle. Obviously, aggressiveness personality attribute of the commanders, and the perceived opponent force level are the two factors that greatly affect the commanders' attack decisions.

F. SUMMARY

The first part of this Chapter introduced the basics of the military planning, the military planning logic, and the principles of the military planning process. The military planning process was divided into two broad categories: force planning and operation planning. The force planning process was covered briefly since this process is outside the scope of this study. The joint operation planning process was also divided into two broad categories: the deliberate-planning process and the crisis-action planning process. The deliberate-planning process was briefly detailed because this process is also outside the scope of this study. The crisis-action planning process was discussed in detail to provide a basic understanding of where naval operation planning fits in the whole military operation planning process. The naval operation planning process was introduced in detail and the Chapter concluded with a short discussion on how and to what extent the naval operation planning process is modeled in this study.

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IV. MODEL DEVELOPMENT

A. INTRODUCTION

The background material presented in the previous Chapters serves as a basis for developing a MAS model to explore the operational-level naval combat. This model does not completely encompass the operational-level naval combat. It was developed as a prototype "proof-of-principle" to initiate work in this area and to establish a "virtual, agent-based simulation workspace" for future developments. The following sections provide a broad explanation of the algorithms and methods used to build the model framework. For a more in-depth comprehension of the model, the reader is encouraged to further analyze the model's computer code.

Section B of this Chapter introduces the simulation environment in which the commander agents and the platforms interact with each other. Section C presents the characteristics of the blue and the red commander agents and their instantiation by the user. The platforms and their instantiation are explained in Section D. In Section E, the goal types, goals, rules, and the goal selection mechanisms of the commander agents are introduced in detail. The stochastic intelligence gathering process is described in Section F, and similarly, the stochastic combat resolution process implemented by the simulation is introduced in Section G. The simulation interface is presented in Section H. Section I gives a brief summary of the entire Chapter.

B. ENVIRONMENT

A user accesses the model program by way of a Graphical User Interface (GUI). The main environment object for the simulation is the ConflictZone object, which represents a zone in the operational area. When a user initiates the program, 15 ConflictZone objects are automatically initiated from within the SimEnv class as five columns and three rows. Three pixels represent one nautical mile in this simulation and a ConflictZone object consists of 240 by 240 pixels, meaning that each ConflictZone object represents a zone of 80 by 80 nautical miles. The collection of these ConflictZone objects constitutes the simulation environment that represents the operational area in which the operational-level naval combat occurs. The resulting graphical dimensions of the simulation environment are 400 nautical miles (1,200 pixels) left to right (east to west), and 240 nautical miles (720 pixels) top to bottom (north to south). See Figure 7 for a depiction of the simulation environment and its dimensions.

The operational area is divided into three *theaters*. The zones numbered *one*, *six* and *eleven* constitute the *east theater* of the operational area. Likewise, the zones numbered *three*, *eight*, and *thirteen* form the *center theater*, and the zones numbered *five*, *ten*, and *fifteen* form the *west theater*. The zones numbered *two*, *four*, *seven*, *nine*, *twelve*, and *fourteen* are also called *transition zones*. Any platform transiting from one theater to another in an east-west or a west-east direction passes through one of these *transition zones*. Additionally, the red commander can replenish his platforms in the zones numbered *two* and *four*. Similarly, the blue commander can use the zones numbered *twelve* and *fourteen* for replenishment purposes.

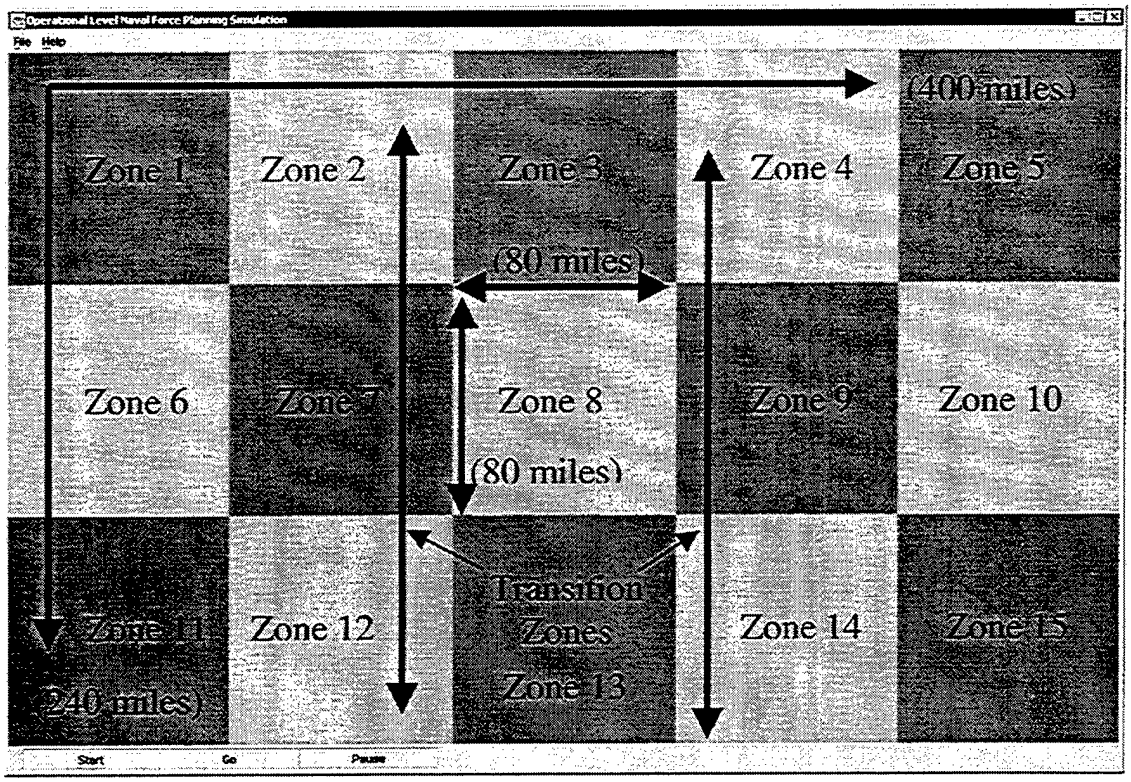

Figure 7. Simulation Environment

Every ConflictZone object maintains the blue and the red platform objects in two different vector structures. The blue and the red commander agents access the information about their own and their opponent's forces through these vectors. They can also manipulate the platforms through the ConflictZone objects.

Every theater in the simulation has a hard-coded *strategic importance value*. This value is the same for all the zones in that particular theater. The *strategic importance value* is a number between *zero* and *one*. As this value increases, the strategic importance of the theater and its zones to the commander agents increases. This prods the commander agents toward assigning more platforms to these zones. Therefore, a theater

that has a higher strategic importance will have more blue and red forces than the theaters that have lower *strategic importance values.*

The only *paint* method used throughout the program is located within the SimEnv class. The *paint* method is the common Java method used to draw the visual graphic display. The *paint* method in the SimEnv class calls the *draw* method within the ConflictZone class to display the conflict zones. The *draw* method in the ConflictZone class then calls the *draw* method within the Vessel class to display the blue and the red vessels in those conflict zones.

C. AGENTS

Agents are the objects, which represent the interactive entities operating within the artificial environment explained above. Agents have ways of gathering information about their environment and intelligently adapt the actions based on their characteristics, propensities, and the perceived opponent. The agents chosen to represent the primary players of this operational-level naval combat scenario are the blue and the red operational-level naval commanders. Note that the platforms that form the blue and the red forces are the objects, not the agents in the simulation. The blue and the red commander agents, which are not visible in the simulation environment, manipulate these platforms.

Separate Java classes are used to create the two types of agents. There are many attributes that must be defined before creating a commander agent. The combination of these attributes leads to one of the most insightful capabilities of the simulation. Different combinations can often result in many different outcomes and agent performances during

a simulation run. The user supplies the agent attributes through Java panels that contain sliders for each attribute (see Figures 8 and 9).

Each agent has certain types of goals that are embedded in it at the beginning of the simulation. The types of goals are *platform allocation*, *force deployment*, and *force movement* goals for the blue and *force movement* goal for the red agent. The commander agents have different goals for each goal type, and these goals compete with each other to be the active goal of their goal type. The details about the goal types, the goals, and the dynamic goal selection process will be discussed in Section E of this Chapter.

1. Blue Commander Agent Attributes

The blue commander is the agent under consideration in this study. This agent solves *force allocation*, *force deployment*, and *force movement* problems in the simulation environment. The user creates the blue commander agent by setting its characteristics at the beginning of the simulation. The blue commander's characteristics consist of *ten* different attribute/propensity values. All of these characteristics range from *one* to *ten*. Once the user supplies these characteristics, except for the *budget*, they are automatically divided by *ten* and converted to a number between *zero* and *one* for the calculations in the simulation. The budget value is multiplied by 100 before the calculations in the simulation. Figure 8 shows how the sliders bars are arranged on the Java panel.

The first agent characteristic enables the user to set the *initial intelligence capability* of the blue commander. This value represents the accuracy of the intelligence received from sources at the beginning of the crisis situation. Some of these sources may

be satellites and/or other military/civilian sources. The difference between the actual and the perceived red force level decreases with an increasing *initial intelligence capability.* The calculation of the perceived red force by using this characteristic will be explained in detail in Section F.

The *speed preference* value represents the commander's propensity to allocate fast naval platforms like fast patrol boats to the task force. Likewise, the *staying power preference* value indicates the commander's tendency to allocate more resilient platforms like a destroyer or a frigate to the task force.

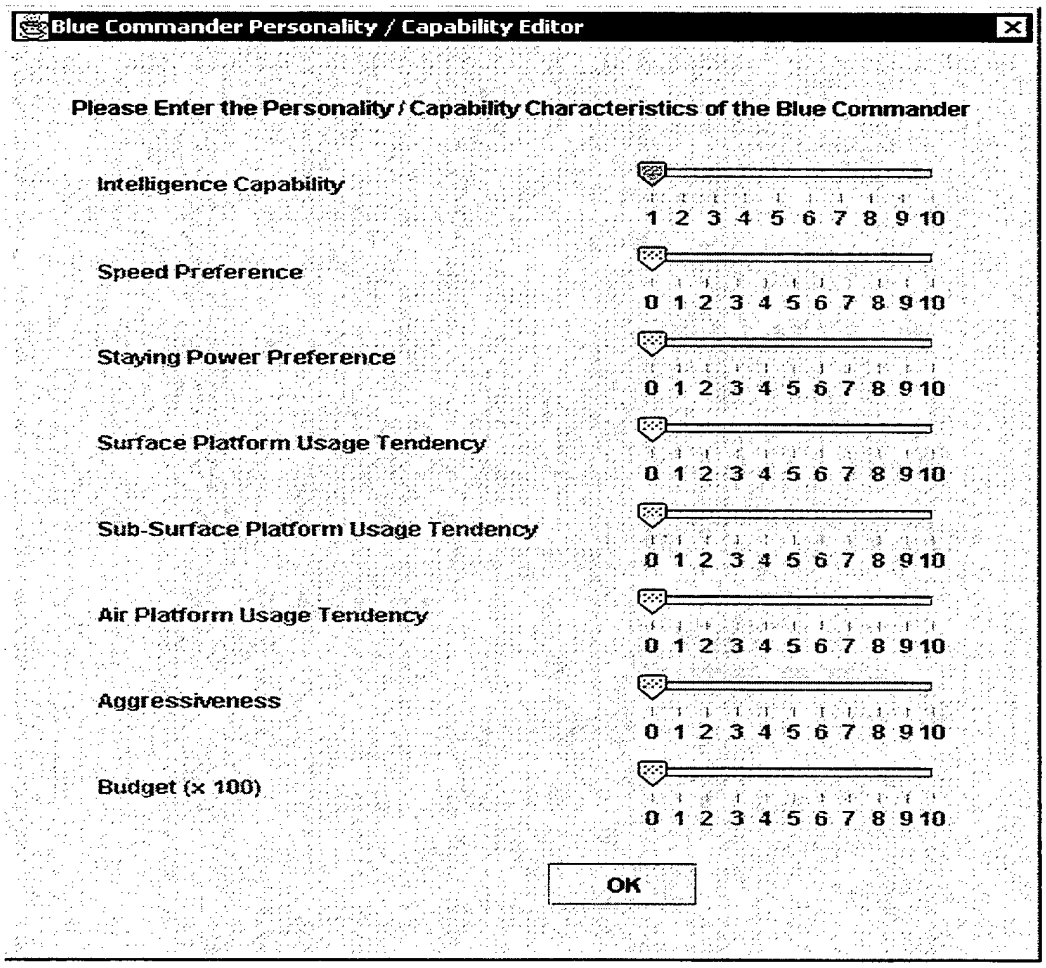

Figure 8. Blue Commander Agent Instantiation Slider Panel

The *surface platform usage tendency, sub-surface platform usage tendency, and air platform usage tendency values* represents the commander's propensity to employ that particular type of warfare in the crisis area. For instance, the number of surface platforms will more likely be greater than the other kinds of platforms (air and sub-surface platforms) when *surface platform usage tendency* is higher than the others. Moreover, the speed and the staying power preference values distinguish the fast patrol boats from the frigate and destroyer in the platform allocation process. However, these are not the only criteria when deciding to allocate a platform from the inventory to the task force. The opponent's force combination and obviously, the budget available to the blue commander affect his force allocation decisions.

The *aggressiveness* personality factor represents the blue commander's aggressiveness level. The higher this value is, the more likely the blue agent will employ his forces in the front lines of the theaters and decide to continue to fight even in cases of a force ratio disadvantage.

The *budget* value of the blue commander represents constraints in the platform allocation process. Each operation has to be succeeded within certain economic limits. Obviously, deploying all of the available platforms in the inventory to the task force is neither an economical nor a feasible solution. Some of the platforms should be kept in hand to conduct other important missions and to be able to respond to any other crisis that may arise in a different region. Every platform in the simulation has a cost value and allocating a platform from the inventory to the task force decreases the blue commander's budget by the platform's cost.

2. Red Commander Agent Attributes

The red commander agent represents the commander who creates the crisis situation. This agent solves only the *force movement* problem in the simulation environment. The user determines the initial red force structure and its initial disposition in the operational area at the beginning of the simulation. Therefore, the red commander agent does not need to solve the *force allocation* and *force deployment* problems. The user creates the red commander agent by setting its characteristics at the beginning of the simulation. The red commander characteristics consist of *two* different personal propensity values. Figure 8 shows how the sliders bars are arranged on the Java panel.

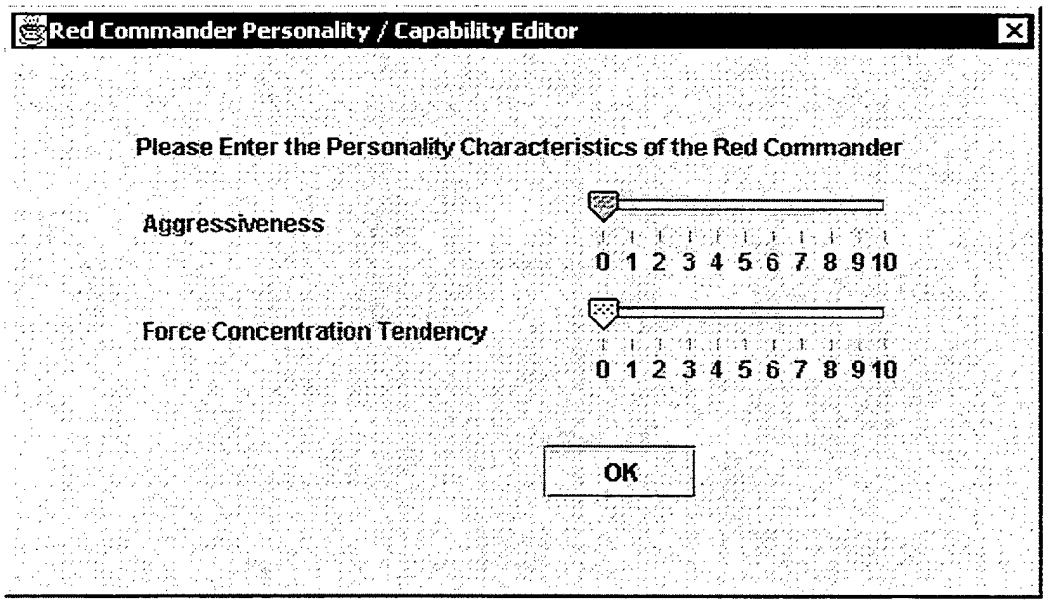

Figure 9. Red Commander Agent Instantiation Slider Panel

The *aggressiveness* value for the red commander functions the same way as it does in the blue commander agent properties. The *force concentration tendency* value is used to control the initial disposition of the red task force in the operational area. If this

value is greater than *nine* (which means that the red commander favors concentrating his forces in a theater), the red commander deploys all of his platforms to a theater that has the highest strategic importance value. An aggressiveness value between *four* and *nine* causes the red agent to deploy his platforms to the two theaters that have the highest strategic importance values. The proportion of the strategic importance of these zones affects the number of platforms deployed to these theaters. Finally, an aggressiveness value less than *four* forces the red commander to deploy his platforms to all of the three theaters of the operational area according to the proportion of the strategic importance values of these theaters.

D. PLATFORMS

The *platforms* are the objects that represent the *surface*, *sub-surface*,, and *air vehicles* in the simulation. The blue and the red commander agents manipulate these platforms. *Seven* types of platforms exist in the environment. These platforms are *destroyer*, *frigate*, *fast patrol boat*, *fast patrol boat with helicopter*, *submarine*, *fighter*, and *anti-submarine warfare (asw) aircraft*. The user supplies the number and the combination of the platforms in the red task force and in the blue inventory to the model at the beginning of the simulation. The GUI for supplying the number and the combination of the platforms in the red task force to the model is shown in Figure 10. Likewise, Figure 11 depicts the GUI used to determine the number and the combination of the platforms in the blue commander's inventory.

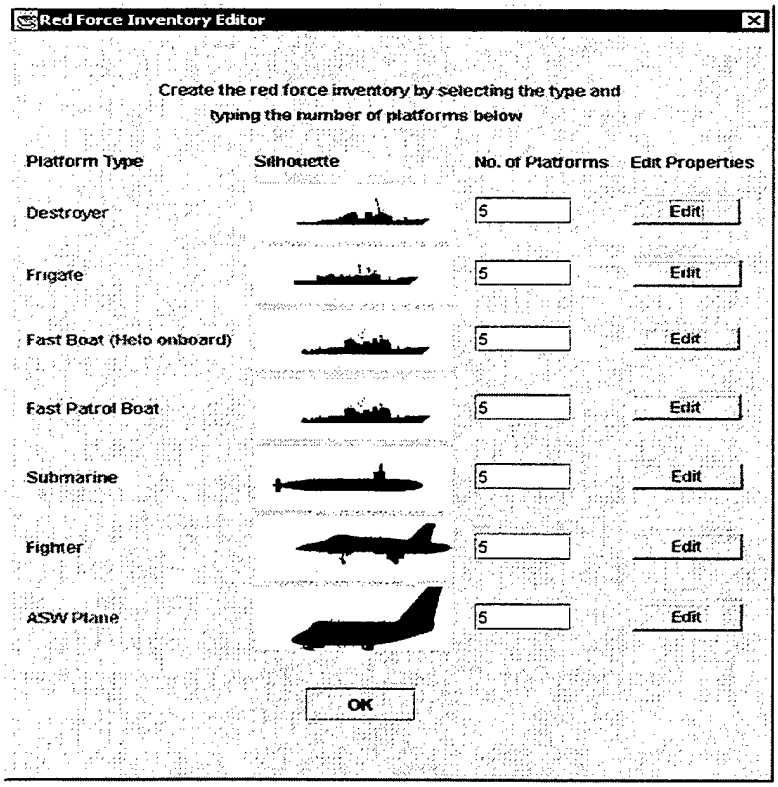

Figure 10. Red Task Force Creation Panel

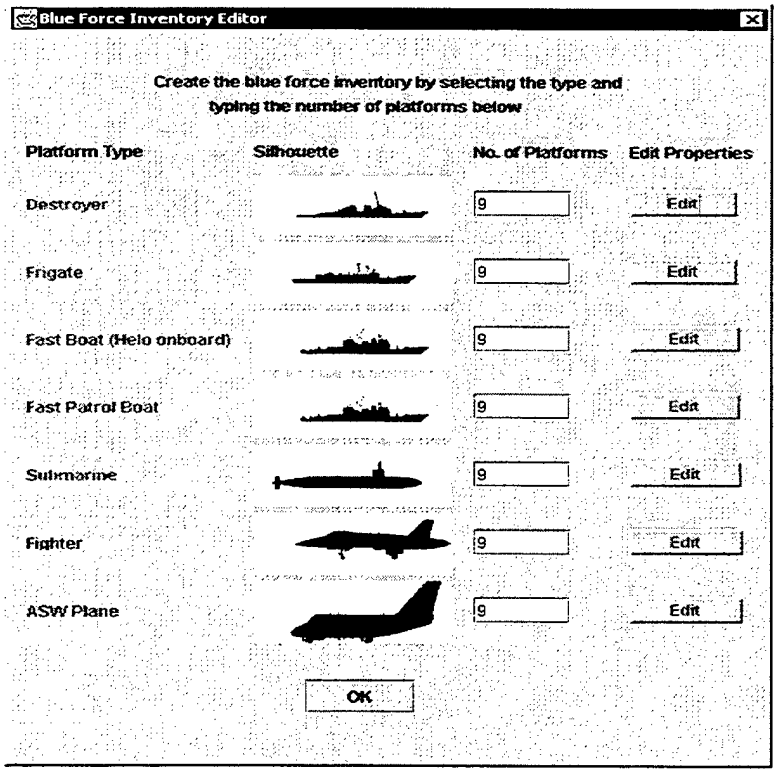

Figure 11. Blue Inventory Creation Panel

Every platform has *thirteen* different properties and the user supplies these properties to the system before the simulation runs. Clicking on one of the edit buttons on the panels shown in Figure 10 or Figure 11 brings up another panel to supply the vessel properties to the system. The panel for supplying the blue frigate properties to the system is depicted in Figure 12.

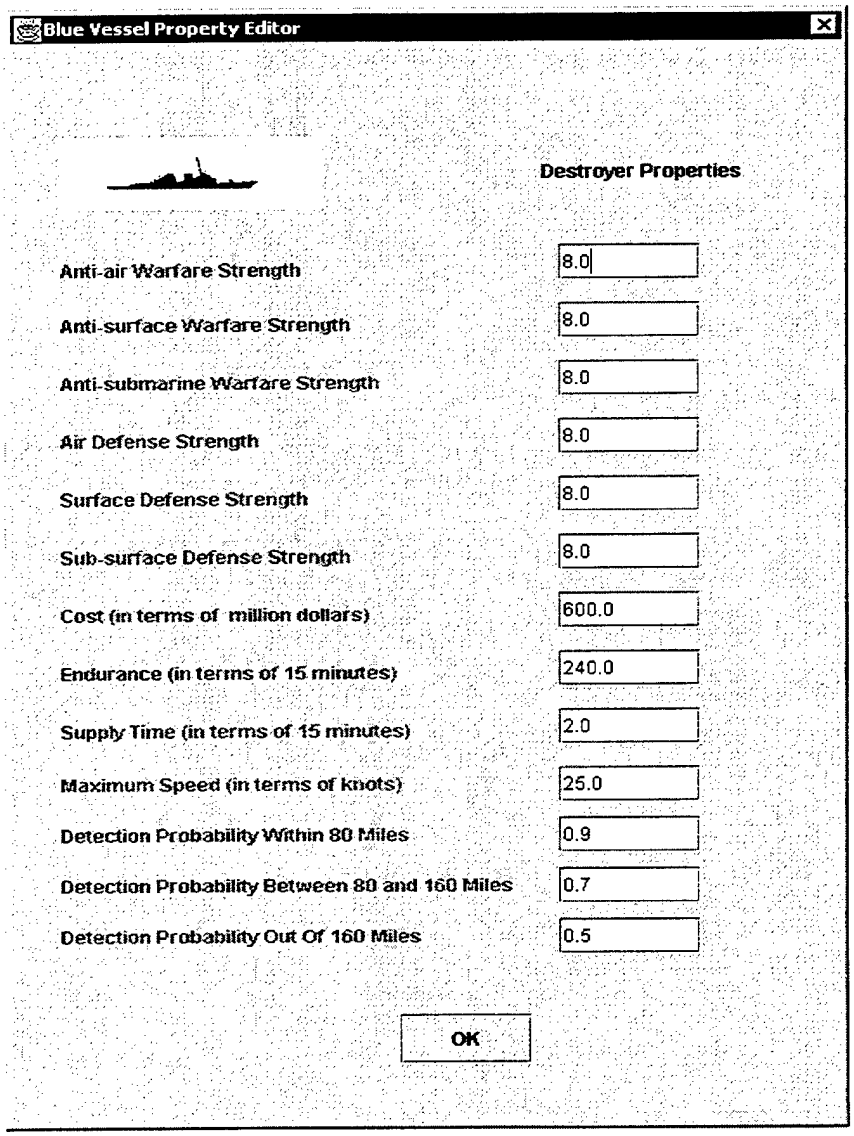

Figure 12. Blue Frigate Property Editor

Only *three* naval warfare types are considered in this study. These are *air warfare*, *surface warfare* and *sub-surface warfare.* The warfare capabilities of a platform are broken into two main categories in the simulation. These are *offensive* and *defensive* capabilities for each type of warfare. The *anti-air warfare strength* value represents the attacking capability of a platform against air platforms. Likewise, the *anti-surface warfare strength* value represents the attacking capability of a platform against surface platforms and the *anti-submarine warfare strength* value represents the attacking capability of a platform against sub-surface platforms.

Similarly, *air defense strength*, *surface defense strength,* and *sub-surface defense* strength values represent the defense capabilities of a platform against air, surface, and sub-surface platforms respectively.

The *cost* value represents the cost of a platform. This value should be supplied to the system in multiples of *$1 million dollars*. Therefore, if the cost of a fast patrol boat is $50 million dollars, then its cost value should be supplied to the system as 50.

The *endurance* value represents the time unit that a platform can stay at sea without fueling. This value is used in the simulation when deciding whether a particular platform needs to be re-supplied before further operating in the operational area. This value should be supplied to the system in multiples of *fifteen minutes*, and should be an integer value. Therefore, if the endurance of a fighter is *two hours*, then its endurance value should be supplied to the system as *eight*.

The *supply time* value represents the time needed for a platform to conduct replenishment. Once a platform arrives in one of the supply zones, it is maintained in that

zone until its supply time expires. At the end of the supply, the platform resumes its initial *endurance value*.

The *maximum speed* value is used when calculating the transition times between zones of the operational area. It is assumed that the platforms are always using their maximum speed when transiting from one zone to another.

Finally, the last three *detection probabilities* represent the platforms' detection capability within its zone, in the neighbor zones, and in the zones, which are two zones away from its current zone. These probabilities are used in the stochastic intelligence calculations during the simulation. The stochastic intelligence calculations will be discussed in detail in Section F.

During the simulation, each platform is presented with a unique shape in the environment. These shapes are;

- Destroyer: filled rectangle (12 by 12 pixels)
- Frigate: empty rectangle (12 by 12 pixels)
- Submarine: filled oval (9 by 9 pixels)
- Fast Patrol Boat: empty rectangle (7 by 7 pixels)
- Fast Patrol Boat With Helicopter: filled rectangle (7 by 7 pixels)
- Fighter: empty oval (2 by 2 pixels)
- ASW Plane: empty oval (4 by 4 pixels)

The platforms on the blue commander side are *blue* and the platforms on the red commander side are *red* in color. In order to distinguish the supplying and the transiting platforms in the transition zones, the supplying red platforms are presented in *green* and

the supplying blue platforms are presented in *gray*. Their colors change to their original (either blue or red) once they finish supplying.

E. AGENT GOAL SELECTION MECHANISM

As mentioned earlier in the Chapter, the blue and the red commander agents perform three different actions in the simulation. These actions are *force allocation*, *force deployment*, and *force movement* actions for the blue and *force movement* action for the red commander agent. Each type of action has a goal type associated with it. Therefore, the blue agent has *three* and the red agent has only *one* type of goal in the simulation. Each goal type has numerous goals associated with it and this allows competing and conflicting goals to exist within the agents. It also provides a straightforward example of dynamic goal selection.

One rule is provided for each goal in the simulation. Additional rules can be included similar to the El Farol simulation discussed in Chapter II. The goal types, the goals within these goal types, and the rules associated with these goals will be discussed in detail as follows:

1. Goal Feedback Mechanism

All of the goals associated with the three different goal types have a feedback mechanism device that allows them to develop a current weight based on the agents' personalities and the perceived changing environment. All goals within a goal type use a standard formula for determining this weight, which incorporates the following terms.

- *Gal Attainment (ga_i):* The measurement of how close a commander agent's current situation is to fulfilling the ith goal (g_i).

- *Goal Personality Factor (gpf_i):* The personality trait that influences the ith goal (g_i).

- *Agent Goal Weight (Agw_i):* The weight of the ith goal that affects the agent's next action. The agent goal weight is determined from the agent's current goal attainment value and the agent's personality factor (i.e. how much the agent cares about that particular goal being satisfied.):

$$\mathbf{Agw_i = Aga_i * Agpf_i}$$

Equation 1. Agent Goal Weight Calculation

2. Rule Credit Assignment

Since there is only one rule per goal, a rule credit assignment is not used in this simulation. After finding the active goal for a goal type (the goal that has the highest weight), the rule associated with this goal is executed.

3. Platform Allocation Goal Type

Only the blue commander has this goal type since the red commander does not perform the platform allocation action in the simulation. There are *seven* different goals of this type embedded in the blue commander. Each goal represents the need of the blue commander to possess one of the seven platforms in the task force. The allocation goal weight calculation formula for the destroyer platform type is shown in Equation 2. The platform allocation process ends when the blue commander agent's budget level is exceeded or there is no platform left in the blue inventory. A complete list of platform allocation goals is given in Appendix C.

$$\textbf{Goal Attainment} = 1 - \left(\frac{\frac{a_{dd}}{i_{dd}}}{1+\frac{a_{dd}}{i_{dd}}} * \frac{\frac{a_{dd}}{p_{red}}}{1+\frac{a_{dd}}{p_{red}}}\right)$$

$$\textbf{Goal Weight} = GoalAttainment * p_{sur} * p_{stp}$$

a_{dd} : The number of destroyers assigned to the blue task force from the inventory

i_{dd} : The number of destroyers in the initial blue inventory

p_{red} : The perceived number of destroyers in the red task force

p_{sur} : The surface platform selection tendency of the blue commander

p_{stp} : The staying power tendency of the blue commander

Equation 2. Destroyer Allocation Goal Weight Calculation

Each platform allocation goal has only one rule associated with it. These rules allocate one of the *seven* types of platforms from the inventory to the blue task force. These rules can also be viewed in Appendix C.

4. Force Deployment Goal Type

Similar to the platform allocation goal type, only the blue commander has a force deployment goal type since the user determines the deployment of the red forces. There are *three* different goals of this type embedded in the blue commander agent. Each goal represents the need of the blue commander to deploy a platform to one of the three

theaters of the operational area. The blue platforms can initially be deployed to the zones numbered *eleven*, *thirteen*, and *fifteen*. Likewise, the red platforms can be deployed to zones numbered *one*, *three*, and *five*. The deployment goal weight calculation formula for the blue commander agent for the zone 11 is depicted in Equation 3. This calculation is performed for each type of platform separately until all of the platforms allocated to the task force in the previous step are deployed to any of the three zones. A complete list of the *force deployment goals* is given in Appendix D.

$$\textbf{Goal Attainment} = 1 - \left(\frac{\frac{b_{p11}}{p_{pred1}}}{1 + \frac{b_{p11}}{p_{pred1}}}\right)$$

$$\textbf{Goal Weight} = GoalAttainment * z_{imp}$$

b_{p11} : The number of blue platforms of a type deployed to zone 11

p_{pred1} : The perceived number of red platforms of a type in zone 1 (same theater)

z_{imp} : The strategic importance value of the theater that spans the zones 1 and 11

Equation 3. Blue Platform Deployment Goal Weight Calculation To Zone 11

Each *force deployment goal* has only one rule associated with it. These rules deploy one of the *seven* types of platforms to one of the three zones described above. These rules can also be viewed in Appendix D.

5. Force Movement Goal Type

Both of the agents have force movement goal type since they both control the movements of their platforms during the simulation. This goal type was further divided into sub-goal types since there is more than one movement possibility for a platform in a zone. A platform in a zone can continue to stay in the same zone or can transit to one of the two or three neighboring zones. Therefore, the agent commanders have a movement goal type for each of the zones in the environment. These movement goal types have either *three* or *four* associated goals depending on the number of possible movements from that zone. The movement goal weight calculation formula for the blue agent from zone 10 to zone 15 is shown in Equation 4. A complete list of force movement goals is given in Appendix E.

$$\textbf{Goal Attainment} = 1-\left(\frac{\frac{b_{ts}}{r_{pts}}}{1+\frac{b_{ts}}{r_{pts}}} * \frac{\frac{b_{tsng}}{r_{ptsng}}}{1=\frac{b_{tsng}}{r_{ptsng}}}\right)$$

$$\textbf{Goal Weight} = GoalAttainment * z_{imp} * (1-agg)$$

b_{ts} : The blue total strength in the west theater

p_{pts} : The perceived red total strength in the west theater

b_{tsng} : The blue total strength in the neighbor theater (center theater)

r_{ptsng} : The perceived total red strength in the neighboring theater (center theater)

agg : The aggressiveness personality factor of the blue commander

z_{imp} : The strategic importance value of the west theater

Equation 4. Blue Agent Move Goal Weight Calculation From Zone 10 to Zone 15

Each force movement goal has only one rule associated with it. These rules either keep a platform in a zone for the time step or transfer it to another zone depending on the weight of the movement goals associated with that particular zone. These rules can also be viewed in Appendix E.

F. STOCHASTIC INTELLIGENCE GATHERING

The intelligence gathering process about the opponent's force level and disposition is implemented stochastically in two different parts of the simulation. The stochastical calculations described below are based on the formulas in Ref. (Gaver, Jacobs, Youngren, Parry, 2000).

The first stochastical intelligence gathering process is conducted at the beginning of the simulation. Once the user determines the red force structure and disposition, the blue commander perceives the opponent force level using a stochastical perception process. For each platform type in the red force, a series of binomial trials are conducted with the probability of success being the initial intelligence capability of the blue commander and the number of trials being the actual number of red platforms of that type. The formulas for this process are provided in Equation 5. This stochastical feature of this perception process allows different perceptions at different times with the same red commander force level.

The second stochastical intelligence gathering process is conducted during the actual simulation runs. Since the number of the red and the blue platforms in any zone changes dynamically during the simulation, it is not realistic to set a probability of detection value for every zone for both the blue and the red commanders. As mentioned

$X_i \sim$ Binomial with the number of trials being the actual number of opponent platforms in the red task force and the probability of success (p_i) being the initial intelligence capability of the blue commander.

The moment estimator $(\hat{r}_i)$ for the actual number of red platforms in the red task force is:

$$\hat{r}_i = \frac{X_i}{p_i}$$

Note that

$$E[\hat{r}_i] = \frac{r_i p_i}{p_i} = r_i$$

So, $\hat{r}_i$ is an unbiased estimator for the actual number of red platforms in the red task force.

Equation 5. Initial Stochastical Intelligence Gathering Calculations

earlier in this Chapter, every platform has a user defined detection probabilities depending on the target range. For each zone, the blue and the red commanders determine the two platforms that have the highest detection probabilities for that zone. These two platforms calculate their opponent's force level estimates for that zone based on their probability of detection values. This calculation is conducted the same way it was explained above for the blue commander's initial estimation of the red force level. Once the commander agents get these estimates from the two platforms, they combine these estimates based on their variance values. The first step in this process is to calculate the estimated variances for the estimates. The following formula is used for this calculation.

$$Var[r_i] = Vi^2 = \frac{1}{p_i^{\,2}} Var[X_i] = \frac{r_i p_i (1-p_i)}{p_i^{\,2}} = \frac{r_i (1-p_i)}{p_i}$$

Equation 6. Variance Calculation For the Platform Estimates

Once these variances are known, the Equation 7 is used to obtain a combined weighted estimate from the two estimates. Note that this formula takes the weighted average with weights the inverse variances.

$$r = \frac{\dfrac{r_1}{v_1^{\,2}}}{\dfrac{1}{v_1^{\,2}}} + \frac{\dfrac{r_2}{v_2^{\,2}}}{\dfrac{1}{v_2^{\,2}}}$$

Equation 7. Combining Platform Estimates

G. STOCHASTIC COMBAT RESOLUTION

The combat resolution part of the simulation is also implemented stochastically. Once the simulation begins, the commander agents continuously maneuver their platforms between the zones to have force superiority in the zones. The decision to fight in a particular zone is made by the commander agents in each time step based on their aggressiveness personality factor and the perceived force ratio for that particular zone. Increasing aggressiveness and/or perceived force ratio prods the commander agents to decide to fight in a particular zone. The combat can occur in any of the zones numbered *six*, *eight*, or *ten*. Once one or both of the commander agents decides to fight in a time step, it is assumed that the combat occurs during that time step in every combat zone.

As described previously in the Chapter, every platform has *three* different types of warfare capabilities (air, surface, and sub-surface). Each warfare capability is further divided into offensive and defensive capabilities. This results in six factors to be considered during the combat resolution part of the simulation. It is assumed that every type of offensive and defensive capabilities are allocated to other platform's offensive and defensive capabilities. For instance, a platform that has an air defense capability of *ten units* can allocate *four units* of this capability to protect its air assets, while assigning *four units* to protect its surface and *two units* to defend its sub-surface assets. Likewise, a platform that has an air offense capability of *ten units* can allocate *four units* of this capability to attack the opponent's air assets, while allocating *four units* to attack its surface assets and *two units* to attack its sub-surface assets. This allocation idea makes the combat resolution calculations more realistic. Obviously, an air attack does not generally degrade the sub-surface warfare capabilities of a platform as it degrades its air and surface warfare capabilities.

Once the warfare capabilities are partitioned to the opponent's warfare capabilities, the second step is to calculate force ratios for each type of warfare combination. These combinations are air, surface, and sub-surface attacks to degrade the opponent's air, surface, and sub-surface assets. This approach results in nine equations for each commander agent. The formulas used to calculate the resulting surface defense and offense capabilities of the blue task force in a zone after the red task force attack is given in Equation 5. The same calculations are conducted to get the resulting air and sub-surface offense/defense capabilities of the blue force. Likewise, all of these calculations are also carried out to get the resulting force level of the red force.

$$A_{sur.sur}(R,t) = 0.4 * A_{sur}(R,t) \qquad D_{sur.sur}(B,t) = 0.4 * D_{sur}(B,t)$$

$$\kappa_{R,B}(sur, sur) = \frac{\dfrac{A_{sur,sur}(R,t)}{D_{sur.sur}(B,t)}}{1 + \dfrac{A_{sur.sur}(R,t)}{D_{sur.sur}(B,t)}}$$

The $\kappa_{R.B}(sur, sur)$ value can be considered as the surface capability losses in the blue force after the red force surface attack. The $\kappa_{R.B}(air, sur)$ and $\kappa_{R.B}(sub, sur)$ values can be calculated the same way. Once these values are known, the following formula is used to calculate the resulting surface offense and defense capabilities of the blue commander.

$$A_{sur}(B,t+1) = A_{sur}(B,t) * (1 - \kappa_{R.B}(sur, sur)) * (1 - \kappa_{R.B}(air, sur)) * (1 - \kappa_{R.B}(sub, sur))$$

$$D_{sur}(B,t+1) = D_{sur}(B,t) * (1 - \kappa_{R.B}(sur, sur)) * (1 - \kappa_{R.B}(air, sur)) * (1 - \kappa_{R.B}(sub, sur)$$

Once the final offense and defense surface capabilities of the blue force is calculated, the resulting capabilities are allocated to the platforms in the combat zone based on their surface, air, and sub-surface defense capabilities. A platform that has high defense capabilities (i.e. destroyer) gets less degradation than a platform that has less defense capabilities (i.e. fast patrol boat).

Equation 8. Combat Resolution Calculation

H. RUNNING THE SIMULATION

The simulation program can be started by typing "java TestSimEnv" in the dos prompt window. When the program is started, the initial GUI element appears on the screen is displayed in Figure 13. Pressing the "Start" button on this window brings up

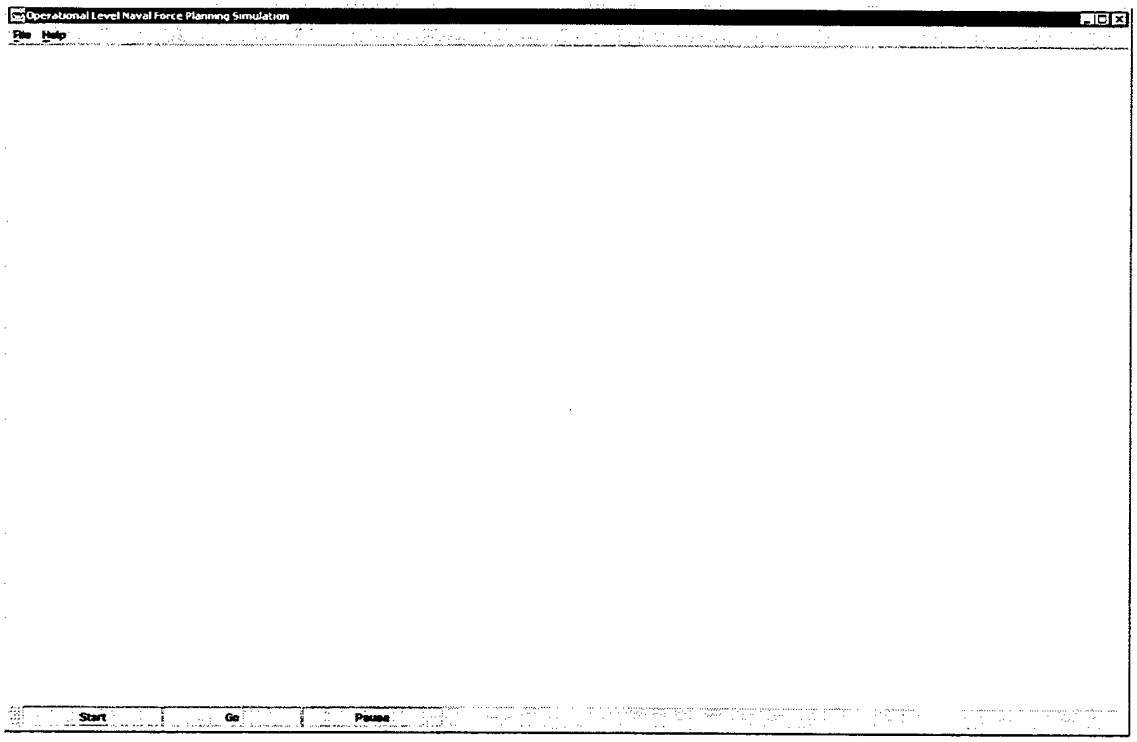

Figure 13. Initial Simulation Environment

the window displayed in Figure 10. The user is requested to create the red task force by typing the number of platforms of each type to the corresponding text fields. Typing the "edit" button across a platform type brings up the GUI window displayed in Figure 12. From this GUI window the user can supply the characteristics of the platform to the simulation. Clicking the "OK" button closes this window and makes the previous window active (window displayed in Figure 10). Once the user is done with typing the number of platforms in the red task force, clicking the "OK" button of the GUI window displayed in Figure 10 closes this window and brings up the window in Figure 11. The usage of this GUI window is nearly identical to GUI in Figure 10. The only difference is that this GUI is used to create the blue commander agent inventory. Once the user is done with this window, clicking the "OK" button brings up the window displayed in Figure 8.

This window is used to supply the characteristics of the blue commander to the simulation. Pressing the "OK" button in this window opens the window in Figure 9 and the characteristics of the red commander agent is supplied to the system through this GUI element. Clicking on the "OK" button in this window brings up one last window before the movement part of the simulation is ready to run. This window is displayed in Figure 14. The simulation parameters are supplied to the model by using this GUI element. Once these values are supplied, clicking the "OK" button in this window brings up the simulation environment (displayed in Figure 7) filled with red and blue platforms.

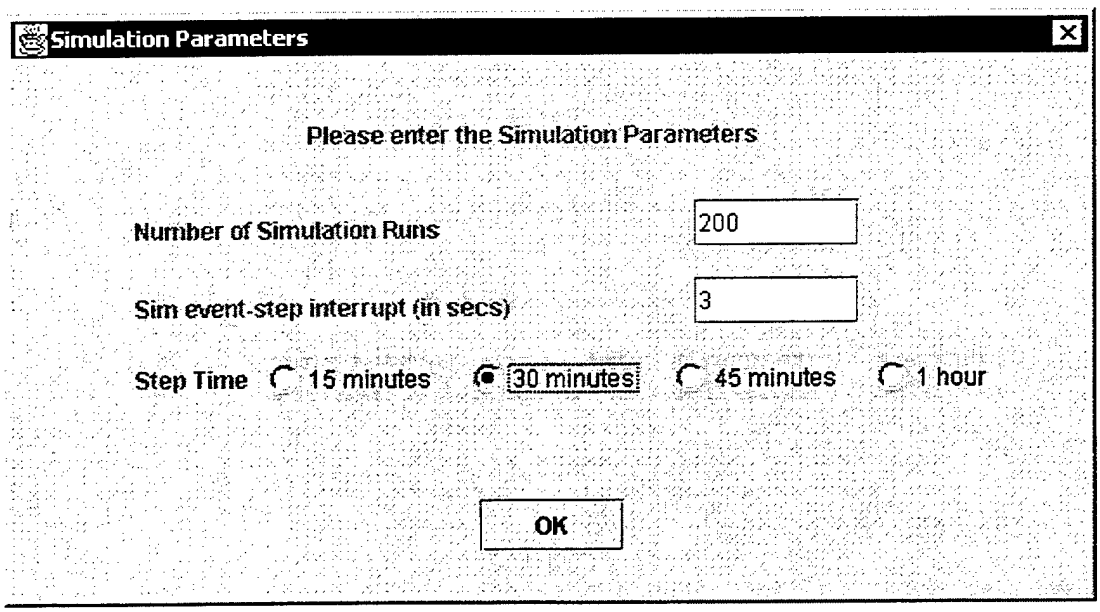

Figure 14. Simulation Parameters GUI Window

Once the red and the blue platforms are displayed on the screen, the next step is to start the movement / engagement part of the simulation by pressing the "Go" button in the window shown in Figure 13. The simulation can be paused at any time by pressing the "Pause" button on the environment window. The user can also access the information

about a conflict zone by clicking on that zone during the simulation. Clicking a zone brings up the window in Figure 15. This window reports the number of the blue and red platforms in the zone, the active movement goals of the blue and the red commander for the zone and the strategic importance value of the conflict zone.

Conflict Zone Report

	Blue Force	Blue In Supply	Red Force	Red In Supply
Destroyers	2	0	1	0
Frigates	0	0	0	0
Fast Patrol Boats (Helo Onboard)	0	0	0	0
Fast Patrol Boats	2	0	1	0
Submarines	2	0	1	0
Fighters	0	0	0	0
ASW Planes	0	0	0	0

Blue Commander Active Goal	BlueStayInZone6Goal
Red Commander Active Goal	RedMoveFromZone6ToZone1Goal
Conflict Zone Importance	0.9
Zone X Position	0
Zone Y Position	240
Zone Number	6

OK

Figure 15. Conflict Zone Report Window

The simulation terminates when the program step counter reaches the number of simulation runs supplied by the user or the force ratio in the operational area drops below

the level of 1/3 for either of the task forces. The user can also terminate the program by selecting the "Exit" menu item under the "File" menu option in the window displayed in Figure 13.

I. SUMMARY

The first part of this Chapter introduced the environment that represents the naval operational area in which the simulation takes place. The dimensions of the environment and detailed information about the conflict zones were provided. The characteristics of the commander agents and the platforms, and their instantiation processes were also presented in detail. It was pointed out that the platforms are the objects, not the agents in the simulation environment. It was also stated that the platforms, not the commander agents, are visible in the simulation environment.

After introducing the environment and the basic entities of the simulation, the goal selection mechanism of the commander agents for each goal type was introduced in detail and the formulas used for the goal weight calculations were provided for each goal type.

The stochastic intelligence gathering and combat resolution processes were also presented in detail in two different sections. The basic idea and the formulas associated with these calculations were also provided to the user. The final section described the interface of the simulation.

The next chapter proves the usefulness of the model through the output and analyses of summary statistics gathered from experimental simulation scenarios.

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V. MODEL ANALYSIS AND RESULTS

A. INTRODUCTION

The goal of this chapter is to investigate the usefulness and potential of the model by using it to analyze the effects of various blue commander agent characteristics against a generically created red agent enemy. Obviously, it is impossible for this thesis to demonstrate all of the capabilities and characteristic combinations that this model possesses.

This chapter introduces three experiments. The first experiment is conducted to demonstrate that the force allocation decisions made by the blue commander agent at the beginning of the simulation are plausible. Likewise, the purpose of the second experiment is to show that the initial force deployment decisions made by the blue commander agent are also plausible. Finally, the last experiment aims at demonstrating that the overall model is producing plausible output that can further be used to explore the effects of different initial conditions to the outcome of the overall operation.

B. METHOD

This section introduces the area of investigation, the agent and the platform characteristics, and the experiments used throughout this Chapter's analysis.

1. Areas of Investigation

In order for any type of model to produce useful results, its sub-models should perform their tasks accurately. Therefore, the first two experiments introduced in this chapter are conducted to demonstrate that the two MAS sub-models (force allocation and

force deployment) of the simulation are generating reasonable results based on the different initial conditions. After demonstrating that the two sub-models are producing plausible results, the last experiment investigates the affects of different blue agent / force characteristics on the result of the conflict resolution.

2. Platforms and Their Attributes

The types of platforms within this model do not encompass all of the different types of vehicles found in the navies of the world. However, they are the major types that are maintained by most of the navies. Moreover, the user can introduce any type of platform to the simulation by simply supplying its characteristics through the corresponding GUI elements.

During the experiments, even though it is possible to assign different attribute values to the same type of platforms on the opposite sides, these values are kept the same. Note that, the model does not let the user supply different attribute values to the same type of platforms within the same task force.

To the author's and his advisors' knowledge, no study has yet been conducted to assign numerical values to the attributes of the naval combat platforms. Therefore, the numerical values assigned to the attributes of the platforms in the experiments are based on the experience of the author who has served six years in the Turkish Navy. Nevertheless, the user can change these numerical values at the beginning of the simulation. Table 1 depicts the platform attribute values used in the simulation.

Red and Blue Platform Attributes							
Attribute	**DD**	**FF**	**SS**	**FPB**	**FPB (Helo)**	**Fighter**	**ASW Plane**
Anti-Air Warfare	9	8	0	6	6	9	6
Anti-Surface Warfare	9	8	7	6	7	6	5
Anti-Sub. Warfare	9	7	9	5	6	0	9
Air Defense	9	8	0	7	7	9	6
Surface Defense	9	8	9	7	7	9	7
Sub-Surface Defense	8	7	9	6	6	0	0
Cost (Million $)	600	400	1000	100	150	40	60
Endurance (Hours)	240	240	240	144	144	4	12
Supply Time (Minutes)	120	120	120	60	60	30	30
Max. Speed (Knots)	25	25	25	40	40	900	150
Pr. of Detect. (0 - 80 miles)	0.9	0.8	0.4	0.6	0.7	0.7	0.8
Pr. of Detect. (80 - 160 miles)	0.7	0.6	0.2	0.4	0.5	0.5	0.6
Pr. of Detect. (160+ miles)	0.5	0.4	0.1	0.2	0.3	0.3	0.4

Table 1. Platform Attributes for the Experiments

3. Red Commander Agent Characteristics

The types and the number of platforms in the red task force are kept constant throughout the experiments. This data are shown in Table 2. The *aggressiveness* personality factor of the red agent is set to .6 to introduce a cautious and proactive opponent to the blue commander. The red commander agent's *force concentration tendency* personality factor is varied in the second experiment to control the initial deployment of the red task force in the operational area. This value is set to .2 in the last experiment to force the red commander to initially deploy its platform to the all three theaters of the operational area.

Red Task Force							
	DD	**FF**	**SS**	**FPB**	**FPB (Helo)**	**Fighter**	**ASW Plane**
Number of Platforms	5	4	4	4	4	4	4

Table 2. Red Task Force for the Experiments

4. Blue Commander Agent Characteristics

The types and the number of platforms in the blue inventory are kept constant throughout the experiments. This data are shown in Table 2. The *aggressiveness* personality factor of the blue agent is also set to .6. Its budget value is set to $10 billion for the first two experiments and varied in the last one to explore the interaction between the budget allocated for the operation and the success of the operation.

Blue Agent's Inventory							
	DD	FF	SS	FPB	FPB (Helo)	Fighter	ASW Plane
Number of Platforms	9	9	9	9	9	9	9

Table 3. Blue Agent's Inventory for the Experiments

5. Experiment One

The purpose of the first experiment is to demonstrate that the *force allocation sub-model* of the entire model is producing reasonable results in differing input conditions. The attributes of the platforms on both sides are set to the values depicted in Table 1. The red task force is composed of the types and number of platforms shown in Table 2. Based on the cost of the individual platforms, the total value of the red task force is $10 billion. In order to see the blue commander agent's trade-off decisions more clearly, its budget attribute is also set to $10 billion. Since the experimenter defines the blue commander agent's budget, there are only two factors that can affect its force allocation decisions. These factors are the *warfare usage tendency* and the *initial intelligence capability* of the blue commander agent.

The blue commander agent's warfare tendency values are varied between the trials to simulate four types of commander agents with different warfare usage tendencies. These tendencies are *surface warfare usage tendency*, *sub-surface warfare usage tendency*, *air warfare usage tendency* and *balanced force usage tendency*. Additionally, two levels of initial intelligence value are used for the blue commander

agent. These are *high* (.9) and *low* (.2) initial intelligence values. Note that because the intelligence gathering process is implemented stochastically in the simulation, the blue commander agent's red force level perception changes between the trials that has the same input values. All data are captured via *out* files and then a clustered column graph is created for each of the runs.

6. Experiment Two

The purpose of the second experiment is to demonstrate that the *force deployment* sub-model of the entire model is also producing reasonable results in differing input conditions. Unless otherwise noted in the following lines, the same input conditions in experiment one are used in this experiment. The blue commander's warfare usage tendency level is set to a *balanced force usage tendency* value (the value of .5 is assigned to all four warfare usage tendency attributes).

Once the blue commander agent creates its task force in the force allocation process, there are three factors that can affect its force deployment decisions. These are the red task force's disposition in the operational area, the blue commander agent's initial intelligence capability (which affects the blue commander agent's perception of the red force level and disposition in the operational area) and the strategic importance values of the theaters of the operational area. In order to avoid a large number of combinations, the blue commander's initial intelligence capability and the strategic importance of the theaters are set to fixed values. The initial intelligence attribute is set to represent a higher intelligence capability (.9) and the strategic importance attribute of the theaters are set to the following values; east theater .7, center theater .5 and west theater .9. The only

parameter varied between the runs is the red task force's disposition in the operational area. This variation is accomplished by changing the red commander agent's force concentration tendency. Again, note that, since the intelligence gathering process is implemented stochastically in the simulation, the blue commander agent's red force level perception changes between the trials that have the same red force and the blue initial intelligence values. All data are captured via *out* files and than a clustered column graph is created for each of the runs.

7. Experiment Three

The model can be used to explore numerous operational-level naval combat scenarios. Obviously, it is impossible for this thesis to demonstrate all of the capabilities that this model possesses. Therefore, a simple scenario is explored in this last experiment.

The purpose of this experiment is to explore the affects of the blue commander's budget level on the naval operation outcome. Specifically, a budget ratio (blue commander agent's budget / red commander agent's budget), for which the blue commander agent gets consistent victories, is being investigated in this experiment. The victory condition is assumed to be having a force ratio of four to one or greater at any time in the simulation. When one of the forces exceeds this ratio, that commander agent is declared the winner of the particular replication. The simulation is run for five days with time step being an hour. If the force ratio does not exceed the victory condition during the simulation run, the battle outcome is assumed to be a draw. Unless otherwise noted below, the same input conditions in the experiment two are used in this experiment. All of the theaters in the operational area have the same strategic importance values. The

red commander agent's concentration tendency personality factor is also set to a low value (.2) to force it to initially disperse the red task force in the operational area. The only variable changing between the trials is the blue commander agent's budget value. 30 replications are run for each budget ratio and cluster column graph is presented for each of budget ratio case.

C. RESULTS AND ANALYSIS

This section discusses the results and method of analyses for the three experiments previously discussed. For all of the experiments, a clustered column graph is depicted for each combination.

1. Experiment One

The data produced by the first experiment resulted in very plausible values. The results of this experiment proved that the *force allocation sub-model* of the whole model is conducting its task effectively. Figures 16, 17, 18, 19, and 20 show the number of platforms of each type in the actual red task force, the blue commander agent's perception of the red task force based on two different initial intelligence level values (low and high), and the number of platforms allocated to the blue task force in these intelligence level cases. Note that the change in warfare tendency (between figures) and the initial intelligence capability (within figures) of the blue commander agent greatly and plausibly influence the structure of the allocated blue task force.

Figure 16 depicts the results of a run in which the blue commander agent's surface warfare usage and staying power tendency attributes are set to represent higher tendencies (both equal to .9). The other warfare usage and speed tendencies of the blue

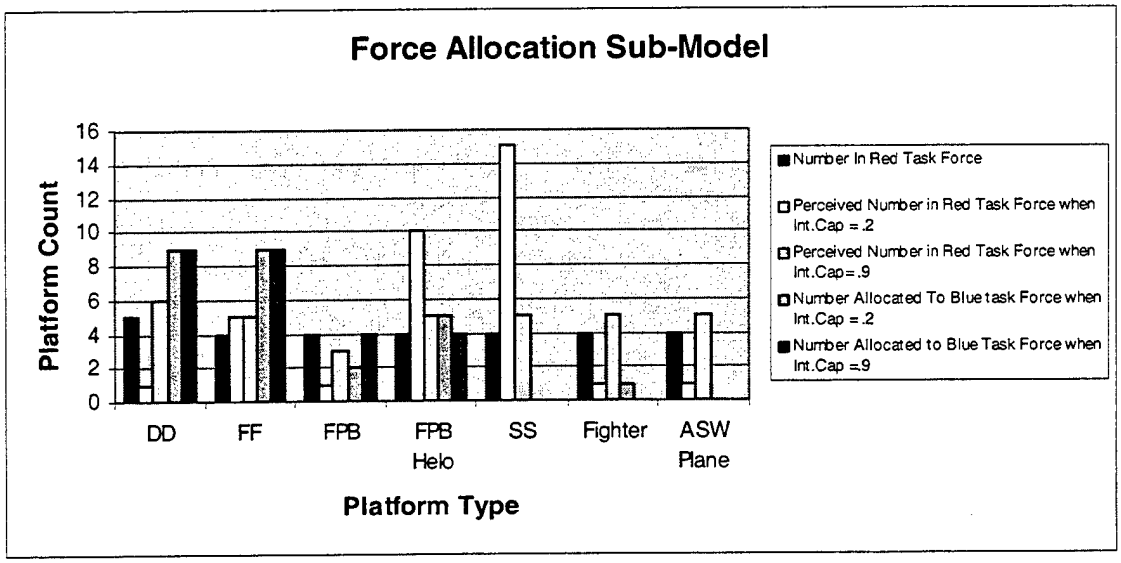

Figure 16. Force Allocation: Surface Warfare and Staying Power Tendencies High

commander agent are set to lower values (all equal to .2). Since the surface warfare usage tendency attribute of the blue commander agent is much larger than the other two warfare usage tendencies, the number of surface platforms allocated to the blue task force is much greater than the other types of platforms. Additionally, since the staying power tendency of the blue commander agent is much greater than its speed tendency, the number of frigates and destroyers allocated to the blue task force surpass the number of fast patrol boats.

Figure 17 depicts the results of a run in which the blue commander agent's surface warfare usage and speed tendencies are set to represent higher tendencies (both .9). The other warfare usage and staying power tendency attributes are set to lower values (all .2). Since the blue commander agent's surface warfare tendency is still much larger than the other two warfare usage tendencies, the number of surface platforms allocated to the blue task force is again more than the other types of platforms. Additionally and in

contrast to the first run, since the blue commander agent's speed tendency is much greater than its staying power tendency, the number of fast patrol boats allocated to the blue task force is more than the number of frigates and destroyers.

Figure 18 depicts the results of a run in which the blue commander agent's sub-surface warfare usage tendency is set to represent a higher tendency (.9). The other warfare usage tendency attributes are set to lower values (all .2). Since the blue commander agent's sub-surface warfare tendency is much greater than its other warfare tendencies, the number of submarines allocated to the blue task force is more than the other types of platforms.

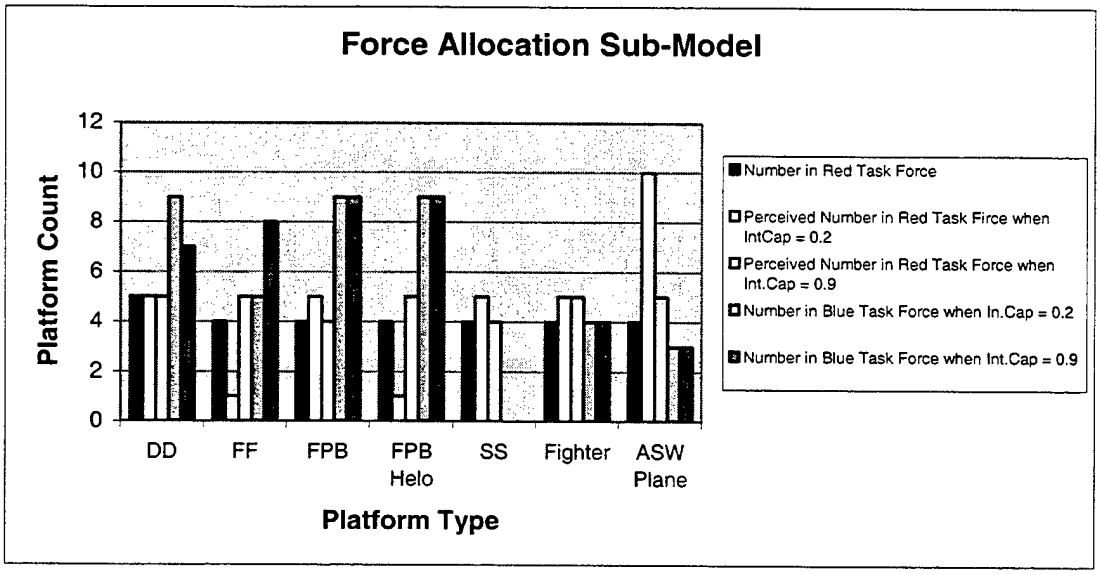

Figure 17. Force Allocation: Surface Warfare and Speed Tendencies High

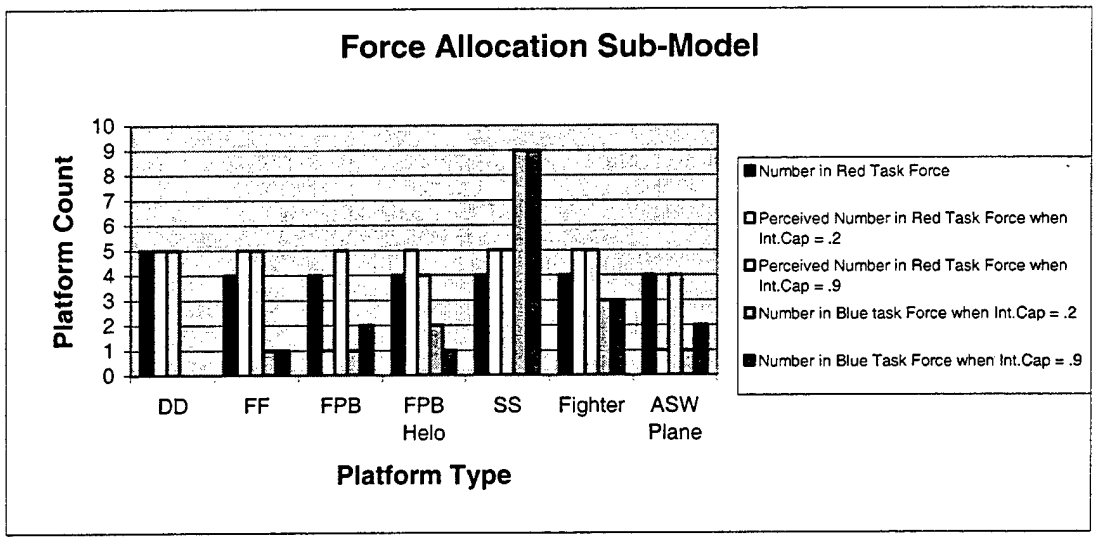

Figure 18. Force Allocation: Sub-surface Warfare Tendency High

Figure 19 depicts the results of a run in which the blue commander agent's air warfare usage tendency personality factor value is set to represent a higher tendency (.9), and the other warfare usage tendencies are set to lower values (all .2). Since the blue commander agent's air warfare usage tendency is much higher than its other two warfare usage tendencies, the number of fighters and ASW planes allocated to the blue task force are much higher than the other types of platforms.

Finally, Figure 20 depicts the results of a run in which the blue commander agent's three warfare usage tendencies are equal to each other. In this case, the blue commander agent does not prefer any type of warfare to another and its goal is to balance the force levels. Since the red task force is a balanced force, the blue task force also results in a balanced structure. If there were twice as many air platforms in the red task force than the surface platforms, the balanced warfare tendency of the blue commander

would allow it to allocate more air platforms to the blue task force even though it does not have a high air warfare usage tendency in its personality.

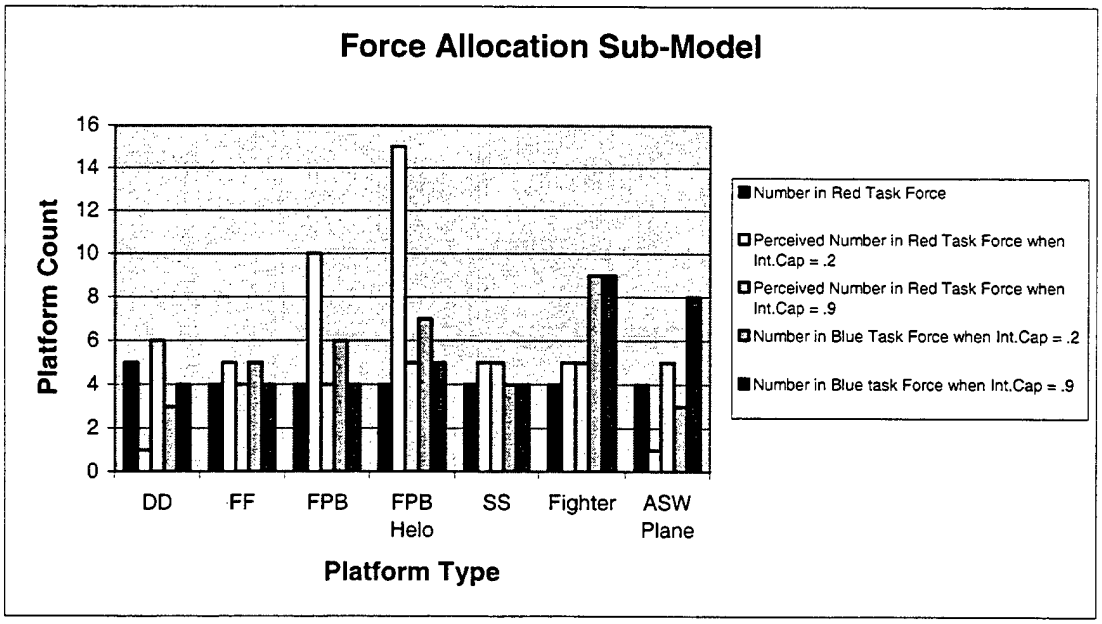

Figure 19. Force Allocation: Air Warfare Tendency High

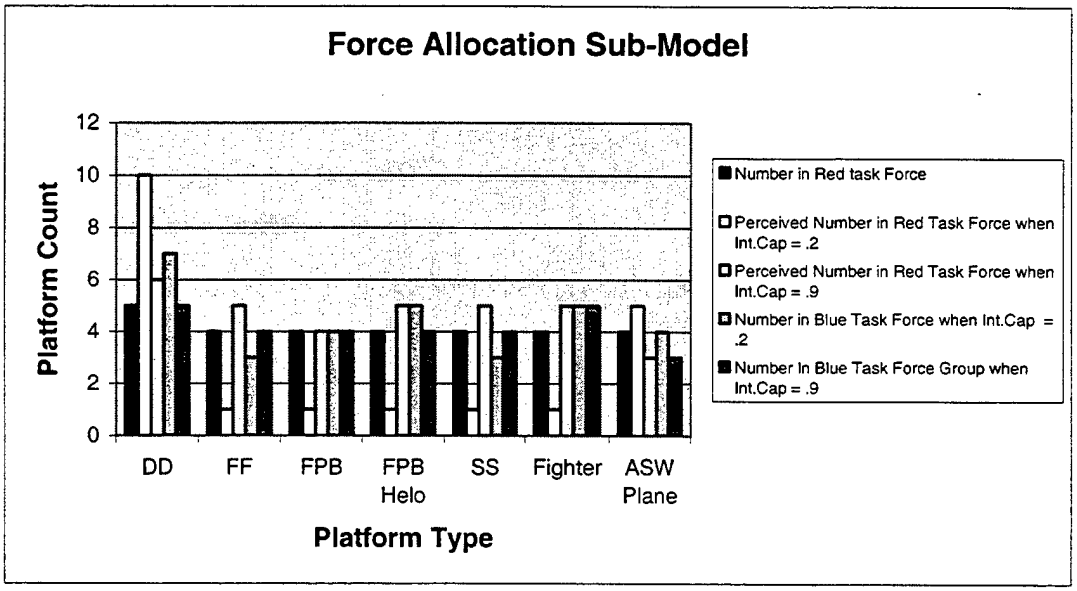

Figure 20. Force Allocation: Balanced Warfare Tendency

2. Experiment Two

The data produced by the second experiment also resulted in very plausible values. The results showed that the *force deployment sub-model* of the whole model is conducting its task effectively. Figures 21, 22, and 23 displays the number of platforms of each type in the actual red task force in a zone, the blue commander's perception of the red task force in that zone, and the number of blue platforms deployed to that zone. Note that the disposition of the red task force greatly affects the blue commander's deployment decisions.

Figure 21 depicts the results of a run in which all of the platforms in the red task force are concentrated in the west theater. We can see that the blue commander agent also concentrates its forces in the same theater. Since the blue commander has a balanced

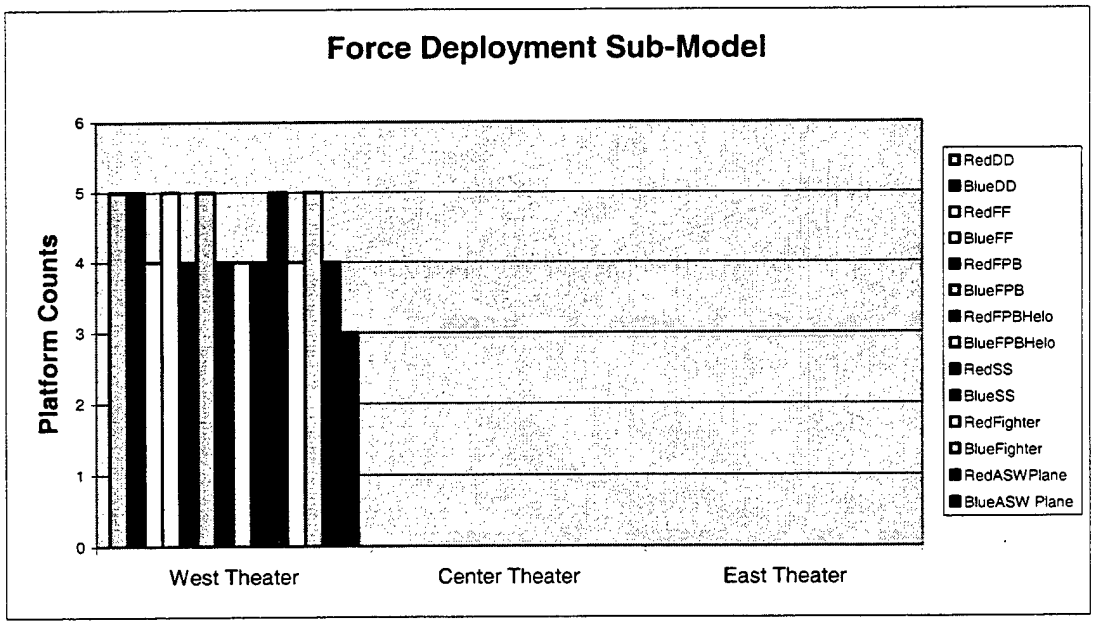

Figure 21. Force Deployment: Red Task Force Concentrates in West Theater

warfare usage tendency in this run, the number of blue platforms of each type is very close to the number of red platforms in the theater.

Figure 22 depicts the results of a run in which the red task force is deployed to two theaters that have the largest strategic importance values. According to the set up of the run, these theaters are the east and the west theaters of the operational area. We can see in Figure 22 that the blue commander agent also concentrates its forces in the same theaters. Since the blue commander agent has a balanced warfare tendency, the number of blue platforms of each type is very close to the red platforms counts.

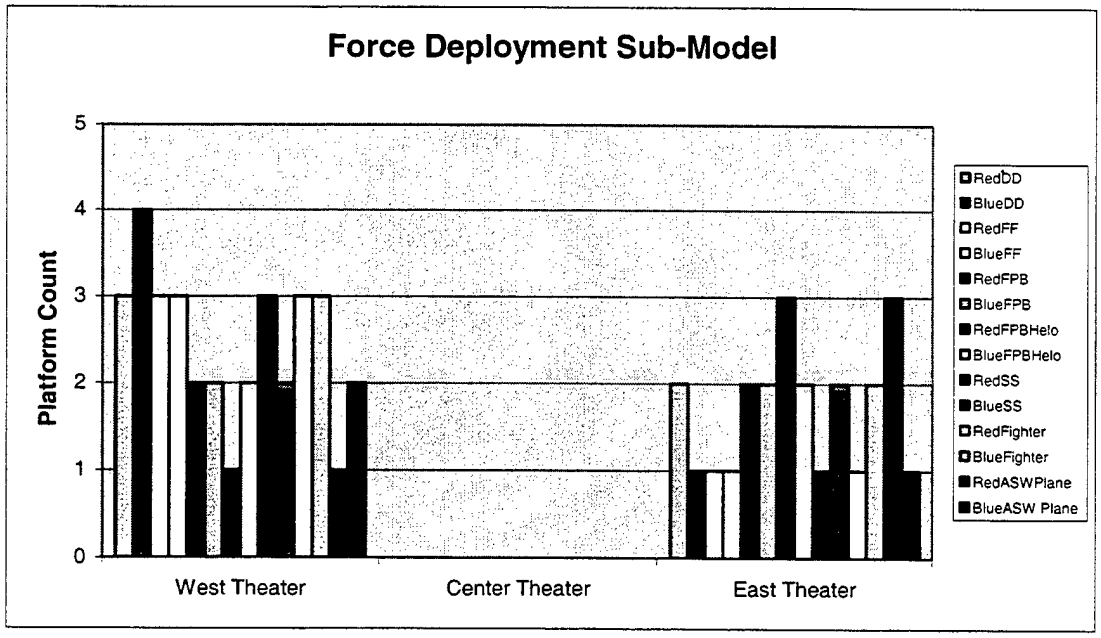

Figure 22. Force Deployment: Red Force Splits between East and West Theaters

Figure 23 displays the results of a run in which the red task force is deployed to all three theaters of the operational area. We can see that the blue commander agent also deploys its platforms accordingly, without having a big warfare disadvantage in any of the theaters. Again, since the blue commander has a balanced warfare tendency, the number of blue platforms in each type is very close to the red platforms numbers.

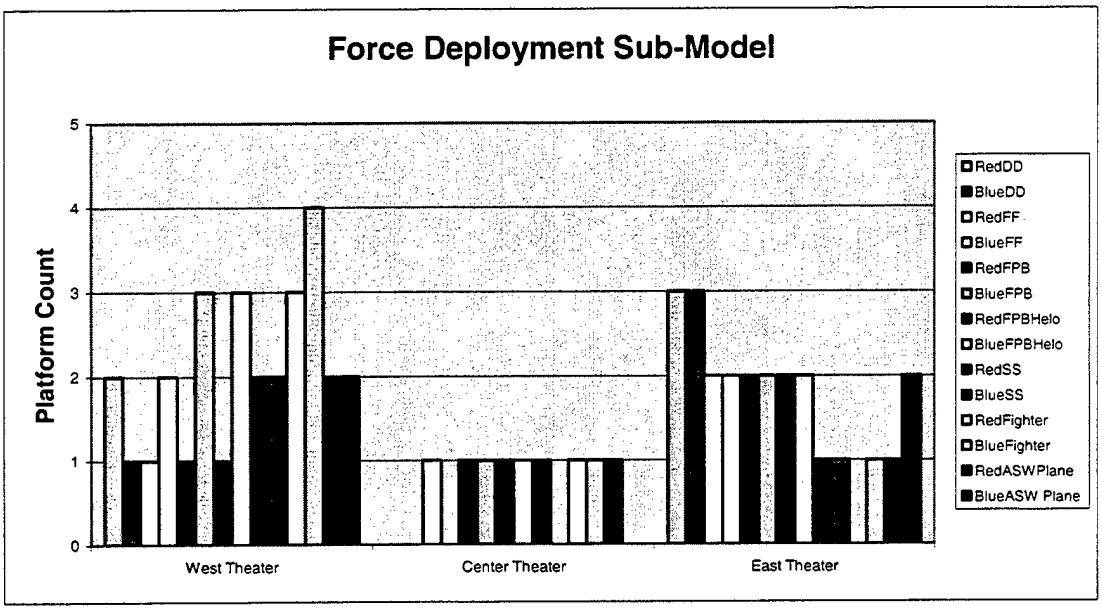

Figure 23. Force Deployment: Red Force Deployed to All Three Theaters

3. Experiment Three

The goal of the third experiment is to demonstrate one of the many exploratory analyses that can be done by using this model. Unless otherwise noted below, everything is the same as it was in the previous experiment. The strategic importance values of the theaters of the operational area are all the same. The simulation is run for five days (120 time step) with each time step representing an hour. Figure 21 depicts the results of 30 trials for nine different budget ratios. We can see that when the budget ratios (blue

agent's budget / red agent's budget) are between .9 and 1.1, none of the sides can win the battle. As the budget ratio increases the number of victories for blue agent increases. At the budget ratio level of 1.5, the blue task force wins 28 out of 30 trials and finally at the budget ratio of 1.6, the blue task force wins all of the 30 trials.

Note that this experiment does not aim at predicting the budget ratios for which the victory is consistent for one side. The whole purpose of this experiment is to show that the model can provide insight into many scenarios of the operational-level naval planning.

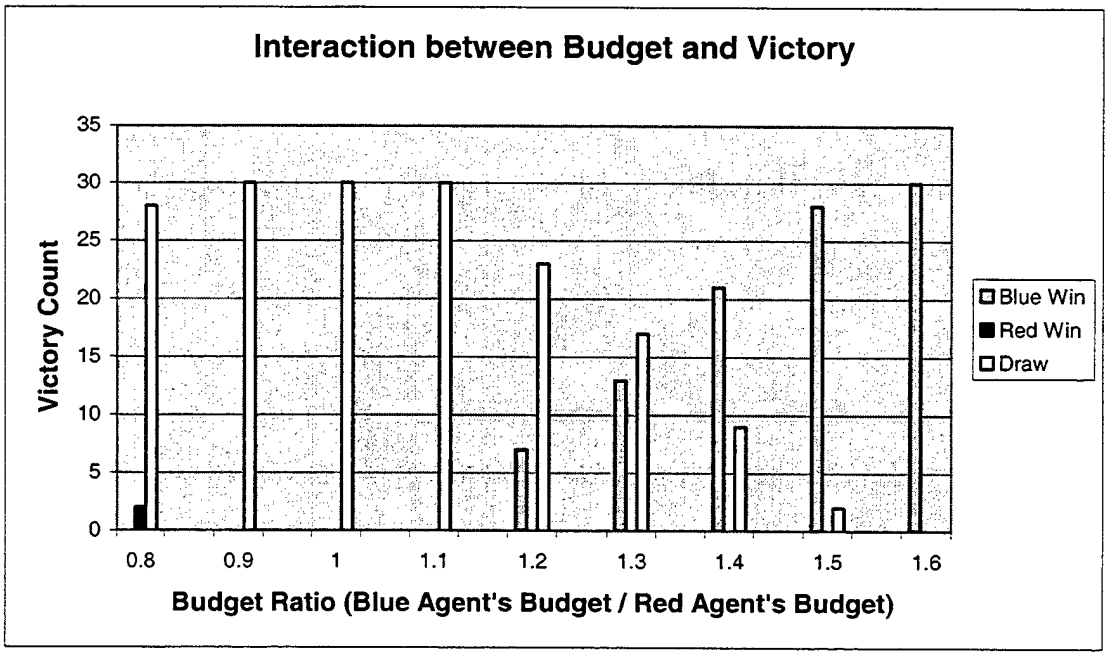

Figure 25. Interaction between Budget and Victory

D. SUMMARY

Three different experiments were introduced in this chapter. The first experiment was conducted to demonstrate that the force allocation sub-model of the whole model was performing its task properly. The results prove that this sub-model works correctly. Similar to the first experiment, the purpose of the second experiment was to show that the initial force deployment decisions made by the blue commander agent were also plausible. The results of this experiment have also proved the usability of this sub-model. Finally, the third experiment was conducted to demonstrate one way of doing exploratory experiments with the model. Specifically, a budget ratio (blue /red), for which the blue agent can get consistent victories, was investigated. The results of this experiment were also plausible. The number of blue victories out of 30 trials increased with the increasing budget ratio. The budget ratio of 1.5 seemed to be sufficient in order to reach a victory in this type of scenario.

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VI. FUTURE WORK AND CONCLUSION

A. FUTURE WORK

This section focuses on some possible future enhancements and modifications to the model presented in this thesis. Many of these enhancements would add to the realistic representation of the operational-level naval planning process and provide decision-makers with better simulation features necessary for force allocation, force deployment and force employment evaluations.

- A command and control hierarchy should be added to the model. In order to implement this hierarchy, platform commander agents and tactical commander agents and their interactions with each other and the operational commander agent need to be introduced.

- The movement and the detection algorithms should be enhanced. Situating the platforms in the simulation environment (assigning location (x, y) coordinates rather than zone numbers) would increase the simulation's spatial resolution and make the movement algorithm more accurate. Likewise, enhancements to the detection algorithm might include introducing probability of recognition, correct (or incorrect) classification, and identification parameters to the model.

- More detailed algorithms should be employed in the combat resolution calculations. This can be achieved by increasing the simulation's spatial resolution and assigning weapon range, probability of hit (P(H)) and probability of kill (P(K)) attributes to the platforms.

- In the current model, a commander agent replenishes a platform when its endurance attribute value drops below a critical level. The platform can use infinite ammunition during the engagements while it is above this critical value. This is a limitation of the model and to overcome 'this limitation, ammunition attribute information for different ammunition types should be assigned to the platforms.

- Logistics platforms should be added to the simulation. This would allow commander agents to supply their platforms anywhere they want (instead of user defined zones) depending on the tactical situation.

- More environment attributes should be introduced to the model. Some of these attributes might be the sea state and the weather condition (i.e. fog, rain).

- More platform attributes should be added to the model. Some of these attributes might be electronic warfare capability, communications capability, and combat readiness factor.

- The user should be provided with an ability to assign different values to the attributes of the same type of platforms in one side. This enables the user to define two or more platforms of the same type with different attributes.

- Mine warfare should be introduced to the model by adding mine warfare platforms and defining mine warfare offense and defense capabilities for the other platforms in the simulation.

- Some naval tactics (i.e. concentration, dispersion, and deception) should be introduced to the model for exploratory testing purposes.

- Genetic algorithms should be added to the simulation to provide a method for determining optimal force allocation, deployment and employment rules.

B. CONCLUSION

This thesis articulates the modeling of operational-level naval planning process through agent based modeling. The model developed for this thesis demonstrates how agent-based modeling can capture many dynamic aspects of operational-level naval planning process. The model is an outstanding thinking tool for the naval decision-makers and is meant to supplement currently available high fidelity models.

As discussed in the previous section, there are many areas for potential future work on this model. The continued modifications and enhancements of the model will assist decision-makers in gaining better insight into the operational-level naval planning process. This insight will enable them to make more informed decisions in the future.

APPENDIX A. LIST OF ACRONYMS

This appendix contains a list of acronyms frequently used in this thesis.

CJCS	Chairman, Joint Chiefs of Staff
COA	Course of Action
CPG	Contingency Planning Guidance
ISAAC	Irreducible Semi-Autonomous Adaptive Combat
ISAACA	ISAAC Agent
JCS	Joint Chiefs of Staff
JSCP	Joint Strategic Capabilities Plan
LEs	Lanchester Equations
MAS	Multi-Agent System
MCCDC	Commanding General, Marine Corps Combat Development Command
NCA	National Command Authorities
OSD	Office of the Secretary of Defense

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APPENDIX B. DEFINITIONS

The definitions in Appendix B are quoted from (AFSC Pub 1, 1997) unless otherwise noted.

Alert Order	A crisis action planning directive issued by the Chairman of the Joint Chiefs of Staff that provides essential guidance for planning and directs the initiation of execution planning following a decision by the NCA that U.S. military force may be required (Joint Pub 5-0, 1995).
Combatant Commander	A commander-in-chief of one of the unified or specified commands established by the President Joint Pub 5-0, 1995).
Commander's Estimate of the Situation	A document reflecting the logical process of reasoning by which a commander considers all the circumstances affecting the military situation and decides on a COA to be taken to accomplish the mission.
Contingency Planning	Developing plans for potential crises or the military requirements that can reasonably be expected in an area of responsibility is contingency planning. It is conducted during peacetime competition, conflict, and war and may be performed deliberately or under crisis conditions (Joint Pub 5-0, 1995).
Course of Action (COA)	The scheme adopted to accomplish a task or mission. The COA is contained in the Commander's Estimate of the Situation document. It includes the concept of operations and an integrated time phased database of combat, combat support, and combat service support forces and sustainment within the constraints of the time available for development. When approved, the COA becomes the basis for the development of an operation plan or order (Joint Pub 5-0, 1995).
Crisis	An incident or situation involving a threat to the United States, its territories, citizens, military forces, or vital interests that develops rapidly and creates a situation of such diplomatic, economic, political, or military importance that commitment of U.S. military forces is contemplated to achieve national objectives (Joint Pub 5-0, 1995).
Crisis Action Planning	The time-sensitive development of joint operation orders in response to imminent crisis. Crisis action planning follows

	prescribed crisis action procedures and implements an effective response within the time frame permitted by the crisis.
Deliberate Planning	The development of joint operation plans for contingencies identified in joint strategic planning documents. Conducted principally in peacetime, deliberate planning is accomplished in prescribed cycles that complement other DOD planning cycles and is in accordance with formally established joint procedures (Joint Pub 5-0, 1995).
Deployment	The relocation of forces and material to desired areas of operation (Joint Pub 5-0, 1995).
Employment	The strategic or tactical use of forces in an area or theater of operations.
Execute Order	An order the competent authority issues to initiate operations.
Joint Operation Planning Process	A coordinated joint staff procedure commanders use to determine the best method of accomplishing assigned tasks and to direct the action necessary to accomplish the mission.
Joint Strategic Capabilities Plan (JSCP)	The Joint Strategic Capabilities plan conveys strategic guidance, including apportionment of resources to the CINCs and the Chiefs of the Services, to accomplish assigned strategic tasks based on military capabilities existing at the beginning of the planning period.
Mission	The task, together with the purpose, that clearly indicates the action to be taken and the reason for taking it.
National Command Authorities	The President and the Secretary of Defense or their duly deputized alternates or successors.
Operation	A military action or the carrying out of a strategic, tactical, service, training or administrative military mission; the process of carrying on combat, including movement, supply, attack, defense, and maneuvers needed to gain the objective of any battle or campaign (Joint Pub 1, 1995).
Planning Order	An order the CJCS issues to initiate execution planning. The order normally will follow a Commander's Estimate and will precede the Alert Order. NCA approval of a selected COA is not required before a Planning Order can be issued.
Supported	The commander having primary responsibility for all aspects of a

Commander	task assigned by the Joint Strategic Capabilities Plan or other joint operation planning authority. In the context of joint operation planning, this term refers to the commander who prepares operation plans or orders in response to requirements of the CJCS (Joint Pub 1, 1995).
Supporting Commander	A commander who furnishes augmentation forces or other support to a supported commander or who develops a supporting plan.
Task	A job or function assigned to a subordinate unit or command by a higher authority.
Unified Command	A command with a broad and continuing mission under a single commander and composed of significant assigned components of two or more Services, and which is established and so designated by the President, through the Secretary of Defense with the advice and assistance of the CJCS.
Warning Order	A crisis-action planning directive issued by he CJCS with the approval of the NCA, that initiates the development and evaluation of COAs by a supported commander and requests that a Commander's Estimate be submitted (Joint Pub 1, 1995).

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APPENDIX C. PLATFORM ALLOCATION GOALS AND RULES

This appendix contains a list of platform allocation goals and rules embedded in the blue commander agent.

Goal - SelectDDGoal

Rule - AllocateDDToTaskForceRule

Goal - SelectFFGoal

Rule - AllocateFFToTaskForceRule

Goal - SelectSSGoal

Rule - AllocateSSToTaskForceRule

Goal - SelectFPBGoal

Rule - AllocateFPBToTaskForceRule

Goal - SelectFPBHeloGoal

Rule - AllocateFPBHeloToTaskForceRule

Goal - SelectFighterGoal

Rule - AllocateFighterToTaskForceRule

Goal - SelectASWPlaneGoal

Rule - AllocateASWPlaneToTaskForceRule

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APPENDIX D. FORCE DEPLOYMENT GOALS AND RULES

This appendix contains a list of force deployment goals and rules embedded in the blue commander agent.

Goal – DeployPlatformToZone11Goal

Rule - DeployPlatformToZone11Rule

Goal - DeployPlatformToZone13Goal

Rule - DeployPlatformToZone11 Rule

Goal - DeployPlatformToZone15Goal

Rule - DeployPlatformToZone11 Rule

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APPENDIX E. FORCE MOVEMENT GOAL TYPES, GOALS, AND RULES

This appendix contains a list of force movement goal types, goals, and rules embedded in the blue and the red commander agents.

Blue Agent Movement Goals:

Goal Type - BlueZone6MovementGoal

Goal - BlueStayInZone6Goal

Rule - BlueStayInZone6 Rule

Goal - BlueMoveFromZone6ToZone8Goal

Rule - BlueMoveFromZone6ToZone8Rule

Goal - BlueMoveFromZone6ToZone11Goal

Rule - BlueMoveFromZone6ToZone11Rule

Goal Type – BlueZone8MovementGoal

Goal – BlueStayInZone8Goal

Rule – BlueStayInZone8 Rule

Goal – BlueMoveFromZone8ToZone6Goal

Rule – BlueMoveFromZone8ToZone6Rule

Goal – BlueMoveFromZone8ToZone10Goal

Rule – BlueMoveFromZone8ToZone10Rule

Goal – BlueMoveFromZone8ToZone13Goal

Rule – BlueMoveFromZone8ToZone13Rule

Goal Type – BlueZone10MovementGoal

Goal – BlueStayInZone10Goal

Rule – BlueStayInZone10 Rule

Goal – BlueMoveFromZone10ToZone8Goal

Rule – BlueMoveFromZone10ToZone8Rule

Goal – BlueMoveFromZone10ToZone15Goal

Rule – BlueMoveFromZone10ToZone15Rule

Goal Type – BlueZone11MovementGoal

Goal – BlueStayInZone11Goal

Rule – BlueStayInZone11 Rule

Goal – BlueMoveFromZone11ToZone6Goal

Rule – BlueMoveFromZone11ToZone6Rule

Goal – BlueMoveFromZone11ToZone13Goal

Rule – BlueMoveFromZone11ToZone13Rule

Goal Type – BlueZone13MovementGoal

Goal – BlueStayInZone13Goal

Rule – BlueStayInZone13 Rule

Goal – BlueMoveFromZone13ToZone8Goal

Rule – BlueMoveFromZone13ToZone8Rule

Goal – BlueMoveFromZone13ToZone11Goal

Rule – BlueMoveFromZone13ToZone11Rule

Goal – BlueMoveFromZone13ToZone15Goal

Rule – BlueMoveFromZone13ToZone15Rule

Goal Type – BlueZone15MovementGoal

Goal – BlueStayInZone15Goal

Rule – BlueStayInZone15 Rule

Goal – BlueMoveFromZone15ToZone10Goal

Rule – BlueMoveFromZone15ToZone10Rule

Goal – BlueMoveFromZone15ToZone13Goal

Rule – BlueMoveFromZone15ToZone13Rule

Red Agent Movement Goals:

Goal Type - RedZone6MovementGoal

Goal - RedStayInZone6Goal

Rule - RedStayInZone6 Rule

Goal - RedMoveFromZone6ToZone8Goal

Rule - RedMoveFromZone6ToZone8Rule

Goal - RedMoveFromZone6ToZone1Goal

Rule - RedMoveFromZone6ToZone1Rule

Goal Type – RedZone8MovementGoal

Goal – RedStayInZone8Goal

Rule – RedStayInZone8 Rule

Goal – RedMoveFromZone8ToZone6Goal

Rule – RedMoveFromZone8ToZone6Rule

Goal – RedMoveFromZone8ToZone10Goal

Rule – RedMoveFromZone8ToZone10Rule

Goal – RedMoveFromZone8ToZone3Goal

Rule – RedMoveFromZone8ToZone3Rule

Goal Type – RedZone10MovementGoal

Goal – RedStayInZone10Goal

Rule – RedStayInZone10 Rule

Goal – RedMoveFromZone10ToZone8Goal

Rule – RedMoveFromZone10ToZone8Rule

Goal – RedMoveFromZone10ToZone5Goal

Rule – RedMoveFromZone10ToZone5Rule

Goal Type – RedZone1MovementGoal

Goal – RedStayInZone1Goal

Rule – RedStayInZone1Rule

Goal – RedMoveFromZone1ToZone3Goal

Rule – RedMoveFromZone1ToZone3Rule

Goal – RedMoveFromZone1ToZone6Goal

Rule – RedMoveFromZone11ToZone6Rule

Goal Type – RedZone3MovementGoal

Goal – RedStayInZone3Goal

Rule – RedStayInZone3Rule

Goal – RedMoveFromZone3ToZone8Goal

Rule – RedMoveFromZone3ToZone8Rule

Goal – RedMoveFromZone3ToZone1Goal

Rule – RedMoveFromZone3ToZone1Rule

Goal – RedMoveFromZone3ToZone5Goal

Rule – RedMoveFromZone3ToZone5Rule

Goal Type – RedZone5MovementGoal

Goal – RedStayInZone5Goal

Rule – RedStayInZone15Rule

Goal – RedMoveFromZone5ToZone10Goal

Rule – RedMoveFromZone5ToZone10Rule

Goal – RedMoveFromZone5ToZone3Goal

Rule – RedMoveFromZone5ToZone3Rule

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   Ft. Belvoir, Virginia 22060-6218

2. Dudley Knox Library 2
   Naval Postgraduate School
   411 Dyer Road
   Monterey, California 93943-5101

3. Dr. Michael Zyda 2
   Chair, MOVES Academic Group
   Naval Postgraduate School
   Monterey, California 93943-5118

4. Mr. John Hiles 2
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5. Deniz Kuvvetleri Komutanligi 2
   Personel Egitim Daire Baskanligi
   Bakanliklar, Ankara
   06100 TURKEY

6. Deniz Harp Okulu Komutanligi Kutuphanesi 1
   Tuzla, Istanbul
   TURKEY

7. LTJG Askin Ercetin 2
   Yildiztepe Imar Iskan Bloklari
   136. Sok. 47/10
   Haskoy-Yildiz, Ankara TURKEY