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DEFINING A SIMULATION CAPABILITY HIERARCHY FOR THE MODELING OF A SEABASE ENABLER (SBE)

by

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Development of SeaBase Operations has brought about the need for Modeling and Simulation (M&S) analysis of prototypes like the Transformable Craft (T-craft) as a SeaBase Enablers (SBE). The uses of M&S tools for the modeling of new capabilities have been problematic, since there are no standard requirements for simulation development. The accreditation process of M&S tools also offers no guidance into the functionalities of simulations. The goal of this thesis was to define a hierarchical framework of capabilities for evaluating a simulation or "suite of simulations" suitable for modeling SBEs. A capability hierarchy is needed to enable decision makers to compare end user needs with M&S tools' abilities. An analysis of alternatives was conducted on six M&S tools to develop a capability hierarchy. The three top level capabilities that were defined in an M&S setting were *Usability*, *Flexibility*, and *Scalability*. A roll-up method was then used to evaluate three time-step and three next-event based models. The end result of the comparisons showed that a "suite of simulations" was more capable of modeling SBEs than a single simulation. The results provide decision makers with a standard approach to define user needs and how to apply them to M&S tools.

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ABSTRACT

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LIST OF ACRONYMS AND ABBREVIATIONS

M&S	Modeling and Simulation
SBO	SeaBase Operations
SBE	SeaBase Enabler
DoD	Department of Defense
ONR	Office of Naval Research
NSS	Naval Simulation System
JCATS	Joint Conflict and Tactical Simulation
MANA	Map Aware Non-Uniform Automata
INP	Innovative Naval Prototype
BAA	Broad Agency Announcement
T-craft	Transformable Craft
VV&A	Validation, Verification, and Accreditation
API	Application Programmer Interface
AABM	Autonomous Agent Based Models
TSBM	Time-Step Based Models
GUI	Graphical User Interface
DES	Discrete Event Simulation
MOE	Measures of Effectiveness
MOP	Measures of Performance
SAF	Semi-Automated Forces
HLA	High Level Architecture
DIS	Distributed Interactive Simulation
NOLH	Nearly Orthogonal Latin Hypercubes

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I. INTRODUCTION

All models are wrong, but some are useful

—Sergey Arkhipenkov

A. BACKGROUND

Modeling and Simulation (M&S) tools typically have been designed for specific purposes but often are used for insight into completely different questions. In today’s technologically advanced world, there has been relatively no limit to the capability of computer-based simulation and what it could provide to understanding an event.

This study focused on the capabilities of M&S tools to represent SeaBase Enablers (SBE) by conducting an analysis of alternatives of computer-based simulations. The context of this study was based on SeaBase Operations (SBO) concept, being developed by the United States Navy, which extends from a concept called Sea Power 21 that advertises power from the sea. Seapower is the concept of globally projecting naval presence to maintain security and advancing the national interests (CNO, 2007). Facilitating these naval operations at sea is a complex naval organization that relies heavily on logistical support ships necessary for sustainment. The SBE concept was defined as the logistical support elements that interact with the SBO to provide cargo and supplies for sustainment operations.

The models chosen were time-step and next-event based models, which are two types of models within the constructive category of M&S. A narrow scope of Department of Defense (DoD) and industrial used models that have had application in SBE modeling are listed in Table 1.

Model Common Name	Simulation Category
Integrated Theater Engagement Model (ITEM)	Defense Threat Reduction Agency in association with (IAW) SAIC Company / Next-Event
Naval Simulation System (NSS)	SPAWAR IAW Metron Co. / Next-Event
Map Aware Non-Uniform Automata (MANA)	New Zealand's Defense Technology Agency / Time-Step
Pythagoras	Marine Corps Warfighting Lab (MCWL) IAW Northrop Grumman / Time-Step
Joint Conflict and Tactical Simulation (JCATS)	Joint Force Command (JFCOM) Joint Warfare Center (JWC) / Next-Event
Simkit	Naval Postgraduate School / Next-Event
EXTENDSim	Imagine That! / Next-Event
Combat Analysis Tool for the 21st Century (COMABT XXI)	TRAC WSMR IAW MCCDC OAD / Next-Event
SimPy	Source Forge Co. / Next-Event
NetLOGO	Connected Mathematics Co. / Next-Event

Table 1. M&S Tools Used in DoD and Industry for SBE Modeling.

Current modeling of the SBE is use of NSS by the System Engineering Group at the Naval Postgraduate School (NPS) to model SBE in peacekeeping, crisis, and stability missions. SimPy is another M&S tool being used by Georgia Tech University to model SeaBase concepts and determine alternative employment of SBE for scenarios around the world when based at different debarkation points.

B. SEAPOWER 21

The Strategy for Sea Power 21 entails joint operational effectiveness and incorporates SBO and Sea Shield operations (Projecting Global Defensive Assurance) to make a unified front called Sea Strike (Projecting Precise and Persistent Offensive Power) with new technology that must be ready to support it. The Chief of Naval Operations (CNO) (2007) has stated that the Navy must maintain an ability that will reaffirm “the use of sea power to influence actions and activities at sea and ashore” (p. 8). Thus, operational focus of the U.S. Navy has shifted from traditional warfare to developing SeaBase concepts and sustained operations in forward deployed areas. SBO is one of the strategic pillars supporting operations in a Naval setting, with Sea Power 21 being the conceptual wave of the future. Sea Power 21 is derived from the unified maritime strategy of the CNO to protect the American way of life. It is the ability of the U.S. Navy to be globally postured around the world to maintain continued operations with adequate resources. This includes pre-positioned capabilities, joint operations, and decreased reliance on infrastructure (Flitter & Sintic, 2009). The SBO establishes a base of operations for U.S. military forces to be inserted into the conflict or crisis (CNO, 2007).

SBO enables National and Naval strategy with the ability to maintain operational sustainment. SBO roles in crisis relief efforts and regional conflict have evolved with the ever changing demands of the world. Contributions to allied nations have been closely linked to the ability to maintain the sea lanes of communication. Relief efforts in crisis-stricken countries like India in 2007, Aceh Indonesia and Sri Lanka in 2008, Thailand in 2008, and most recently, Haiti in 2010, have shown the versatility of the U.S. Navy and the U.S. military to perform operations other than warfare. The U.S. government has made it a priority to make humanitarian and relief operations just as important as warfare operations.

According to the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics (USDAT&L), SBO are enablers of Sea Power 21 (CNO, 2007). SBO require development of new capabilities to enable its use in the 21st century. SBO is a chain of interdependent operations that have systematic issues with current capabilities for sustainment. The recommended capability for development is for a long-range heavy-lift cargo vessel that is able to handle environmental conditions. Through industrial and academia research, the SBE is being formed into that capability with the focus being to fill current technology gaps.

C. SEABASE ENABLER PROTOTYPES

One way of maintaining seapower is through research and development of new technologies in naval ships that can serve as SBE. SBEs are projected to provide rapid transportation of needed cargo and materials to and from the SeaBase to debarkation point. The Office of Naval Research (ONR) began the Innovative Naval Prototype (INP) program in 2006 to refine conceptual ideas, develop technology, and ultimately manufacture SBE capabilities. Military industrial companies have been designing a new amphibious craft called the Transformable Craft (T-Craft) to meet the SBE needs.

There are three prototype designs in competition for contract awards by ONR. The first design is the Alion, which is being developed by Raytheon in conjunction with Nichols Bros and CDI Marine. The second design is Textron Marine, being developed by CDI Marine with Naval Surface Warfare Center Panama City Division, Jacobs Engineering, Littoral Research Group, and Mid-City New Orleans (MiNO) Marine Inc. The third design is the Umoe Mandal, designed by the Goodrich EPP in association with Kiewit Offshore Services, Island Engineering, General Atomics, Ultra Poly Inc., Griffon Hovercraft Group, Applica Inc., and Massachusetts Institute of Technology (MIT) (Flitter & Sintic, 2009).

1. Transformable Craft

The T-craft is an amphibious craft being designed to fill the technology capabilities gap in SBO and server as a SBE. There are technical challenges associated with developing prototypes of this design: minimal manning versus operational requirement, multi-mode propulsion systems, external seals for bow and stern and retractable hover shirts. Along with technical issues, there are operational considerations that are focused on placing T-craft capabilities in future operations. The real question is where will T-craft fit into the U.S. military’s concept of operations? The initial deployment vision is centered on worldwide fast response to crisis missions, followed by combat supply missions. Further details on T-craft missions will be explored in Chapter V.

2. Industrial Designs

The T-craft prototype designs are based on ONR capability requirements with only slight differences. The Textron Marine is projected to have an open bay deck, unlike the other two prototypes, which have closed bays. Deck space varies, with the Umoe Mandal having 6000 feet $(ft)^2$ to the Textron Marine having 8000 square feet $(ft)^2$. One important capability consideration with the development of T-craft is the limitation on landing abilities. T-craft hover capability is projected to be able to maneuver onto shore slopes with gradients of approximately 2 percent or less. All M&S tools were assumed to model shore landing site with less than 2 percent slopes and be sufficient for SBE Scenarios. Figure 1 depicts the three T-craft prototypes.

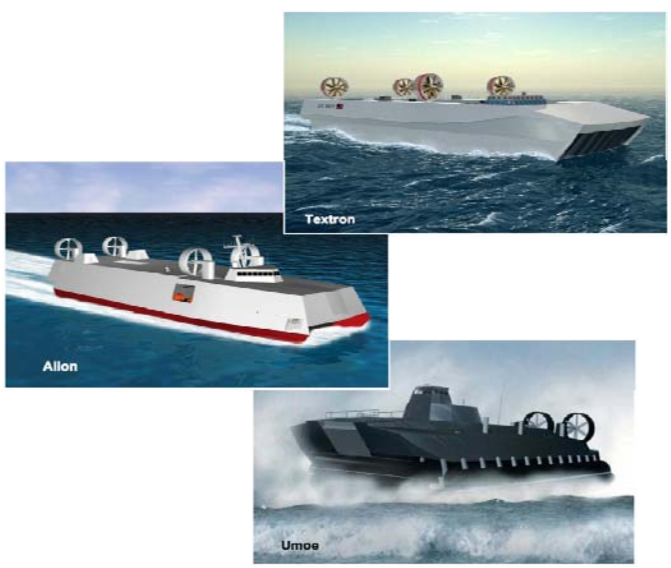

Figure 1. Proposed Prototype Designs by Industry.

3. Initial T-Craft Analysis

A capstone project conducted by a group of Systems Engineering students at NPS working in conjunction with ONR sponsored funding investigated whether the T-craft prototype was a suitable SBE. Their research performed a simplified Analysis of Alternatives on the SBE concept. Their results identified key stake holders that contributed to the validation of the capabilities for SBE. Additionally, these students provided insight to decision makers on transport capabilities and benefits to the SeaBase. Lastly, their project gave technical recommendations to ONR on where the T-craft program should proceed (Flitter & Sintic, 2009).

D. T-CRAFT DEVELOPMENT

T-craft is being designed to fill the gaps in current SBE capabilities. ONR defined capabilities for the T-craft are:

1. 2500 nm range maintaining fuel efficiency (20kts).
2. Operate in sea state of 4 at high speeds, with or without cargo.
3. Maintain a maximum speed of 40+ knots and a 500 nm combat range.
4. Amphibious mode for landing on the beach.
5. Freely convert between modes at sea.
6. Transfer cargo to SBO units and beach landings sites.
7. Carry 500 Long Tons (LT) of Cargo (ONR, 2005).

ONR (2005) began developing the T-craft “Game Changing” capability with the issuance of the Broad Agency Announcement (BAA) 05-020 and a call for an INP for SBE operations. The ideal use for T-craft is in a high-speed sealift scenario less than 300 nautical miles (nm) from the shore in no more than sea state 4 and with a payload of 500 long tons. BAA focused on industrial competition of designing T-craft with the ultimate desire to acquire a material solution to current gaps in SBE. In each Phase of development, ONR has pointed out the need to use M&S tools in analysis and evaluation of T-craft capabilities in a cost reduction effort. The final goal is to develop the concept, build, test, and demonstrate the concept’s ability in given scenario settings.

There are four scenario requirements for which T-craft is being developed: Peacekeeping and Peace Enforcement, Regional Crisis Intervention, Security and Stability Operations, and Major Theater War. These requirements were the basis for scenario development in this study. The scenarios were based on a possible North Korean threat to the South Korea peninsula. The area of SBOs was based in the Sea of Japan regional layout. The geography allowed for a logistic hub to be within 2500 nm of the SBO and that could vary in distance from the shore line. The scenario was designed with two phases: Basic and Advanced. The Basic Scenario was a non-opposed scenario similar to a regional crisis intervention. The Advanced Scenario added onto the Basic Scenario hostile and escort forces in the SBO area.

E. MODELING & SIMULATION

This research focused on M&S tools' ability to allow for visualization and comprehension of the SBE Scenario. The Validation, Verification, & Accreditation (VV&A) process requires that M&S tools be analyzed for correctness and usefulness. This process will be described in Chapter II. Further research could be conducted to determine the general capabilities of a Federate of simulations for modeling of a SBE concept. The subjective analysis of a group of simulations for SBE Scenario was the main objective of this thesis.

There are seven M&S Domains that cover M&S within the DoD. In this thesis, four domains were used to define the capabilities of a simulation of the SBE: Acquisition, Planning, Test & Evaluation, and Analysis. The advantage of using these domain fields was to narrow the scope of the M&S Domain space for developing technology like the SBE. The three capabilities that can be derived from these domains are usability, flexibility, and scalability. These capabilities were designed to ultimately provide decision makers with adequate information on M&S tools to apply throughout the life cycle of the SBE. Constructive-based M&S tools are poised for the development of scenarios to enable analysis with time-step and next-event based models.

1. DoD M&S Community Domains

The goal of this thesis was to define the needs of SBE as they apply to M&S. A capability hierarchy framework was used to translate the SBE needs into listing of functionalities for a simulation or a "suite of simulations" to be evaluated. The purpose was to apply the framework broadly across the M&S solution trade space for SBE modeling. Ultimately, the Systems Engineering approach used was to define a process to evaluate the contribution simulations may have on SBE.

There are seven domains in M&S: Acquisition, Analysis, Planning, Testing, Training, Experimentation, and intelligence. These domains are a way for the DoD to manage and shape M&S tools for practical use. Below, the first four domains and how each pertains to the SBE are defined. The last three domains were not discussed in this thesis because the scope was to address M&S tools that contribute to the development of an INP. Training, Experimentation and Intelligence pertain to operational considerations and post production (DoD, 2009).

First, Acquisition is the overall process of material solutions in the cumulative joint capabilities of the U.S. military. There are two options in acquisition: (1) Material solutions, which are the development of new technologies for capability gaps, and (2) Documentation solutions, which are the development of doctrine to adjust for operational deficiencies. M&S can provide assistance in the development of a SBE throughout the T-craft life cycle (DoD, 2009).

Second, Analysis is the ability to understand how a process or situations potentially unfolds in the future. In other words, Analysis can provide proof of concepts for SBO in forward deployed areas. M&S gives researchers the ability to model operational considerations in an effort to develop systems with well rounded capabilities (DoD, 2009).

Third, Planning is a stage for developing systems tactics and strategy for use in military operations. The SBE is new concept that is going through extensive research in interoperability and capability limitations. Planning can identify key performance parameters in a SBE by examining situational requirements (DoD, 2009).

Fourth, Testing is the opportunity to stress systems in virtual and real environments to give the warfighters advanced capabilities. M&S can stress systems to the maximum limits in a virtual environment allowing for a spectrum of information to be gathered (DoD, 2009).

2. M&S Capabilities Derivation

The M&S domains described above encompass three aspects that a simulation should possess to model a SBE, and these are Usability, Flexibility, and Scalability. Usability seems to relate to interoperability issues in a joint environment where new technology must be able to interact and/or support other service functions. Flexibility seems to directly reflect the versatility of new technology to evolve and be sustainable in an ever changing environment. Scalability seems to be associated with realistic goals of mass production and survivability in multiple environments.

3. Simulation Categories

There are several types of simulation that are used for modeling and analysis. The three M&S types that were associated with this study were next-event, time-step, and autonomous agent-based modeling. Time-step based models use equal time-steps between processing functions of events to advance the simulation. Next-event based models process each event in a scenario that occurs with no regard to a regular review of simulation status. Agent-based models are centered on offering attribute adjusted abilities to the user for more robust actions.

These three types of M&S tools were examined across the SBE missions. The first of those missions entail high-level operational missions like peace keeping and were utilized for modeling a Basic Scenario. The Basic Scenario involved relief efforts of transporting humanitarian aid directly to shore sites. The second mission was regional conflict within hostile waters surrounding areas of SBO, which were used to model an Advanced Scenario.

Evaluation of M&S tools in time-step and next-event based modeling assisted in determining the capability hierarchy. Time-step and next-event based models are key types of M&S tools in the constructive simulation category that are used in the DoD. Table 2 presents the flow of this thesis from capability generations to determining a trade space of alternatives for a simulation or “suite of simulations” for SBE M&S. The M&S tools for this research are delineated in Chapter III.

Chapter	Title
I	Introduction into SeaBase Enablers
II	Capabilities Generation based on M&S Domains
III	Possible Solutions for M&S of SBE Scenarios
IV	Capability Hierarchy definition
V	Simulation Modeling of the SBE
VI	Results Analysis of M&S
VII	Capability Evaluation of M&S tools
VIII	Simulation Comparison of M&S tools
IX	Conclusion

Table 2. Thesis Chapters Summary.

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II. CAPABILITIES GENERATION

The concept of defining a set of capabilities for M&S programs evolved from the idea of using several modeling tools together for SBE analysis and testing. The questions became, which M&S tools were to be used and what capabilities should they possess? It was clear that any M&S tool used in this research must be accredited to show that results from SBE analysis were valid. This lead to the DoD acquisition system that offers the most insight into M&S capabilities based on the fact that there are seven M&S domains created to shape the development of M&S tools. This chapter addresses how the capability hierarchy was generated from the established M&S domains areas and their uses to define a basic set of functionalities that were later complied together in a framework to evaluate the capability of an M&S tool.

A. VALIDATION, VERIFICATION, & ACCREDITATION

Use of M&S in DoD is regulated by the VV&A process. Decision making agencies like the Defense Planning and Joint Requirements Oversight Council (JROC) utilize M&S for specific purposes based on M&S tools capabilities. Currently, there is not a standard for all simulations because VV&A requirements limit on the scope of models to a single or narrow purpose (DoD, 2003). The capabilities hierarchy can allow for M&S developers working with SBE to be aware of user (DoD) needs and provide more functionality in M&S tools.

Developing simulation standards is important because of the impact M&S has at all levels of DoD decision making in the life cycle. The capability hierarchy that was proposed in this study attempted to identify standards needed to model SBE by grouping a set of functionalities together in an evaluation hierarchy. Functionality refers to a single method within an M&S tool that is used to enable the user to manipulate the model or simulation. The definition of a hierarchy was an attempt to increase the reusability of M&S tools while simultaneously reducing ad hoc program combinations that are being used to fill gaps in DoD M&S. The capability hierarchy can allow for M&S developers working with SBE to be aware of user (DoD) needs and provide more functionality in M&S tools. The functionalities were directly related to Verification, Validation, and Accreditation (VV&A) along with the Defense Standardization Program (DSP).

The M&S Coordination Office (MSCO) promulgated in 2000, operating procedures for simulation developers on standard methodologies, programming practices, and data processing with no mention of simulation requirements or potential capabilities. These requirements were not stated and left for developers to interpret end user and stakeholder needs. Defining capabilities required to model a SBE may hopefully aid in the development of M&S tools specifically for SBE, with emphasis on modeling T-craft. The VV&A process was put in place to govern simulation products and ensure that there was quality control that matched user’s needs with results. The VV&A process seems to have led to specific tools for specific needs, which has limited the use of M&S tools in the DoD. Providing a list of general capabilities that are required by the DoD to be present in M&S tools may increase their uses in decision making.

B. LINKS TO M&S DOMAINS

The purpose of M&S in DoD has always been to accomplish requirements with less money, time, and loss of life. M&S offers decision makers, developers, and warfighters the ability to experiment with ideas without the risk associated with real-world experimentation. Users of M&S are important to the development of tools that are used in the DoD communities. Given that there are defined community domains for M&S within DoD, the link between those domains and a capability hierarchy should be self-evident. The characteristics of M&S domains lead themselves to be interpreted in a way to suggest that M&S tools need to be usable, flexible, and scalable as introduced in Chapter I. Four of the seven DoD Communities are steeped in M&S application of developing technology and material solutions—Acquisition, Analysis, Planning, and Test & Evaluation. The remaining three, Training, Experimentation, and Intelligence tend to be directed at operational considerations post production phases. Acquisition is the overarching domain, where Analysis, Planning, and Test & Evaluation begin to narrow the scope of M&S applications. These domains provide data and understanding of systems for further development. The derivations of M&S requirements from these communities provide an essential framework for defining a capability hierarchy. A description of each of these communities follows, along with the ways in which a capability hierarchy would be useful for that domain.

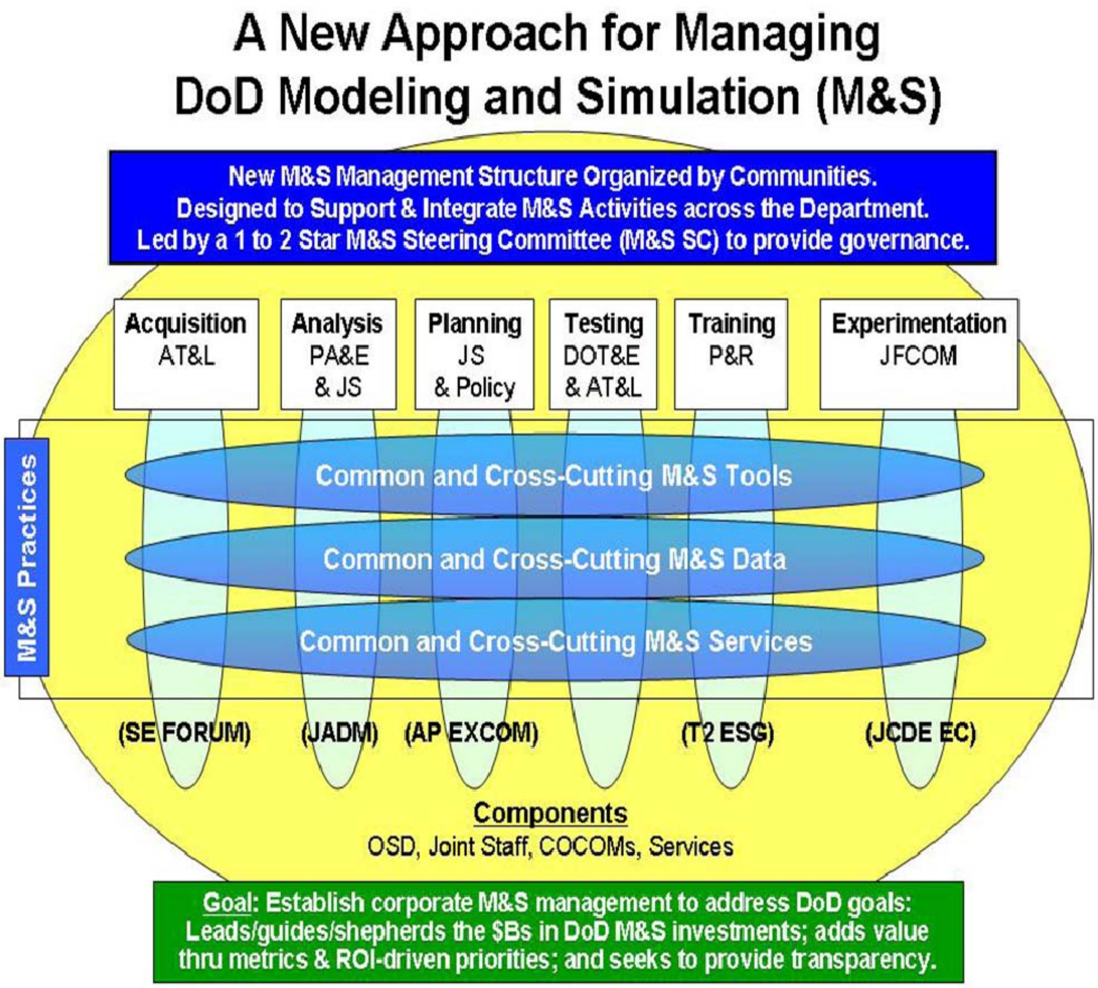

Figure 2. M&S Domain Management Diagram (From MSCO, 2007).

1. Acquisition

The first community acquisition is at the heart of major developmental concepts that govern the progress of the concept's evaluation from birth to death, which is referred to as the life cycle. M&S is rooted in initial phases of system life cycles because of the potential reduction in time, risk, and cost it offers. As noted in the Office of Secretary of Defense report (1997), The Study on the

Effectiveness of M&S in the Weapons System Acquisition Process, M&S can be used to integrate acquisition functions like design, manufacturing, and requirements together. M&S tools can contribute to the development of actual prototypes of T-craft by modeling capabilities and testing them in extreme conditions. The complexity of the SBE concept lends itself to use of M&S to integrate physical research with operational tactics and joint effectiveness. Defining the M&S capabilities based on the process can assists in system acquisition of SBE by affecting multiple aspects of the time delay in reaching for the warfighters.

2. Analysis

The Program Analysis and Evaluation (PA&E) department within the Office of the Secretary of Defense (OSD) is tasked with breaking acquisition projects in smaller understandable parts. This basic concept is the core of DoD acquisition analysis and how it was applied in this research. The analysis of SBE effectiveness in situations provides insight to decision making on the future of systems and in how to further develop the programs. This goal is accomplished by collecting data on cargo transfer rates and amounts, transit times in a given environment, and survivability rates with varying defensives. M&S tools used for analysis should be able to provide basic information on systems by performing statistical analysis on simulations iterations. They are also associated with exploration of the solution space SBE occupies. This method uses the trends that models display in M&S environments to develop a common performance measurement. Operators are involved at all levels of the analysis process; therefore, usability in the capability hierarchy is important in M&S.

3. Planning

Planning has many different roles in system development. The first role is production factors like manufacturing schedules that affect the delivery of systems. The second role is logistical needs for operating forces. Lastly, operational planning plays a major role in determining the requirements for systems uses. The requirements are wrapped within the capability of M&S tools to model and simulate planning elements that affect SBE deployment. M&S can integrate production elements into the planning process. A driving factor is measuring flexibility in M&S tools used for planning SBE craft capabilities and in its use within military applications. Thus, flexibility is a capability crucial to planning.

4. Test & Evaluation

The office of the Director of Operational Test and Evaluation (DOT&E) is responsible for prescribing policy of Testing and Evaluation (T&E) in the DoD. T&E is used to measure prototype status and determine when systems are ready for full rate production. T&E is important in system development in determining capabilities achievement. M&S can greatly assists in this process by simulating models of systems in virtual environment. M&S may not complete validate their effectiveness, but can make considerable steps towards evaluating measures of effectiveness. M&S should be used throughout the development of SBE, as well with T&E craft performance.

Dividing industry from DoD is the fact that commercial M&S is not regulated. Industry’s use of M&S can be dramatically different than DoD at times, even more of a reason to standardize the capabilities of M&S for use with military concepts. M&S, on the other hand, must be flexible enough to handle extreme situations that are required in a testing environment and that are where the hierarchy is limited in its application. Standards are not all encompassing and some amount of non-standards can be beneficial.

C. ACQUISITION FRAMEWORK

The three capabilities derived in this study overlap multiple M&S domains. Usability is essential to Analysis but is less critical in planning and testing. Conversely, flexibility is important in planning but less in Analysis. Scalability is no different and is grouped into the acquisition system, but it is more involved in planning and analysis by focusing on large number high fidelity unit operations. Figure 3 illustrates the relationship between M&S domains and the upper levels of the capability hierarchy.

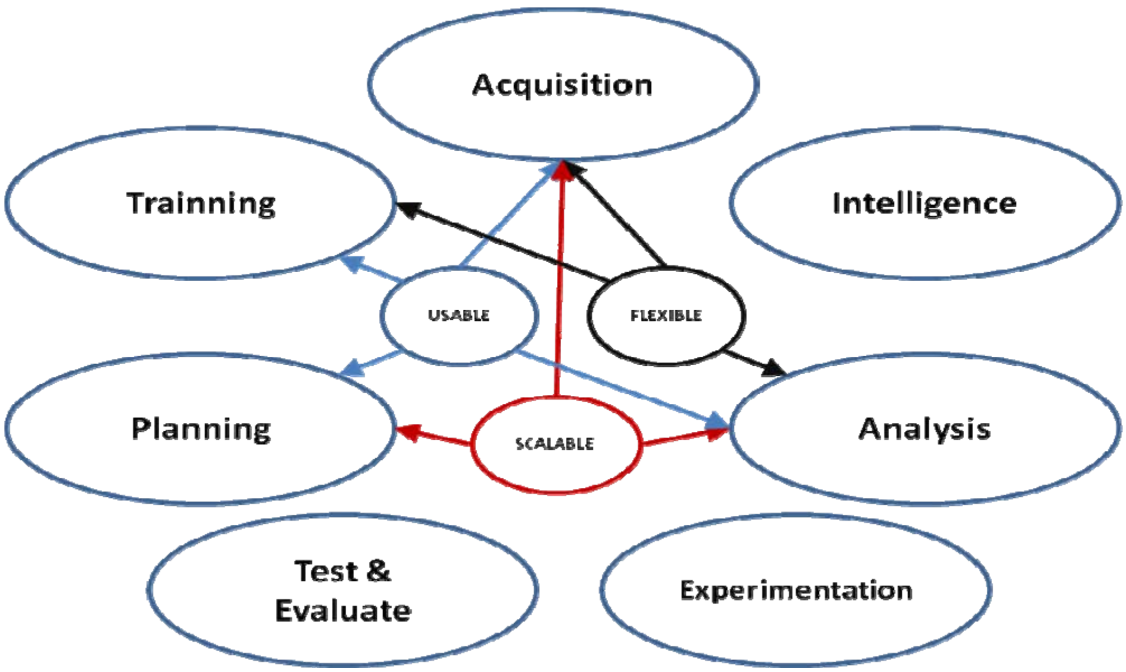

Figure 3. Capabilities Hierarchy Links to M&S Domains.

III. POSSIBLE SOLUTIONS

This chapter discusses the constructive-based M&S tools that are contained in the SBE M&S possible solutions. The solution space for modeling a SBE, encompasses a wide variety of M&S tools and presents a challenge to selection. Listings of M&S tools that have the capability of modeling a SBE Scenario are identified to help focus research efforts. There were three time-step based models and three next-event based models selected for evaluation of capabilities. This chapter was designed to identify and briefly introduce the selected M&S tools used for modeling an SBE Scenario. Table 3 displays the six M&S tools selected and its corresponding information.

M&S Tool	Version
Joint Conflict and Tactical Simulation (JCATS)	Version 8
Map Aware Non Uniform Automata (MANA)	Version 4.04.1
Pythagoras	Version 2.1.0
Naval Simulation System (NSS)	Version 3.4.1 (Beta)
Simkit API	Version 1.3.8
Arena Simulation Software	Version 12.0

Table 3. M&S Selection Information.

A. M&S CATEGORIES

There are two classical ways to study a system: experiment with the actual system or with a model of the system. This study utilized the latter approach on the SBE concept to determine a basic capability hierarchy. All models are a part of the live, virtual, or constructive taxonomy. This taxonomy has varying levels of human interface with different types of simulations. The first category is a live simulation that has actual operators interacting with real systems in a real environment. The second category is virtual simulation, which differs from a live simulation by the fact the systems are simulated and there is a human-in-the-loop. The third type, constructive simulation, is a man-made model that executes with simulated operators and simulated systems (DoD, 1998). This research focused on the use of constructive models in the DoD and industry.

1. Constructive Models

DoD defines a constructive based model as one in which users operate and provide inputs to the simulation scenario where the adjudication is determined strictly by the algorithms coded into the program (DoD, 1998). All simulations used for comparison were within the constructive simulation trade space. In this thesis, six different simulations were chosen to give a clear representation of two separate types of simulation, time-step and next-event based models. These two types shared autonomous and non-autonomous agent entities qualities. Figure 4 depicts the relationship between the two types.

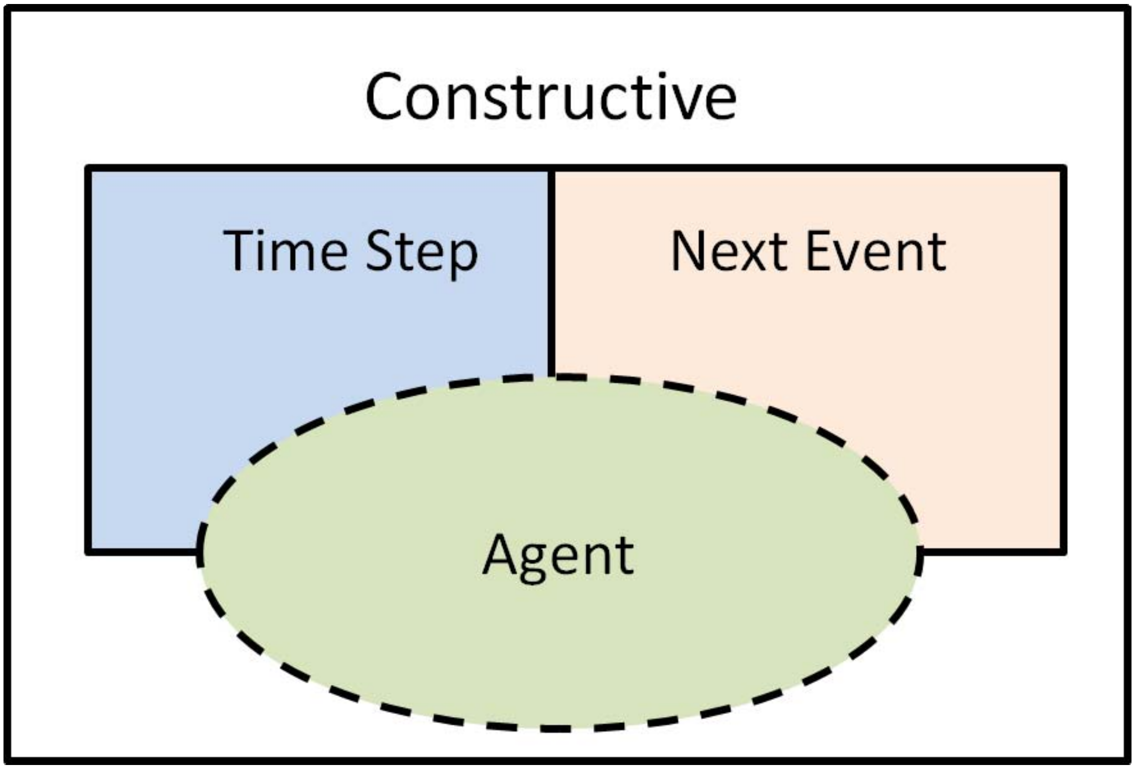

Figure 4. M&S Space for SBE Modeling.

According to Law and Kelton (2000), there are three dimensions to classify M&S tools. The first dimension is a dynamic model that changes over time to allow for interaction of the simulation in a SeaBase environment. The second is a stochastic model that provides random inputs to produce a realistic capability. The last is the capability of the simulation to take discrete time-steps for analysis of a single event to observe interactions of the model.

There is no one single program to simulate the SBE concept that incorporates the three dimensions. When used together, the three types of simulation are a possible solution that can provide information on one or all Measures of Performance (MOP) of the SBE Scenario that the U.S. Navy has defined as apart of the Sea Power 21 concept. The hierarchy of capabilities was used to determine the level at which a tool could be suitable to model and simulate a SBE.

2. Autonomous Agent Based Models

An Autonomous Agent-Based Modeling (AABM) was defined in this study as a program that makes use of personal attributes to govern the actions of simulated models. Programs are created to have individual entities act in a common way to make autonomous decisions based on a set of organized rules. According to Bonabeau (2002), there are three benefits to AABM that may prove to be an important factor when under evaluation for SBE modeling. The first was the ability of AABM to interact with the environment as the scenario unfolds and make decisions not based on probabilities. This benefit will make the AABM highly usable in SBE scenarios. The next was the flexibility of the agents to behave like live operators and be easily modeled into the scenario. The third was the resolution control of AABM being able to adjust force levels, making them scalable.

There are several AABM programs that are available commercially or open source that can be useful to decision makers. The two AABMs used in this study were New Zealand's Defense Technology Agency (DTA) Map Aware Non-Uniform Automata (MANA), and dual development by the U.S. Marine Corps and Northrop Grumman on Pythagoras Simulator, an agent-based model. The development of AABM has produced tools that can provide analysts the capability of experimenting with scenarios. Agent attributes are integrated into the various simulations and used to create agent actions that are indicative of real motion by real players.

B. TIME-STEP BASED MODELS

Time-Step Based Models (TSBM), or continuous-based models, are designed to handle the propagation of predicted agent action changes over infinite time increments. Continuous-based simulations are represented by the changing of state variable with respect to time (Gordon, 1978). TSBM used in problem-solving situations with high resolution scenarios should provided strong analysis tools. TSBM have also been useful in enabling the modeling of dynamic phenomena that autonomous agent-based simulations typically model. The complexity of the simulation's functionalities introduces many issues that are directly related to simulation capabilities. For example, the larger number of entities in a model may cause the computational times to increase.

The three TSBM were Lawrence Livermore National Laboratory's Joint Conflict and Tactical Simulation (JCATS), MANA, and Pythagoras. Each is posed for the T-craft scenario and provided insight into the survivability of units in a hostile environment. JCATS was created with detailed physics model for engagement and motion through water, where MANA and Pythagoras have evenly distributed terrain effects on entities motion. These models are highly scripted, which give them a high degree of usability but limited stochastic application. Their rigid and complex development gives them validation in real-world applications, such as training and mission rehearsals; however, scenario generation was dependent on a high level of proficiency.

1. JCATS

The JCATS simulation results were used from a previous study conducted by Lieutenant Richard Jimenez, U.S. Navy. His results are described within the unpublished article "Assessing the Requirements for the transformable Craft: A Framework for Analyzing Game Changing Capabilities." Jimenez's (2010) study that was in conjunction with the Systems Engineering studies of T-craft research at NPS. This work was designed to support a direct evaluation of JCATS simulation capabilities of an SBE using the Advanced Scenario as the basic framework. Jimenez was also able to establish a concept of operations scenario for data farming and conducting large-scale, multi-variable analysis on SBE capabilities.

JCATS is a deterministic computer-based model that offered a high level of accuracy to SBE Scenarios. Its high fidelity of entity capabilities, which incorporates actual physical restraints, enabled simulations results to emulate real-world characteristics. Military applications have been for training, analysis, and mission planning. JCATS usability comes from its ability to simulate urban terrain to support both asymmetrical along with conventional threat environments, along with allowing users to manipulate entities. JCATS has a wide range of functionalities with models of individual soldiers, vehicles, and weapons systems (USJFCOM, 2010). JCATS was designed to be a virtual simulation with human-in-the-loop decisions being made. However, a constructive approach was taken.

2. MANA

MANA is a stochastic AABM that attempts to bridge the gap in deficiencies in highly detailed models such as Janus Simulator from Training and Doctrine Command White Sand Missile Range, Close Action Environment model from the Defense Science and Technology Officer (DSTO), and JCATS. The use of AABM is centered on analysis of individual unit actions in a bottom-up approach to warfare. MANA was developed from two basic concepts: behavior and priority settings. This simulation design expanded from the Marine Corps Combat Development Commands' Project Albert and the Enhanced Irreducible Semi-Autonomous Adaptive Combat (ISAAC) Neural Simulation Tool (EINSTien). The use of the model was derived from the use of entity attributes that govern actions and decision making. The non-linear nature of model outcomes was important in obtaining a stochastic result (Lauren & Stephen, 2002).

3. Pythagoras

Similar to MANA, Pythagoras is a next generation Project Albert concept that is open-sourced from the U.S. Marine Corps. Pythagoras is the introduction of AABM into simulation by Northrop Grumman to use Fuzzy Logic in a Graphical User Interface (GUI) program. The basic idea behind Pythagoras was to enable analyzers to create behaviors and not the software. It has the capability to use probability tables, but more importantly is stochastically based on single entity decision making (Bitinas, Henscheid, & Troung, 2003).

Time-step based models can provide a wide range of interactions for the SBE Scenario analysis. Models like MANA and Pythagoras incorporate autonomous agent-based models and inject stochastic processes into a scripted model. JCATS supports entity based physics of individual T-craft units allowing for the environmental factors to be integrated into the SBE Scenarios. MANA and Pythagoras provide attribute based interfaces that enable users to influence entities actions and provide randomness to the SBE Scenarios.

C. NEXT-EVENT BASED MODELS

A next-event or Discrete Event Simulations (DES) are applied to many computational problems that occur over a finite amount of time (Gordon, 1978). The typical models are single server and queuing event scenarios. The M&S tools evaluated were NPS Simkit DES, Rockwell Automation Arena software simulation, and Lockheed Martin's Naval Simulation System (NSS), located at NPS. The T-craft scenario was applied to the three simulation programs and evaluated for desired functionality for modeling and simulating. DES's wide range of applications made it suitable for measuring performance parameters. DES provided analysis data on processes involving T-craft and its ability for cargo and equipment transfer to and from the SeaBase Operations.

1. Naval Simulation System

NSS is an object-oriented Monte Carlo simulation developed by Space and Naval Warfare Systems Command (SPAWAR). It is a DoD M&S tool for multi-warfare mission area analysis. Previous uses have been operational planning, systems effectiveness, and fleet exercises. Its ability to receive information makes it useful for analyzing ongoing operations course of actions. NSS provides measures of effectiveness and performance for predetermined categories that enable analysis of virtual systems (Metron Inc, 2007).

2. Simkit

Simkit is a simulation package used for creating DES models with a Java based computer program language. Time-steps within Simkit are event driven rather than timed incremented. Simkit can be utilized for movement and sensing events in a military scenario and is based on event graph logic. Entities were represented in an abstract way as to emulate the real characteristic of systems. Simkit is a component-based modeling tool that used an Application Programmer Interface (API). This is fundamentally different that GUI models (Buss, 2002).

3. Arena

Arena is a Monte Carlo DES similar to Simkit but provides a GUI vice an API. This difference in simulation design allowed for animation of the model and user interface vice direct interface with program code. The usability of Arena is what enables decision makers to easily obtain results through their current operating system. According to the Rockwell Animation Company, the use of Arena simulations in the health care industry has shown benefits in patient, staff, and facility studies to improve admission processes and planning (RA, 2007).

Next-event based models enhanced processing of the SBE Scenario events to allow for precise adjudication of interactions. NSS was similar to JCATS, in that the physic modeling of the entities provides environmental restraints, but added to the processing power of the SBE Scenario by precisely accounting for interaction or engagement. M&S tools like Simkit and Arena provided another benefit to a SBE Scenario, which was modeling the interactions vice the entities. The flow chart analysis enabled the user to analyze the SBE Scenario to affect changes and improvement the efficiency. Simkit added another adjudication dimension by being able to adjudicate limited interaction (user defined), where Arena was strictly flow chart assessment.

IV. CAPABILITIES HIERARCHY

A. DEFINING SEABASE ENABLER CAPABILITIES

The overarching goal, as described in Chapter I, was to define the needs of a SBE in future operations and translate them into capabilities for a simulation or a "suite of simulations" that can be applied broadly across the M&S solution space. The capability hierarchy is defined as the body of functionalities that a simulation may possess to model SBE Scenarios. An example of functionality is the control panels used in the windows operating system for Personal Computers where settings of the display (screen) can be directly adjusted with instant feedback to the user. User feedback is at the heart of M&S and why it is extremely useful for analysis. Modeling a system seems to require unique setting properties that enable the translation from real world to a synthetic environment. These properties that allow for modeling are what will be described as capabilities for a simulation. The generation of capabilities discussed in Chapter II link to the application of these capabilities within the seven M&S domains (DoD, 2000).

M&S attempts to offer insights into performance of technology in artificial environments. The development of advanced technology has started to rely heavily on M&S for testing of concepts. M&S partially allows for a translation of simulation results to performance parameters that advanced systems may possess in real settings. The specific needs of SBE present a challenge to developers, requiring assumptions to be made on future environments and capabilities. Decision makers are, in turn, forced to consider key system parameters and performance levels without the benefit of having a proven system to base judgment on. Simulations available to those groups are also available to academia, including research work conducted by NPS. Simulations chosen for this comparison of capabilities were based on M&S tools available at NPS.

The T-craft is an ideal candidate for M&S analysis. The modeling of T-craft as an SBE involves the development of scenarios to help identify potential requirements of a simulation. The dynamics of the SBE situation allowed for the extraction of simulation functionalities that were essential for actually modeling an SBE. What drives that need for modeling a SBE? The T-craft projected capabilities are not typical of a traditional amphibious craft. SBEs are being designed to fill the gaps of current landing craft that are limited in cargo capacity. The overarching goal of using M&S tools for analysis of T-craft is to show options in SBO.

B. MEASURES OF EFFECTIVENESS

The objective of modeling a SBE, such as T-craft, was to represent Basic and Advanced Scenarios, allowing for the assessment of T-craft’s responses and simulation capabilities. Given that SBE concepts are being developed for cargo transfer, the Measures of Effectiveness (MOE) could then be directly linked with the outcomes of the four situations mentioned in the previous chapters. MOEs were only briefly introduced to relate the importance of cargo transfer in SBE situations to the simulation capabilities.

A possible MOE that was considered with humanitarian relief efforts is the approval of public opinion towards relief efforts that are received by host nations. Measures used for performance were the delivery of cargo and equipment to forces in combat operations. In other words, 100 percent of cargo and equipment delivery should effectively increase public opinion or sustain combat operations by use of SBE large capacity capabilities. Thus, T-craft’s cargo capacities offer potential support to a wide range of military operations.

C. MEASURES OF PERFORMANCE

The Measures of Performance (MOP) that were used for the Basic and Advanced Scenarios were general and may not be available in all M&S tools. These MOPs were introduced to evaluate whether an analysis capability was available within a simulation program. The main MOP was defined as the amount of cargo transferred to the line of embarkation. In this research, the line of embarkation was defined as the shore landing site along the coastline. Cargo transfer was defined as the transfer of any resource carried by T-craft to an entity in the model that represented a shore landing site similar to the crisis relief area of operations. The secondary MOP was transit times associated with movement of the SBE to shore landing sites from debarkation points. The third MOP was the survivability of T-craft in a hostile environment with varying hostile and escort forces.

1. Cargo Transfer

It was important to distinguish the differences between cargo and equipment that could be carried by naval craft. In this research, cargo referred to supplies other than large machinery that could be used for amphibious assaults. T-craft is projected to have a cargo-carrying capacity that is unprecedented by previous landing craft used for cargo transport. According to Jane's Fighting Ships, current capabilities in cargo transfer craft are nominally at 60 ton payload. The capability of T-craft storage capacity is projected to be approximately 10 times that of those craft in use today. Cargo capabilities are difficult to represent in real-world systems and in simulations where modeling the dynamics of transferring quantities is not standardized.

Representing cargo in M&S tools was limited, and use of unrelated simulation objects were used to act similar to a type of resource. In the two types of simulations, time-step and next-event, there were different methods of modeling cargo and transfers of quantities from one entity to another. Given the diversity of the simulations, there was no standard way to represent cargo or a transfer of that cargo. Common elements present across simulations were fuel elements that were used in time-step simulations.

2. Transit Times

Logistics support is highly dependent upon what time the supplies arrive to the front lines. Sequencing operations are often limited to logistic capabilities. An important aspect of modeling a SBE was the time required for a T-craft to transit from debarkation point to the SBO and then to the shore. Transit times are helpful in determining needed speeds of a T-craft in different modes. These needs are derived from mission requirements and end users needs. Transit times were used to confirm the presents of a capability within a simulation, and its ability to measure time distance problems that could be integral to decision making and planning.

3. Survivability Rates

The third MOP, survivability of a SBE, was the constant element in simulation development. T-craft prototypes are being developed with limited self defense and will require protection in a hostile environment. The Advanced Scenario introduced a hostile environment through which the T-craft transited. Survivability was defined as T-craft being able to transfer cargo to the shore landing site, while maintaining a capable speed of 40+ knots through the hostile environment. The use of this MOP on simulation capabilities was that damage sustained by T-craft in iterations should have an effect on performance.

D. M&S IMPACT ON SEABASE ENABLER SITUATIONS

The introduction of a potential revolutionary platform like T-craft may have dramatic effects on current force structures and deployment considerations. Stakeholders like the Navy, Marine Corps, Army and other key military entities have collaborated with ONR to develop the SBE capabilities required for operations in SBO (Flitter & Sintic, 2009). These capabilities were published in the BAA 05-020 by the

ONR. In general, M&S is well suited to model INPs like T-craft and give decision makers key insights to its potential as a SBE.

Although the two types of simulations contributed to the goal of analyzing a SBE in the situations like Peace Keeping and Major Theater War, their advantages vary. AABM, which is commonly found in time-step based models, provided a dynamic environment to model interaction with other forces in a given scenario. This allowed for adjudication of engagements with force-on-force. Time-step based modeling also enabled replications and the integration of complex algorithms to perform data analyses. A DES modeled specific processes within a scenario to isolate factors and measure parameters that may be critical for decision makers.

The disadvantages were centered on the purpose and use of each type of simulation. Defining capabilities of a simulation for a SBE required analysis of a wide range of simulation functionalities that were partially incorporated into these two types of M&S tools. DES were not as versatile as agent-based models. DES are queuing models that have stochastic inputs with distributed results. Agent-based models were usable and scalable but rigid in applications of performance measures. Most simulations did not allow access to programming code, which was critical to modeling a SBE for accurate representation in simulation environments. AABM was highly usable and offered the fewest disadvantages. AABM had complex requirements for measuring performances and obtaining tangible results.

The downside to M&S was that a single simulation could not be used to answer every question of the SBE Scenario.

Investigating the four MOP required multiple points of view into the SBE concept. These types of simulation offered different perspectives on all MOPs that were analyzed in T-craft scenarios. For example, an AABM determined the effective number of escort ships needed in an Advanced Scenario for the safe transit of the SBE with limited defenses. AABM could not be used to assess the cargo load capacity and transfer rates that a DES could model with more accuracy, with regards to waiting queues processes. DES was also well suited for measuring multiple iterations in tandem or in series. Nevertheless, the survivability of T-craft with escort ships may have been best analyzed in a time-step simulation with look up tables for real-world probability engagements.

Basic surface engagements and cargo transfers were used for modeling T-craft projected capabilities. The Basic and Advanced Scenarios described in Chapter V were used for the purpose of defining a set of capabilities that all models possessed. The following sections delineate the capability hierarchy used for analysis of the six M&S tools.

E. CAPABILITY HIERARCHY

M&S tools have inherent functionalities that can be used in all areas of DoD and industry for analysis, testing, training, and planning. These functionalities were the backbone of the capability hierarchy. Figure 5 illustrates the tiers of the capability hierarchy. The four levels of the capability hierarchy are: Capability of a simulation, Characteristics of a Capability, Abilities of a characteristic, which were referred to as “ilities,” and Traits of “ilities.” The Trait tier represented functionality groupings that were used to evaluate M&S tools. This section delineates the hierarchical structure and body used for analysis of the six M&S tools used in this study. The levels of description directly reference M&S domain ideology and use of common applications in DoD to support the preferred capabilities of an M&S tool.

The capabilities in the hierarchy were derived from M&S Domains in DoD, and are Usable, Flexible, and Scalable (DoD, 1995). Each simulation was evaluated based on how well it fit into the hierarchy of capabilities using the Basic and Advanced Scenarios.

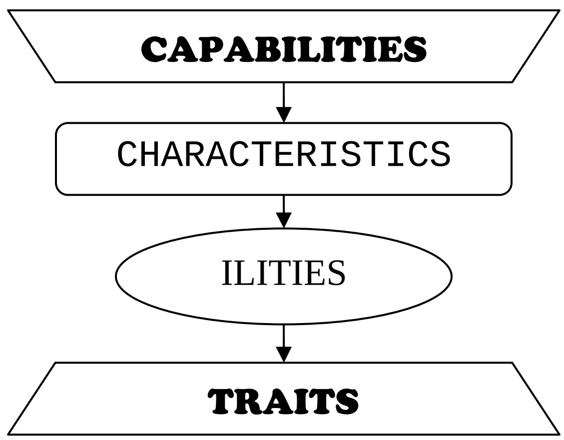

Figure 5. Capability Hierarchy Structure.

1. Evaluation

The evaluation of M&S tools were based on a Boolean value in an attempt to removed subjectivism from the base of the hierarchy. The functionalities were observed and recorded as being present or not. This enabled the application of values to be applied to functionalities.

Value of one was assigned to an observe functionality, where the total number of observed functionalities were used as proportions. The use of probability properties were used for evaluation. This research kept the values the same for all functionalities but recognize that a weighted scale be applied to future evaluations where elements of the hierarchy could be more important than others.

2. Roll-Up method

The functionalities within the capability hierarchy were used as the baseline total proportionality for evaluation. This section explains the method used to roll up the total probability of the individual capability. A single functionality was set equal to a value of one. The total number of functionalities within a given capability was then used to determine the contribution of each one, where the variable (f) represents functionality. The summation of each capability was then combined up the hierarchy to the characteristic level and follows the Probability Assignment Rule (De Veaux, Velleman, & Bock, 2009, p. 371).

$$\sum_{i=1}^{n} f_i = f_i + f_{i+1} + f_{i+2} + \ldots + f_{n-1} + f_n \qquad \text{Equation (1)}$$

A roll-up method was then used to calculate the contribution of hierarchy elements in the capabilities. Using Equation (1), the total contribution of functionalities of a trait were summed and rolled up into the hierarchy to determine the capability of an M&S tool.

This was done by normalizing the capabilities vector. The variable (c) represents the three capabilities defined in the hierarchy.

$$\hat{C} = \frac{C}{|C|} \left\{ \begin{array}{l} c_1 = \textbf{Usability} \\ c_2 = \textbf{Flexibility} \\ c_3 = \textbf{Scalability} \end{array} \right\} \quad \text{Equation (2)}$$

The roll-up method was used to compare the three capabilities of an M&S tool. The asymmetrical design of the capabilities hierarchy was not conducive for a one on one comparison of single elements. The number of functionalities in each capability was not standardized across the hierarchy, therefore, a standardization method needed to be used. Normalizing the probability values were calculated similar to normalization of vectors where the varying number of functionalities are accounted for. Once the capabilities were standardized, the average was then calculated to compare the capabilities of all the M&S tools to determine the best solution for a simulation or "suite of simulations."

F. USABILITY

The definition of usability as defined in American Heritage is the capability of any given object to be used. The ability of a simulation to be used by users certainly was a capability that was required when applying it to analysis. The meaning of usability was also open to interpretation of the users. There are many aspects of M&S that could be measured and observed to determine if a simulation is (1) available and (2) usable by decision makers (who are not computer programmers). Figure 6 shows the hierarchical structure for Usability.

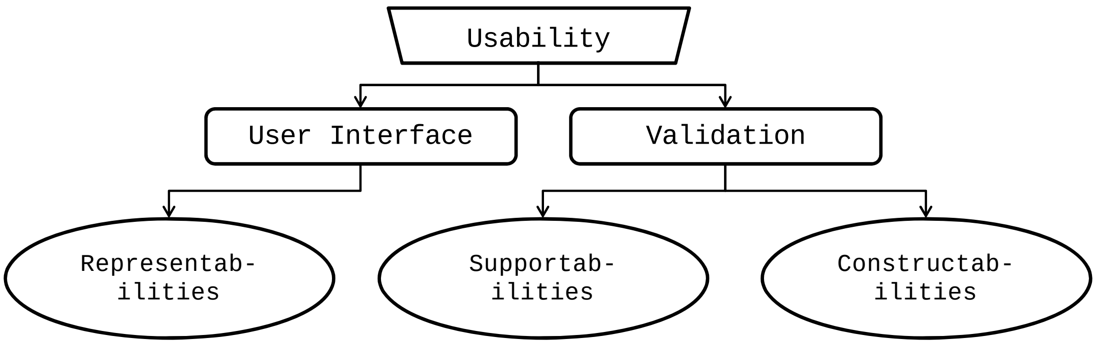

Figure 6. Usability Hierarchy Branches.

The end user's level of knowledge of simulations was ultimately dominated in how usable it was, but there are other factors that allow for a simulation to be useful in DoD. One important aspect of a simulation must be that it has been VV&A. This concept of VV&A was considered as a key characteristic to usable simulation due to its rigorous testing and application of a simulation's capabilities (DoD, 2003).

The second characteristic, user interface, applied to features that the user accesses for manipulation of settings in the M&S tool and those functionalities to create models. DoD applications of M&S tools often require explicit interface methods to handle a wide range of settings for modeling scenarios.

1. Validation

The validation of M&S tools was important because of the continued support of major DoD decision making organizations and processes. Validation was defined as the process of determining the degree to which the simulation could accurately represent the real world (DoD, 1998). This was a key element with regards to usability of a simulation. The VV&A process was not directly used for determining the simulation capabilities, but had a role in defining those end user needs (DoD, 2003).

a. Construct Abilities

Given that a simulation was validated for use, the first step in assessing its usability was to assess its ability to handle complex SBE Scenarios. This included the ability to simulate multiple entities in an environment that presented interactions among multiple entities. An entity was a single player or agent in a simulation that was defined by the user of the M&S tool (Bonabeau, 2002). Figure 7 shows the hierarchical structure for “construct abilities.”

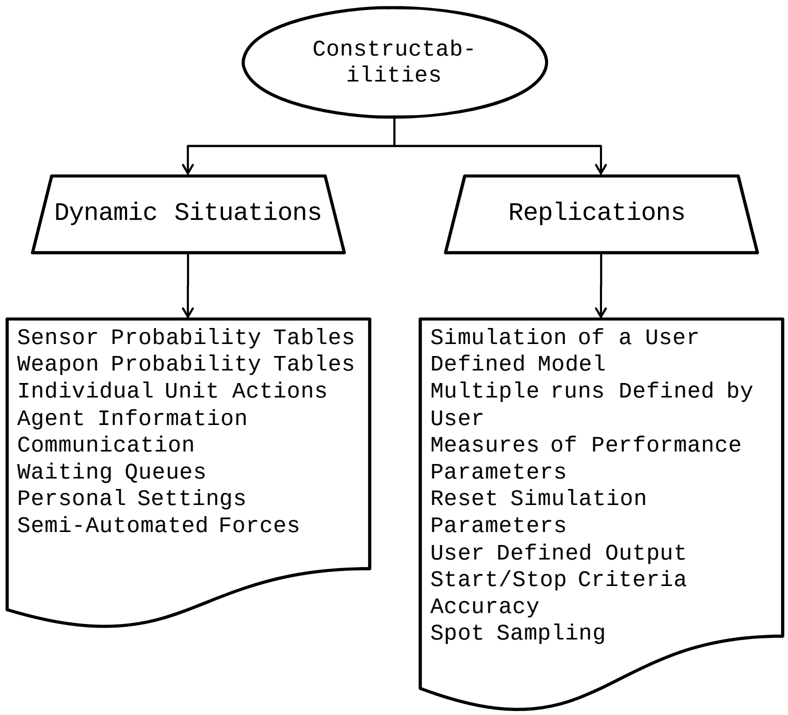

Figure 7. “Construct Abilities” Hierarchy Branches.

(1) Dynamic Situation. The first situation to consider was the dynamics of possible scenarios with multiple entities that acted as individuals interacting in a simulation environment. In this thesis, a dynamic situation was defined as a non-deterministic model where entities acted independently from one another and whose actions were not predetermined. AABM are an example in which the simulations could create a dynamic situation with multiple personal attribute settings. Other aspects of dynamic situations were associated with the individual entities and their place within the simulation environment. There are several functionalities that were present in a dynamic situation that begin with probabilities to facilitate a non-deterministic model. Other functionalities included

individual entities properties and interactions of those individual entities with each other, which did or did not include probabilities.

The idea of using probabilities is not new to military operations and planning. Classic war gaming methods have used probability tables to simulate the partially random results of interactions of units on the battlefield. One way to make a model non-deterministic is to use sensor and weapon probability tables. The level at which they were implemented was based on the resolution needed, but in this thesis basic use of probabilities was sufficient to display the functionality in the simulation.

Inherent in dynamic situations is the individual entities characteristics that are displayed. AABM represented this functionality with a high degree of effectiveness. The level of resolution at the individual entity provided the maximum amount of dynamics in the simulation. The first functionality was that the individual unit actions were different from all other elements within single simulation iterations. It then followed that if high resolution was present, individual entities also needed to possess basic viewable characteristics like entity course, speed, positional data, refueling rates, and cargo capacities levels.

An important functionality in dynamic situation was the access to individual entity controls. AABM are rooted in the concept of controllable attributes for agents within the simulation. These personal settings included but were not limited to preferences to other entities, task oriented actions, and objective completion.

A simulation that enabled the user to adjust personal settings of an entity possessed this functionality.

The use of Semi-Automated Forces (SAF) has become obsolete in the development of AABM. The reason for listing these types of forces was to include a wide range of aspects in the hierarchy to be able to apply it over simulations in M&S. SAF were the first attempt to represent human behavior in a constructive simulation. There may be some level of automation to entities in M&S that is not associated with AABM. SAF covered all other force automations that were encountered through this research (DoD, 1995).

Communications added complexity to dynamic situations by allowing information of scenario events to be distributed to multiple entities. The use of communications by entities provided a situational awareness influencing actions. Operations that relied on communications were defined as: Command and Control, Military operations other than Warfare, and Logistical.

Waiting Queues are typically characterized in logistical operations where transfers occur and are time dependent. A DES is designed to specifically create waiting queues to measure transfer rates and amounts. This property was the basis for introducing waiting queue functionality in the hierarchy. A simulation with the capability to delaying transfers based on facilitation restriction of entities capabilities was defined to have waiting queue functionality.

(2) Replicable. The ability to run a simulation over multiple iterations is to allow for varying results in a dynamic situation. The main reason for simulations to be replicable was to provide statistical data. The M&S tools provided a range of possible answers for users. The data collected from the replication provided insights to model performance. This information would otherwise not be obtained without the expensive generation of actual prototypes in the physical development of the system.

M&S tools should have certain control functionalities associated with the replication of models. The users should have the ability to define and use a model in the simulation. This classically is seen in time-step simulations where entity models are available for use in the simulation without access to action settings. This has been recently addressed in AABM where the default settings are not sufficient for simulation and attention must be paid to the design of the simulation. The second functionality was the ability for the user to define a predetermined number of replications for a simulation. When dealing with complex models, time played a considerable factor in computational run time.

Along with replication, control is the ability to select specific MOP. A user should be able to select pertinent MOP for the simulation. This functionality also assisted in reducing time in other ways. Simulation output often was not designed effectively to allow users to rapidly depict analysis information at any point in the iteration. A spot sampling of information in the run should be functionality to allow the user to select key MOP for output files increased the analysis capability. MOP included system parameters associated with times or user defined variables.

A simple functionality was for users to have the ability to reset simulation parameters during the simulation. This included the need to start and stop the simulation base on certain criteria. User needs vary with situational requirements and M&S tools must be versatile in handling both depth and breadth of requirements.

The last functionality of replication that was used in this research was accuracy. Accuracy was defined as the ability of a simulation to produce a result, and/or contained in a confidence interval common to statistical analysis. Optimization methods often had difficulty in determining solutions to complex situations with multiple variables. This often left simulations without ends. It was foreseeable that optimization approaches will be employed in M&S analysis of DoD systems, therefore accuracy was included in the capabilities hierarchy.

b. Supportabilities

The second step in assessing M&S tools usability was the level of supportability that simulations had in the form of user execution. VV&A required simulations to have minimum levels of information (support and documentation) associated with M&S tools to be approved for DoD use (DoD, 2003). These support issues may be key to use of simulations in DoD at the higher levels of the decision making process. VV&A requirements for accreditation were the basis for support "-ilities" of a simulation in the hierarchy. The information listed in the VV&A instruction is the standard for M&S tools used and are common in high profile models. The two categories of supportabilities are contractor support and user documentation. Figure 8 shows the hierarchical structure for Supportabilities.

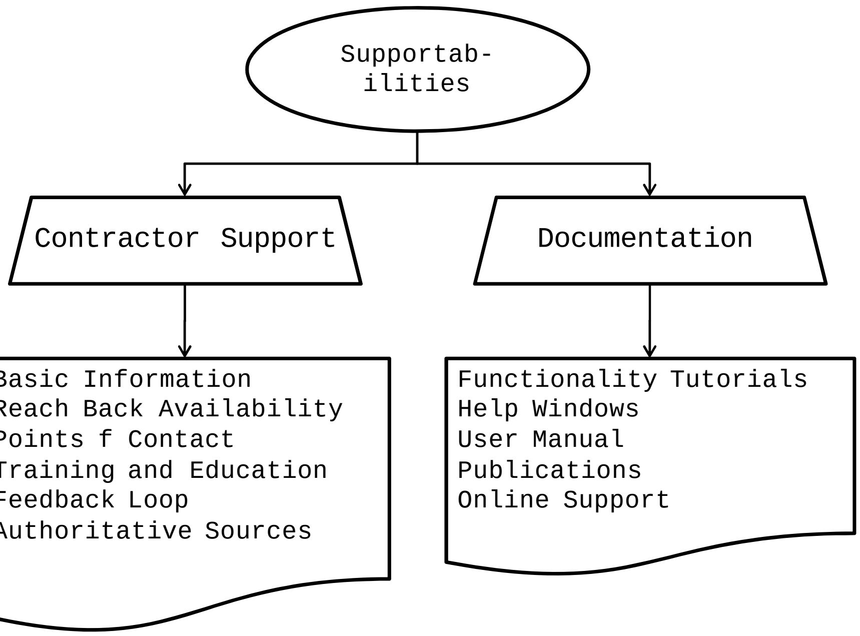

Figure 8. Supportabilities Hierarchy Branches.

(1) Contractor Support. There are basic elements of simulation information that should be contained in the associated files of a program that the contractor or programmers provide. A comparison between the defined capabilities hierarchy and the VV&A process are listed in Table 4. This comparison was used to show the validity of informational items that were used in the capability hierarchy, which indicated what additional items were used

in evaluations with All items listed in the supportabilities category are delineated in the capabilities hierarchy.

Supportabilities Comparison	
Verification	*Support ilities*
Verification Agents	
Version/Release	Simulation Version Number/Release information
Identify Developing Organization	Listing authority sources used to produce simulation code
Methodologies	
Verification Results	
Validation	*Support ilities*
Validation Agents	
Federation Version	
Identify Developing Organization	Listing authority sources used to produce simulation code
Simulation Conceptual Model	
Methodologies	
Validation Data	
Validation Results	
Limitations	
Sponsors information	Listing of Points of Contacts held with the M&S tool
Model Intended Use	
Requirement Gaps	
Assumptions	

Scenarios		
Representation of concepts, Processes		
Environmental, Missions, Organization, & Systems Representations		
Doctrine Tactics, Behaviors, and Performance Algorithms		
Capabilities and Limitations Evaluation		
VV&A Documentation		
	Support ilities	
	Last Upgraded Information of program code	
	Reach-back Availability – User Capability to correspond with contractors on simulation issues	
	Internet Availability – Access to documentation and information items through the internet	
	Training Availability – Contractor supported training session provided to DoD agencies for employees professional development	
	Feedback Loop – System in place to provide lessons learned, answers to current questions, and update center for users	

Table 4. Supportabilities Comparison Against VV&A.

Basic informational items are self explanatory and contain the simulation specifications. The more complex items like contractor support items were expanded in this section. The first was a reach back availability that pertains to the continued support of M&S in DoD throughout the life cycle process. The availability that was described in the hierarchy referred to contractors' use of simulations in parallel with DoD components for experimentation. The reach-back support line item was created for M&S application in military operations that required expertise of development experts for analysis of real-world scenarios. Simulations used in DoD to solve non-trivial processes may be relatively simple to contractor development entities.

Exchange of program user information was common with use of the internet. Web site availability of M&S tools was included in Supportabilities. Simulations that were widely used in the DoD provided web site services to users for capabilities listed in Table 4. Copyrights and proprietary rights should not be a blocking factor for contractors in providing information to users that have access to simulations but not source code access. Web site availability was defined in this hierarchy as internet availability that provided an outlet to find operational information on simulations. Along with internet availability, there should be a feedback loop or method to give users the positive indications of progress assistance with challenges. This was in the form of observable simulation results or actual correspondence with contractors. The goal of these “ilities” was to enable users to understand and correct issues with operating M&S tools.

Purchase of M&S systems often is accompanied with training for employees but training is not necessarily up to standards. Contractor provided training of M&S tools was invaluable to operating and analyzing military situations. DoD maximizes its investment in M&S with knowledgeable operators using simulations and systems to their full capacity. Ultimately, these support abilities contributed to the usability of a simulation. There were no measures to determine the level of support a contractor provided to the implementation of M&S; supportabilities were considered to possess the “ilities” if a single aspect were present.

(2) Documentation. Use of M&S in DoD often relied heavily on how simulations were supported for independent modelers and decision-markers. Documentation for open source M&S was critical. There were essential forms of documentation that made the M&S tools considerably easier for use when included in simulation packages. The most common form of documentation was the user manual associated with the simulation. Documentation was defined in the capabilities hierarchy as any simulation that contained a link to the user manual within the running program. User manuals provided a complete set of information for operations of the simulation. Other publications, similar to the user manual, aided the user in M&S applications and uses and provided additional information.

Functionality tutorials were those informational programs within the simulation to facilitate the creation of models with developer's instruction and methods for proper set-up. This was defined as an instructional function in the simulation that assisted the user in step-by-step procedures to create a basic model that can then by personalized by the user for their specific requirements. Associated with tutorials was the use of help windows and pop-up information that rapidly provided assistance to users.

The last element of documentation that was defined in the capabilities hierarchy was on-line support provided by contractors. These elements were considered a part of documentation because the information provided by the above elements was derived from the developers of the simulation. Online support from contracting companies, and specifically the developers, was consistent with referring to user manuals. This is another form of documentation that involved correspondence with live people vice documented information.

2. User Interface

M&S user interfaces must handle the needs of non-computer programmer users in DoD applications. The invention of the GUI has provided the capability for all users to interact with computer software. GUIs were an important functionality and considered vital to M&S applications. Along with GUI, there were "comprehensive ability" parameters that are DoD requirements for operating M&S tools. Operation of M&S tools meant that users be able to understand and work with symbols, programming language, and results across difference branches and components of U.S. Armed Forces. Figure 9 shows the hierarchical structure for User Interfaces.

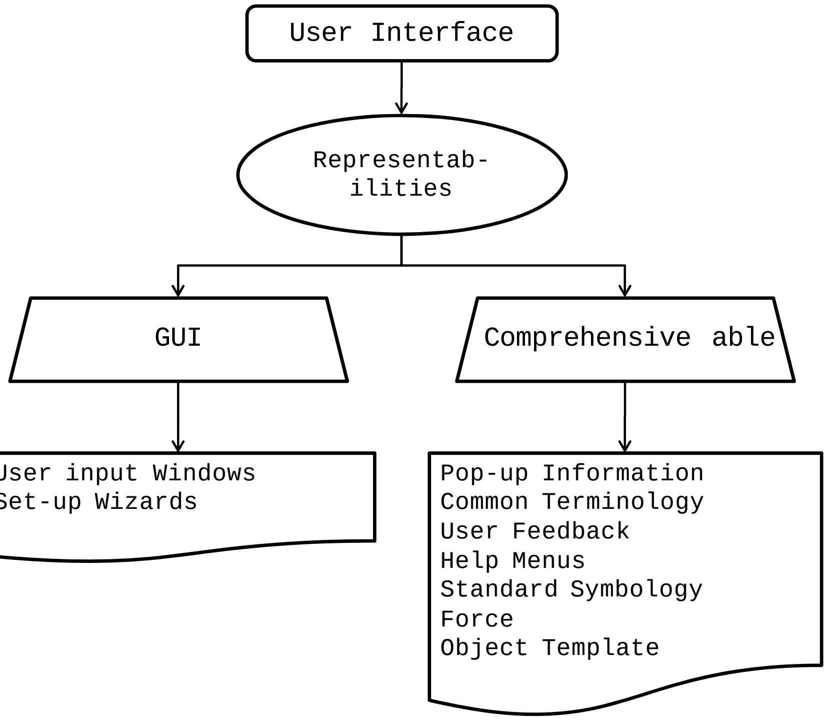

Figure 9. User Interface Hierarchy Branches.

a. Represent Abilities

Represent abilities were the key for users to interface with simulations. It was divided into two traits; presence of GUIs, and “comprehensive abilities”. The common GUIs in software are interactive windows with options available for users to select. Comprehensive able traits referred to the use of common terms and knowledge within simulations: Can a simulation be used by different users and obtain similar results? Representation is important to decision makers and modelers that attempt to use M&S tools in vastly different ways than initial design. The “ilities” were critical to modeling advanced concepts that were not well defined for previous models like a SBE.

b. Represent Abilities (GUI)

There are common GUIs associated with the commercial operating systems. M&S users are familiar with common GUIs and can quickly adapt to a simulation with GUIs. The functionalities listed in the capability hierarchy were not a complete listing of GUIs. There was an understanding that there was no limit on interface options, however, this selection of items was presented to allow for a comparison of M&S tools in this research. There were two functionalities that were examined that made comparisons of simulations, input GUIs and set up wizards that were similar to tutorials.

User input windows were found in virtually every software program. Input GUIs were defined to have four basic functions: pull-down menus, check boxes, typed in values, and adjustment varying sliders. Other GUIs that did not fit into these functions were recorded in the analysis of each simulation.

The second function that was defined in the capabilities hierarchy was the presence of set-up wizards. A wizard was defined as the integrated instructional GUI that enabled users to create a model with the assistance of the simulation. This was included in a step-by-step instructions created by developers to build a skeleton model. The wizard assisted in modeling a specific process.

c. Represent Abilities (Comprehensive Able)

"Comprehensive abilities" refers to the common application of simulation and their results across components of the DoD. There were two parts to "comprehensive abilities"; information availability and transferability. The amount and type of information that was displayed by a simulation was important to the user's understanding of model processes. Presenting accurate information was a capability that was considered in this hierarchy. The method in displaying information was measured in this analysis. There are three functionalities that were considered: the presences of (1) help menus, (2) pop-up information, and (3) user feedback information. User feedback information included messages that give status or completion indications.

Transferability was defined similarly to the ability of simulation models used and interpreted by outside entities across a variety of users and user backgrounds. There were three functionalities that enable this ability: Common terminology, Standard Symbology, and Object templates. Simulations are under implementation restrictions dictated by DoD as set forth in Joint Pub 1-02. The set of general terms common to DoD were used and apply to M&S tools (DoD, 2001). The use of symbology was not as common in DoD, each service has adopted its own standard symbols. Simulations were measured by the use of any standard set of symbology employed by the services. The last functionality in this trait was the object templates that referred to entities used in protocols like Distributed Interactive Simulation (DIS) and High Level Architecture

(HLA). Simulations were analyzed for the functionality that they could send information to other simulations based on the above protocol standards. Networking involves protocols with common entities that are predefined in Institute for Electronic and Electrical Engineers standards. DoD instituted the use of HLA in all simulations by the Under Secretary of Defense (Acquisition and Technology) in 1996. Object templates were incorporated into comprehensive able to illustrate simulations were integrated in multiple ways other than internet considerations.

G. FLEXIBILITY

Flexibility was defined as the ability of all levels of M&S users to use M&S tools for analysis. Flexible simulations were able to model different military applications and allow users to set model parameters to test a wide variety of outcomes in a timely manner. The first characteristic of a flexible simulation was the ability for it to handle a spectrum of functionalities that could represent real-world systems. Unfortunately, the level of flexibility was difficult to measure and had considerable variation. The amount of “model ability” needed was determined by elements of the specific model. BAA 05-020 listed T-craft capability requirements, and was used as MOPs for “model ability” (ONR, 2005). Figure 10 shows the hierarchical structure for Flexibility.

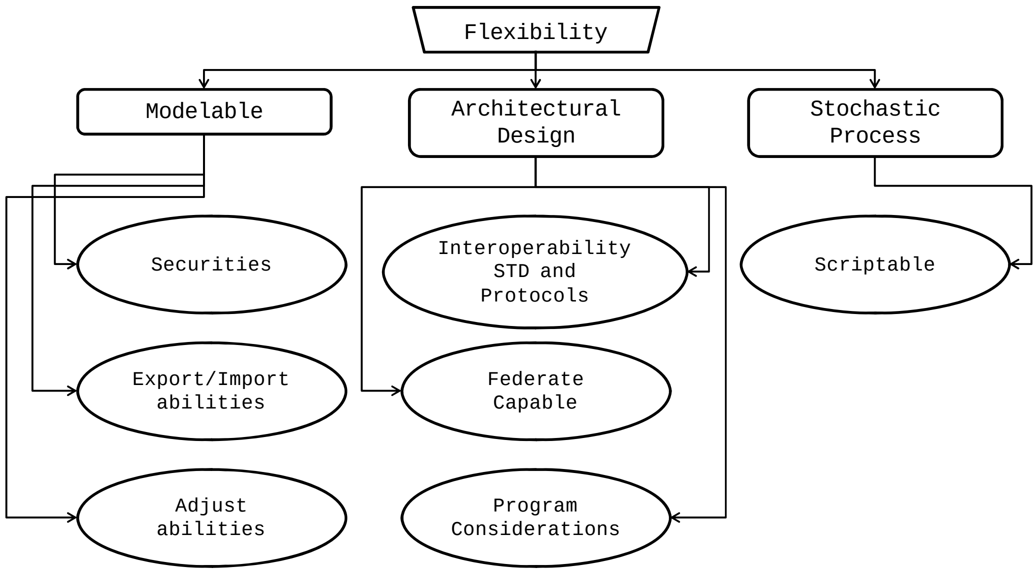

Figure 10. Flexibility Hierarchy Branches.

The second characteristic of flexibility was stochastic processes in simulations that apply randomness to provide a sense of realism in outcomes. This randomness introduced the idea of chance and uncertainty into the planning phase. The T-craft concept was untested and required the full degree of uncertainty and randomness into its required capabilities. Simulation capabilities did not serve the interest of developing T-craft as a viable asset without the use of stochastic processes in simulations. Both of these characteristics contributed to effective use of M&S tools and enabled users to rapidly produce results.

1. Model Able

There are five “ilities” used to define “model ability” in the capability hierarchy that extend over a limited spectrum of functionalities used in M&S tools. This section is used to analyze the simulations’ effectiveness in representing a system in M&S. These “ilities” ranged from environmental effects to system parameters that included the ability to process classified material, input environmental databases, and scenario object representations. Adjustability contributed to being able to model a SBE and involved the basic system attributes. Other “ilities” referred to how the model was handling within simulations, resolutions of forces, and scenario environment. “Model ability” enabled simulations to render a real-world system in a constructive simulation environment.

a. Securities

Securities were defined as the safeguards of a simulation to handle information that may be present in DoD modeling. The advantage of using M&S was that it can provide insight to scenarios. These scenarios often contained secure information that may be sensitive in nature and require certain considerations. The single trait of simulation classification was defined as the ability to handle and safeguard secure information in accordance with DoD security regulations and instructions. All model scenarios used were unclassified. This trait was defined to allow greater range of the capability hierarchy that was applied across M&S tools. Simulations equipped with encryption and decryption devices added functionality and increased flexibility.

b. Export/Import Abilities.

Export/import abilities in M&S tools were defined as the ability to transfer scenario files from one simulation to another. The information extrapolated needed to be in a useful form as to enable cross simulation interoperability. These “ilities” were an extension of program considerations in that data from other sources may be needed to model and simulate scenarios. The focus was to have M&S tools that had the capability to handle specific elements of available information be used to enhance simulation execution. There are different forms of model data that can be exchanged between simulations and were referred to as databases. Databases were composed of single entities that represented systems defined by users. They were also defined as the object files of the environment effects. Imagery data imported into a simulation was grouped in databases trait because the form taken by the information imported was in most cases a database object in the software.

c. Adjust Abilities

The majority of “model ability” in M&S tools came from having the ability to adjust parameters and settings of a model. Adjust Abilities are the user defined properties that represented the modeled system characteristics. This section was critical to physically representing a SBE in a virtual environment. The following traits were a collection of observed functionalities, not a comprehensive listing for M&S tools to be analyzed by. Figure 11 shows the hierarchical structure for Adjust Abilities.

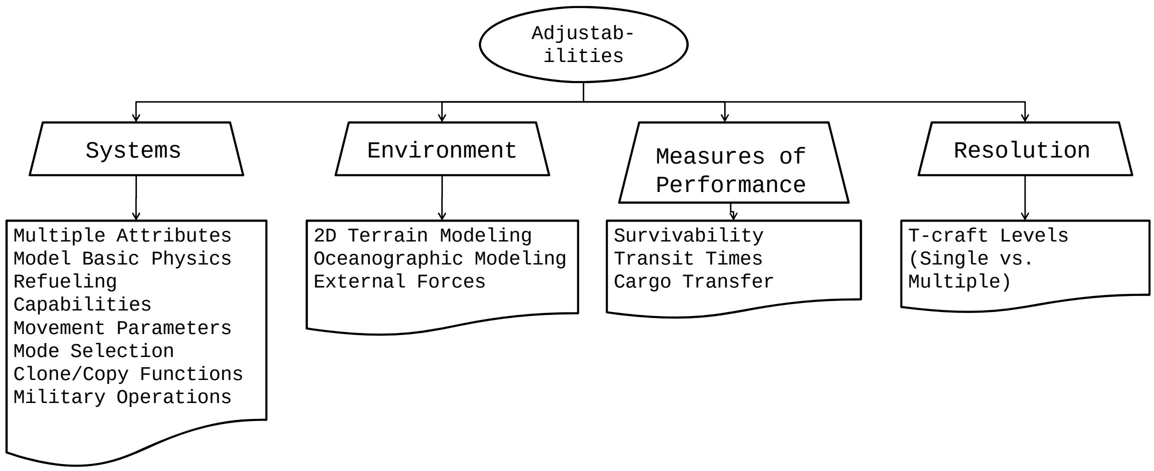

Figure 11. Adjust Abilities Hierarchy Branches.

(1) Systems. System traits described in Table 5 were a limited scope of capabilities that M&S possessed. Simulations were measured on presence of functionalities and not performance. The capability hierarchy was defined to have the following system traits which include basic system properties. These were available for user to adjust as needed from model to model or situation to situation.

System Traits	
Functionality	*Definition*
Multiple Attributes	Model properties that control actions of units based on resolution. Provide flexibility of users to model multiple interaction decision points.
Model Basic Physics	Interaction of model in simulation environment that effect movement and motion. SBE models needed to float in water and be affected by wind, sea state, and shore transitions.
Refueling Capabilities	Logistic requirements modeled to measure performance and usages.
Movement Parameters	Model scenario requirements specified and limit entities motion/actions in the simulation.
Mode Selection	Two modes of movement for a SBE model, Sea Mode and Hover.
Clone / Copy Function	The ability of an M&S tool to create copies or multiple entities with the same properties and attributes. Provide scalability of the model to increase SBE's used in a scenario.
Military Operations	For use in the DoD, M&S tools model joint operations and have capabilities to handle classic offensive and defensive actions. The following functionalities were defined in the hierarchy as military operations. Guard – Stay in position and protect units or area surrounding location. Patrol – Movement of entity to search and protect units or area surrounding designated location. Orbit – Continue repeated movement on designated path in any geometer shape. Attack – Perform actions to other entities to affect their status. Flee / Run –Detect an attack from a hostile force and be able to decide on withdrawing from the engagement based on user predefined limits. Grouping Functions – Multiple entities act together in un-nascence to perform a single goal. Inter Communications – Entities communication with each other during simulation. Remain in place – Entities ability to decide to remain in place or be directed to by attributes. Waypoint selection – User defined weapon selection. Unit operations – High resolution of entity actions that enable single units to act independently. Provides scalability to model.

Table 5. System Traits Definition.

(2) Environment. Environmental factor starts to increase importance on “model ability” of T-craft’s capabilities as greater forces are applied. The environment traits defined were not designed to limit M&S capabilities in other areas of simulation, but rather address factors on land, sea, and in the air with reference to a SBE. M&S tools were measured for presence of factors in this comparison study.

There were three environmental traits defined in the capability hierarchy: terrain, ocean topography, and forces. The first trait, terrain, was at a minimum two dimensional (2D) that could model traditional warfare. There were three functionalities associated with terrain: surface configuration, natural and man-made feature representation. The ability of users to create a terrain in simulations was needed to develop custom scenarios. Surface configuration functionality enabled users to build and populate terrain surfaces with a variety of objects. Use of terrain objects were dependent on flexibility of the simulation to accept or create those program objects. These objects had the ability to be natural or man-made to present a realistic environment.

The second trait, oceanographic modeling, applied to use of ocean depths that were needed in a naval environment. The ability to model contour depth data was used for the addition of submarine operations on the scenario. Water depth was also needed for operations of naval assets near the shore. M&S tools handled the case of ships running aground in shallow water. These points were eclipsed by the need of SBE’s to shift from transit mode to hover mode at certain ranges from the shore. Modeling the water features were used for T-craft to meet mode shifting requirements in the scenario.

Third, M&S tools modeling SBE's were able to model sea state and wind effects within the scenario. Sea state was defined as the level of effects from water motion applied to T-craft movement and survivability. The wind was defined as the amount of force used to slow or push T-craft in the simulation environment. The capability hierarchy analyzed M&S tools for the presence of sea state and wind effects on entities.

d. Measures of Performance

Users were able to select and/or create MOPs within a scenario, which allowed for analysis of specific factors. Simulation results were likely to be used by decision makers to gain insights into system capabilities, thus enabled users to narrow their search in collection data methods. The three MOPs that were defined in the hierarchy correspond to Paragraph B, above. Simulations were determined to have an MOP "ilities" if the yielded output data was user defined measures that related to measures of survivability, transit times, and cargo transfer.

e. Resolution

The factors associated with the Basic and Advanced Scenarios called for a high resolution model. The level of resolution was measured as the capability to model T-craft force levels (Single vs. Multiple units). The M&S tools used in this research were examined to determine what resolution capabilities were present to see if a single unit was modeled with individual actions. Future scenarios may require the use of multiple SBE's with a high resolution. The "ilities" may be useful to decision makers in acquisition of SBE technology.

2. Architectural Design

Simulation program design was extremely important in the wide use M&S tools in the DoD. There are several design issues that must be addressed early on in the progression of an M&S tool to pertain directly to its usability. Standardization of functionalities is crucial for users to be able to understand simulation processes. Just as important as interface standards may be a background of simulation conception. DoD protocol requirements for M&S have put standardization of simulation at the forefront of M&S development. Interoperability of M&S tools enable higher levels of computation to be performed adding to application flexibility throughout M&S. Figure 12 shows the hierarchical structure for Architectural Design.

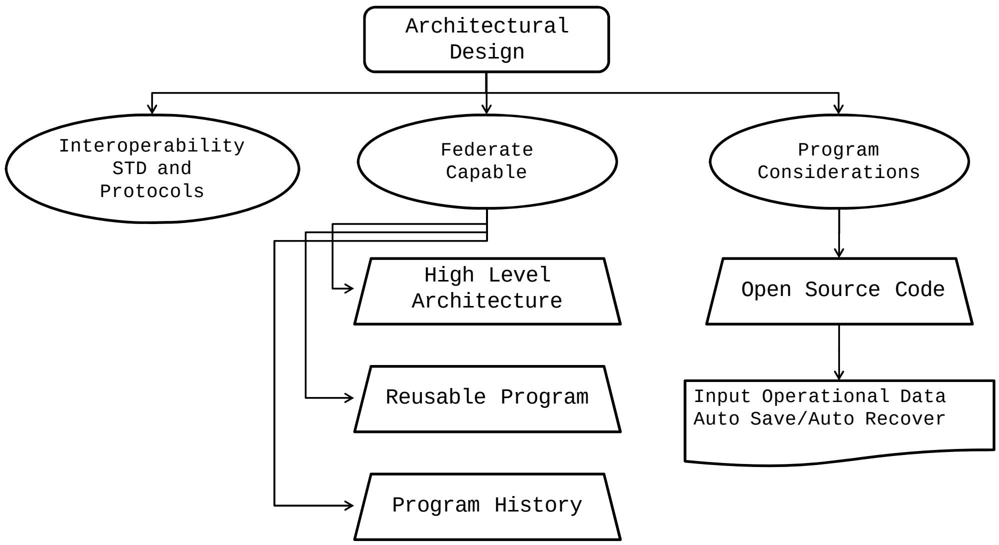

Figure 12. Architectural Design Hierarchy Branches.

a. Federate Capable

Federate capability was defined as “ilities” where simulations were integrated into a multiple code federation: A federate is a model networked into a HLA application (DoD, 1998). There are three traits that were derived from federations: current DoD regulations on M&S interoperability, reusability of models, and program history. M&S tools that were federation capable increased their use in DoD. This added to a model’s flexibility to simulate SBE scenarios. The use of compatible simulation code allowed for the rapid exchange of information across M&S tools. Program history was simply defined as the access to dates and historical references to model uses.

(1) High Level Architecture (HLA). HLA is the standard protocol for DoD M&S. M&S tools were considered for the presence of HLA protocol, not merely computability. HLA is a strong measure of flexibility which

allowed for incorporation of M&S tools with DoD established models further validating the model, as well as the ability to import current models being used for analysis.

(2) Reusability. Reusability was defined as the ability of a model to be recycled into future M&S capabilities. The development of M&S tools is costly and time consuming. Simulations like Combat XXI have reused existing code and modified it to fit into a federate that can then handle a boarder range of scenarios. This allows for further comparisons of traits among M&S in this hierarchy to determine flexibility.

b. Program Considerations

Given that M&S tools may handle secure information, an important consideration to architectural design was the flexibility of simulation features. M&S tools were measured on three aspects of programming. An inspection of six M&S tools was conducted to record if the programming code was open sourced or proprietary. This was important to understanding and believing the validity of simulations. The magic black box effect, where only inputs and outputs are handled without a clear understanding of underlying model algorithms and processes, does not assist DoD components if processes are not full accessible. The second trait was the capability of a simulation to input operational scenario data. This capability was used to decrease set-up and execution times. The ability of a simulation to import object libraries is a requirement to being HLA capable. Therefore, flexible simulations should possess both. The third was the auto-save and recover trait that also assisted in set-up and execution times.

3. Stochastic Process

Stochastic processes were defined in the capability hierarchy as simulation characteristics that were not deterministic. These processes were extremely difficult to describe and define, and were not limited to a narrow definition. This did not exclude the need to have simulations have stochastic characteristics. M&S tools were measured on how well the model allowed for entities to react to the scenario given movement and attribute inputs by users. Therefore, the only "ilities" that was listed under stochastic processes was script ability. The scenarios were dominated by naval operations which required special consideration to produce the proper outcomes.

a. Scriptable

Scriptable simulations were defined in the hierarchy as having abilities to simulate the model in the same method but obtained varying results. The Basic and Advanced Scenarios were based in the same environment, with the same routes and areas of operations. Having the same starting point was useful in analysis but problematic in deterministic simulations. There were four traits associated with script ability; user defined scriptable scenarios, Next-event models, time-step models, and random variables and/or Markov principles. Scriptable was defined as the ability of users to predetermine movement of entities by waypoint or attribute methods.

(1) Next-event/time-step models. M&S tools fell into one of these categories, both of which had strengths and weaknesses. The trait was defined by the

simulation being either type. The properties of Next-event and time-step simulations provided the flexibility that SBEs scenarios utilize.

(2) Random variables and/or Markov principles. By extension of stochastic, a simulation should posses some degree of randomness. This trait was defined as a simulation that had random variable to produce pseudo random actions within the iterations. Markov chains processes were made of random changes that depend on current states of the entities that entered a stable state.

H. SCALABILITY

Scalability was defined as the capability to regulate any given object's dimensions. Dimensions referred to the different functionalities of simulation in this context. The ability of an M&S tool to adjust to the conditions within the scenario was crucial to exploring the solution space. A scalable simulation enabled users to adjust force level parameters, as well force on force engagement. These two extremes often were not feasible, but certain degrees of freedom coincided with each other. The first characteristic of scalability was adjudication, which referred to the interactions of units with a given scenario. The user was able to select or adjust interactions of elements in the simulation to judge its importance to the results. Figure 13 shows the hierarchical structure for Scalability.

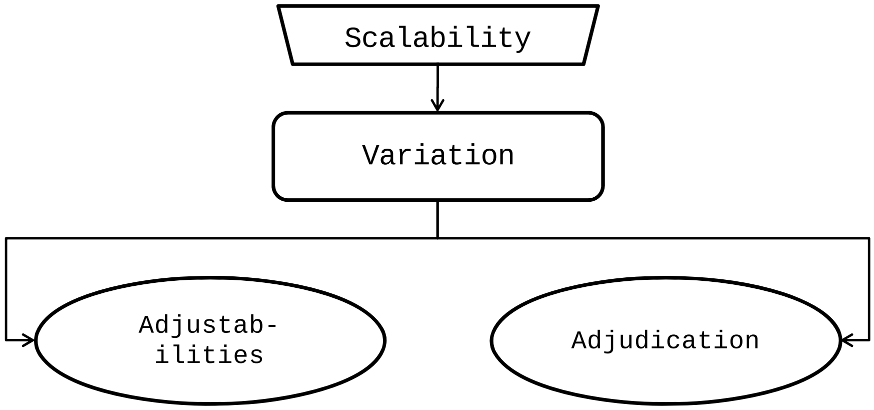

Figure 13. Scalability Hierarchy Branches.

The second characteristic, variation, pertained directly to resolution of a simulation. Variation in force levels were linked to scenario modeling and were often adjustable within scenario settings. SBE Simulation provided the user with the ability to vary resolution within the scenario along with providing controls for expected results. The adjustable traits of this characteristic that were used to define the capability of a scalable simulation are delineated in Appendix A.

1. Variation

Variation of M&S tools in the capability hierarchy was defined different than in traditional uses, such as statistics. This research utilized statistical analysis and referred to both terms. Variation characteristic was used as a method to control numbers of units and level of interaction in a scenario. M&S tools had two traits associated with user controls, adjudication and adjust abilities. The amount of scalability a simulation offers to decision makers could provide insights into possible solutions to capability gaps.

2. Adjudication

Adjudication was defined in the capabilities hierarchy as the methods to determine engagement status of entities during a simulation. Simulations offered the user the ability to determine and select adjudication methods. This included traditional probabilities tables, algorithm integration, and battle damage capabilities. M&S tools allowed for these interactions to be created and stored during simulation. As well as to determine engagement results, there was the ability to record and display them. This was a scalable "ilities" because its traits were adjustable. Figure 14 shows the hierarchical structure for Adjudication.

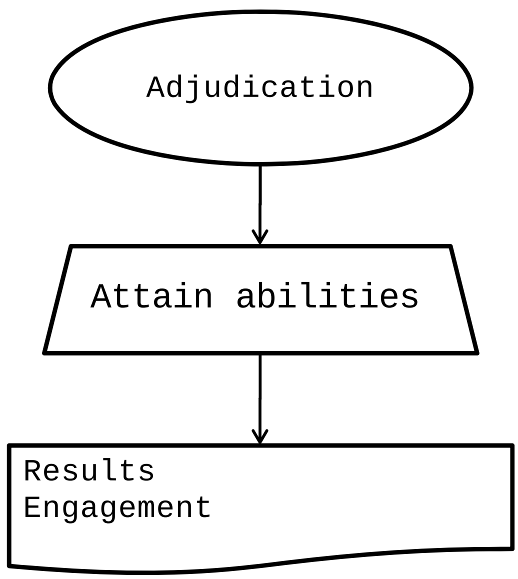

Figure 14. Adjudication Hierarchy Branches.

a. Attain Abilities

M&S tools were defined to be attainable if the following functionalities were available for users to adjust over multiple iterations. Attainable was, in the strictest sense, the internal workings of entities interactions with other entities. The first functionality was the ability of a simulation to calculate results of a scenario's outcome, which enabled the users to predetermine output data and collect it for analysis. This functionality was called Results and used data points that allowed for analysis of the scenario. These were representations of unit measurements, MOP translations, and battle damage assessment reports. MOP translation meant that the model parameters were interpreted in multiple ways. The second functionality was the availability of users to adjust engagement types of code in the model that governed the interaction of entities conducted in simulation iterations. The types of code that was accessible were probability hit and kill tables, sensor and weapon settings, indirect fire capabilities, sensor detection settings, and battle damage adjustment methods.

b. Adjustability Traits

The adjustability traits listed in variation are the same as described previously in the capability hierarchy under "model ability."

V. SIMULATION MODELING

Modeling & Simulation (M&S) is a power analysis tool used by all elements of DoD. M&S provides decision makers the ability to examine the SeaBase Enabler (SBE) in a virtual environment to test capabilities, operational impact, and influence on relief efforts. The requirements of SBE employment are discussed by those same decision makers as to what situation SBE could best be served. M&S tools were used to answer this question by modeling possible SBE scenarios. A model was specifically developed for representing the SBO to compare the various M&S tools that were available to industry and academia alike. The T-craft was used as a SBE for transportation of cargo to and from the SeaBase Operations (SBO).

The approval of the T-craft to an acquisition program may rely heavily on the role M&S plays in evaluating the SBE's capabilities in given scenarios. The SBE model developed was used to compare M&S tools capabilities to determine simulations usability, flexibility, and scalability. The scenario utilized the baseline capabilities for T-craft to define model parameters. The M&S tools provided performance data, which could be given to developers and decision makers alike. The diversity of individual M&S tools was considered in initial simulation selection over individual M&S tool capabilities.

A. SBE SCENARIOS

There were two scenarios types, Basic and Advanced, that were created in this study to address T-craft requirements; peace and war time environments. The peace time environment was modeled without the presence of hostile forces to allow T-craft free transit. This was called the Basic Scenario and enabled M&S tools to collect MOPs data on T-craft’s capabilities. The war time environment introduced hostile forces to the measure survivability MOP. This was referred to as the Advanced Scenario. Between the two scenarios, a wide scope of application was designed for the model to deal with SBE real-world projected scenarios.

There were four real-world scenarios in which the SBE concept is projected to have direct involvement. First, Peace Keeping and Peace Enforcement Operations (PKO) in a peace-time setting are defined by Milan Vego as the principle peace operations. These operations are designed to control and eliminate hostilities using force and regain or maintain peace. The timeframe is nominally after the conclusion of major theater war (Vego, 2007). This is also keeping in mind that all countries have reached an agreement of ceasefire. Second, Major Theater of War Combat Operations is the series of tactical battles that are used to achieve operational objectives. Actions are often conducted parallel or sequential in accordance with the operational plan (DoD, 2001).

Third is Regional Crisis Intervention Operations that are commonly centered on a single nation’s objective or security. This is a situation that develops quickly, creating the need for diplomatic, economic, political, or military resources. The resources are used to divert the crisis and reestablish stability. These operations are normally associated with low threat risks to forces. Lastly, there is Stability Operations that include military missions, task, and activities that occur in conjunction with other nations. They are deployed to provide security, services, and relief to host nations during times of conflict (DoD, 2001). A generic model was developed to encompass elements from these four operational concepts. The Basic and Advanced Scenarios were designed to input the generic SBE model in a series of simulation tools to compare their capabilities. This evaluation was based on the previously defined hierarchy.

B. T-CRAFT MODEL

T-craft capabilities were modeled like that of current amphibious landing craft transferring cargo from the area of SBO to shore landing sites. The T-craft concept is being developed in the vision of current amphibious transportation craft capabilities with a call for technology to increase key performance parameters. T-craft is projected to offer a wider scope of operations (by being able to transit 500 nm at 40+ knots) than current logistic crafts are not able to fulfill. This is a capability that may provide options for military planners in both non-hostile and hostile environments. T-craft also provides the capability of transiting from debarkation point fully loaded. These capabilities are truly game altering. They are significant challenges to analysts and developers comparing SBE’s against current capabilities.

The T-craft model was designed to make cargo parameters flexible, as well as for a time component to measure transit times. The generic model also attempted to measure the scalability of simulations within M&S tools by introducing hostile threat interactions and engagements. Figure 15 shows the battle space for the T-craft scenario that was modeled. The area represented the Sea of Japan with the separation between land masses as approximately 500 nm at the widest point. This location was selected based on the availability and model set up of debarkation points along the western coast of Japan.

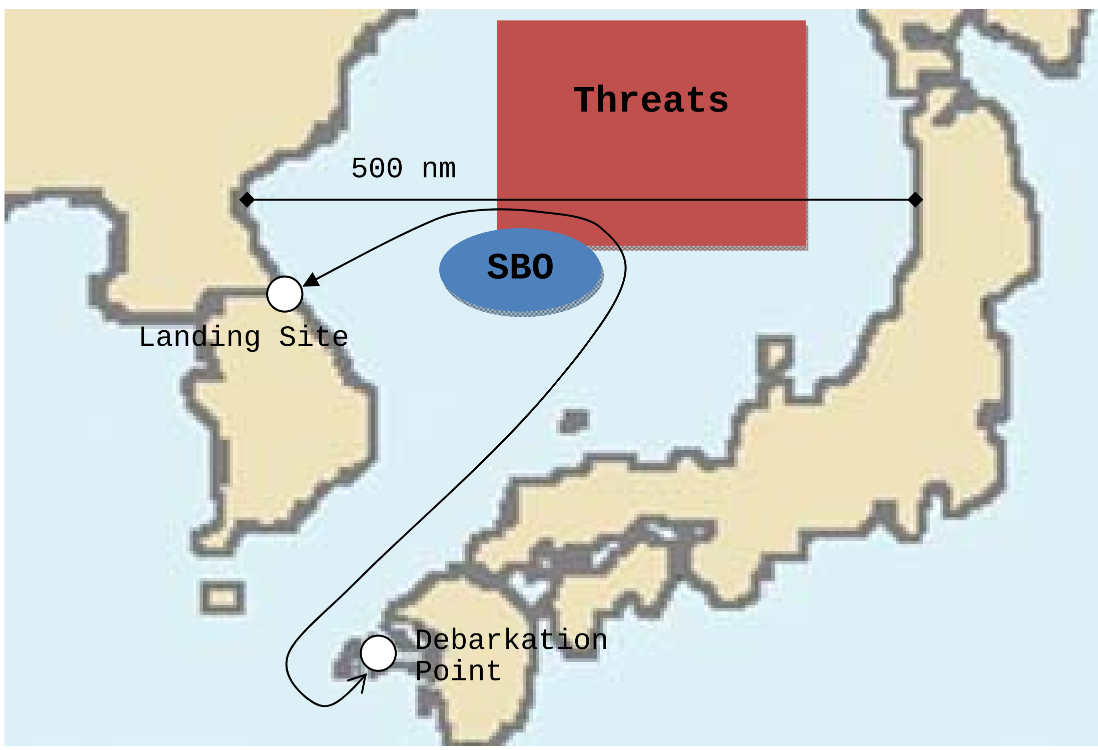

Figure 15. SBE Modeled Battle Space.

C. BASIC SCENARIO

The Basic Scenario was based on Regional Crisis Intervention Operations. The SBE mission was designed to provide relief aid (cargo) and other supplies to ground forces operating on a peninsula region near the coast. The debarkation point was notionally a sea port which corresponds to Sasebo, Japan. A debarkation point is a logistic hub where SBE are loaded with cargo for heavy transfer. The transit to the SBO was approximately 350 to 400 nautical miles (nm). The battle space characteristics were designed to test the T-craft high speed transit capability.

The Basic Scenario modeled a simple transit with two phases. The first phase was T-craft transiting from debarkation point to SBO area. The second phase was from the SBO area to a landing site on the northern part of the peninsula. The T-craft model used was the same as industry prototypes that created a craft with desired capabilities and no self defense. The Basic Scenario was designed to determine a baseline for transit times and cargo load-outs that were used to compare against in the Advanced Scenario.

1. Non-Hostile Operations

T-craft's transit in the first phase was designed to have no external forces acting on it. The Regional Crisis Intervention Operations provided the scenario set up that enabled T-craft to transit to the SBO area without the threat of hostile forces or interference. Given the regional make up of the Sea of Japan, the assumption that T-craft could transit un-escorted and uncontested was valid.

The T-craft was able to transit while loaded or unloaded and varied transit speeds to allow for separate baseline measurements in multiple iterations. The experiment design offered independent measurements of these factors to possibly observe relationships between further studies.

2. Interactions

The interaction of T-craft with the shore line is a significant physical problem being experienced by developers. T-craft capabilities are required to carry large amounts of cargo and equipment but design considerations are limiting landing capabilities. The T-craft is projected to be able to land on shore lines that are less than 2 percent incline. The scenario used in this study assumes there is sufficient shore line supportability on the landing site on the peninsula.

3. Cargo Transfer

Cargo transfers in amphibious operations and in the SBO have loading spot considerations that affect MOPs. This required waiting queues or time delays in the scenario model. Time-step and DES handled this delay in different ways causing a variation in the Basic Scenario baseline measurements. The variation in simulation results were assumed to not affect the comparison of M&S tools based on the definition of the capabilities hierarchy.

4. Refueling Requirements

The number of factors associated with any given scenario was exponential with the depth of detail presented. A major factor of military operations is the logistical support needed by units in the field. T-craft logistical requirements were assumed to have been adequate. Fuel requirements were assumed to be sufficient for transits and transfers in both phases of the scenario, and that fuel levels were not modeled for unit movement usage. This was critical for M&S tools like MANA that have no resource measure capabilities and fuel levels were adapted to be used as cargo levels.

D. ADVANCED SCENARIO

Non-hostile environments were ideal for operation but not without the need for tactical protection. The Advanced Scenario was based on PKO and Stability Operations that presented a battle space that had the potential for conflict within the region. Political tensions could present a possible SBE situation on the peninsula. The robust range of operations that were possible for the area used both an Advanced and Basic Scenario to measure MOPs key to evaluating SBE performances in a simulation.

T-craft is being developed with limited defense capability and is susceptible to attack from the air and surface. The Advanced Scenario introduced hostile threats, using the Basic Scenario as the starting point. Surface and air threats were inserted into the first phase to intercept T-craft in the first phase and during SBO transfer. Escort ships and aircraft were in direct response to T-craft’s lack of self defense capabilities. T-craft was escorted by varying number of warships. Escort’s areas of operations were focused on protecting T-craft in high threat regions (first phase) of the scenario. The second phase was relatively unprotected by escorts while T-craft commenced high-speed runs into the landing site.

1. Escort Requirements

There were three surface escorts modeled that were assigned to provide protection to the T-craft during transit and cargo transfer in and around the SBO area. This is where the hostile forces were generated and modeled to patrol. The escort forces were varied from a single escort up to a total of three during specific runs. The number of hostile forces was also varied from a single surface ship or aircraft up to a total of three surface and two aircraft threats. This design allowed for a robust design of experiments to be utilized in the simulating the model over multiple iteration. The varying of forces was used as a proof of concepts in the MANA simulation.

2. Interactions

The interactions of friendly escorts in the Advanced Scenario were modeled with superior capabilities. U.S. forces were assumed to have valid overwhelming capabilities compared to regional threats. The other interaction was threat areas of operations that limited hostile forces movement. The high threat was assumed to be a general approximation to where they originate from and not where they remain during simulation runs. This assumption was clearly observed in time-step models with agent based models.

3. Combat Survivability

Combat survivability was highly variable based on simulation settings. The critical aspect of measuring survivability was that it could be user defined and that the option was available. The Advanced Scenario introduced this MOP by adding hostile forces to the model. The assumption for combat survivability was that the damaged sustained by T-craft was probabilistic and not constant across M&S models. The standardization of probability tables or adjudication methods was not addressed in this research.

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VI. RESULTS ANALYSIS

This chapter presents simulation parameters of the six M&S tools used for modeling a SBE. The SBE Scenario was the basis for all models and was implemented in slightly different ways depending on the capabilities of the M&S tools used. The SBE Scenario issues, like collection of MOPs, modeled entity interactions, and graphical interfaces that were discussed in the previous chapter sections. This chapter listed the SBE Scenario model parameters for MANA, Pythagorus, NSS, and Simkit that were directly used in the course of my research. JCATS and Arena model results were used for comparison only, with no formal stating of model parameters. The M&S models created were functionally operational, with every effort made to present complete models. However, this research comes with a disclaimer that this was the best attempt by a master's degree student to build models for thesis work.

A. CONCEPTUAL REPRESENTATION

The reproduction of a SBE Scenario in a computer based model provided the evidence needed to evaluate each M&S tool used for modeling. In both types of simulations (time-step and next-event) the SBE Scenario was modeled in relatively similar ways. This included a SBE craft, escorts, and hostile forces. Variations in M&S tools did not allow for parameters of one model to be emulated exactly in every model, but did allow for a comparison across simulations of capabilities. Two models, MANA and Simkit, provided data for MOPs, with limited collection and analysis efforts.

Other M&S tools were merely observed to have the capability to produce MOPs. Because data collection was not the focus, it was assumed to be similar for the remaining simulations within the given types. This section details the differences in implementation of the SBE model.

1. Survivability of T-Craft

The survivability of T-craft in the SBE Scenario relied heavily on the scalability of each model. The adjudication "ilities" in the capability hierarchy was used to compare how models attain abilities varied in simulating the T-craft in the scenarios and if survivability was affected by differences in adjudication controls. Table 6 lists the similarities between M&S tools.

Capability Hierarchy	MANA	PYTH	JCATS	NSS	Simkit	Arena
Scalability						
Adjudication						
Attain ability						
Results						
Units of Measure	D*	S	S	S	S*	S*
MOP Translation	S*	S*	D	D	D	D
User Defined Data	S	S	S	D*	S	S
Battle Damage	S	S	S	S	S	S
Engagement (Access by the User)						
Probability Tables	S	S	D*	D*	S	S
Sensor & Weapon	S	S	D*	D*	S	S
Indirect Fire	S	S	D*	D*	S	S
Sensor Detection	S	S	D*	D*	S	S
Battle Damage	D	D	D	D	D	D

D – Difference in M&S tools used.

D* - Difference in M&S tools in same type.

S – Similar to other M&S tools used.

S* - Similar to other M&S tools in same type.

Table 6. Simulation Similarity Comparison.

2. Graphic Representation

There were three different representations of the SBE Scenario that were available across the types of simulations. The first was the classic sand box representation that JCATS and NSS depicted with blue water and brown colored land. This was the traditional look of M&S tools with which decision makers are probably most comfortable. JCATS and NSS also had model controls on the same screen as the battle space for the user to visualize adjustments. This was completely different from the other models like MANA and Pythagoras that offered separate control windows for agent attributes. The other difference in simulation with MANA and Pythagoras was that waypoints and other control options remained on the screen during iterations of the model. The last difference was that Simkit and Arena models did not offer any battle field depiction for users. These differences greatly affected capability hierarchy evaluations of the M&S tools.

3. Agent Based Modeling

Use of AABM was observed in four of the six simulations with Simkit and Arena having no capability. MANA, Pythagoras, JCATS, and NSS had AABM elements that enabled a stochastic process within the simulations. While JCATS and NSS used AABM algorithms for agent actions, MANA and Pythagoras had AABM built in to govern actions of their entities in the form of attribute settings. The SBE Scenario was modeled in both MANA and Pythagoras with similar settings but could not be duplicated. The attribute settings were used at a minimum to obtain results as the evidence that the different M&S tools did have the functionalities. MANA and Pythagoras models were different even though the modeled attributes for the T-craft entity were held relatively constant.

4. Deterministic Attributes

Deterministic attributes were meant to describe the probability based models. Simkit and Arena were models that had no agent elements but offered probabilistic results to the SBE Scenario. These models were limited to modeling the scenario in DES. The models were not deterministic by definition but could be repetitive over multiple iterations. The other differences with DES models were that the scenario focused on the processes within the scenario that the other four models were not capable of modeling or measuring. DES models modeled the delay interactions of the T-craft as it moved from one point or process to another. Simkit and Arena modeled the loading and unloading of T-craft in the SBO and the shore landings site, where other M&S tools inserted constant delays. DES's capability to stochastically model the interaction characteristics made the SBE Scenario narrower in scope compared to the full scenario models.

5. Simulation Start

Time and events were measured differently for both types of M&S. Time-step based models enabled MOPs like transit times and survivability where next-event based models isolated cargo transfers, which made the SBE Scenario, vary across M&S. The start of simulations was the only time in which the parameters were constant. DES models applied probabilities where designed, during every iteration. AABM applied probabilities when the agent selected the path to engage T-craft. The stochastic properties of the M&S tools caused the SBE Scenario to unfold rather quickly into multiple directions that could not be accounted for in data analysis. The M&S tools selected did provide a wide range of capabilities that were available.

B. TIME-STEP BASED

Time-step based models were centered on processing events that occurred at a given time interval. The updates were made to the simulation after a process cycle of all events had been calculated and was complete. Time-step based models processed all events at every time interval and sent updates as needed. Time-step enabled such models as AABM to recalculate search algorithms on demand in a stochastic environment. The process time grew as more complex events were added to the model.

1. Joint Conflict and Tactical Simulation

The model used in evaluating the capabilities of JCATS was created by LT Richard Jimenez, U.S. Navy, at the Naval Postgraduate School in the System Engineering department. Together with LT Jimenez, the SBE Scenario was the basis for implementation of his SBE Scenario into JCATS assessment that was referenced in my research. Additionally, his work was designed to provide a baseline model for the SBE Scenario to test concept of operations ideas that would be used in further data analysis. The Jimenez Scenario was based on the geographical east and west coast of the Korean peninsula and was modeled in a regional conflict setting. The bulk of the research was focused on T-craft’s survivability in the SBE Scenario; therefore, the Basic

Scenario was not simulated due to time constraints with iteration times of the JCATS model.

The major difference in the Jimenez scenario was the use of multiple T-craft entities within the simulation to increase survivability measurements. JCATS was well suited for theater level simulations at a high resolution. Modeling a single T-craft was not effective for JCATS. The T-craft was modeled with a higher resolution. Future work in JCATS could experiment with the resolution as a resource.

a. Parameters

The Jimenez Scenario used entities built from entities within the JCATS database. Air superiority was assumed in the scenario; hence, there were no air units modeled. Escort units were modeled as cruiser and destroyer platforms and SBO units were modeled as standard amphibious platforms. Extra considerations were taken because of JCATS modeling requirements to properly create a working model. The first assumption was that logistic support was available without special implementation. U.S. Naval auxiliary platforms were modeled into the Jimenez Scenario to provide fuel and cargo for transfer to the shore by T-craft from the JCATS database.

Hostile forces were modeled as foreign destroyer and coastal patrol platform vessels as well as ground forces. The ground conflict of the model was not discussed in this study because the measurements of the T-craft were collected prior to ground conflict occurred in the scenario and therefore did not affect interactions at sea. The initial settings of the Jimenez Scenario started with a sea state of 1 at night with a full moon, with weather effects at a minimal, and hostile force capabilities set to 10 to 15 percent less than Escorts. Figure 16 displays the Jimenez Scenario at simulations start.

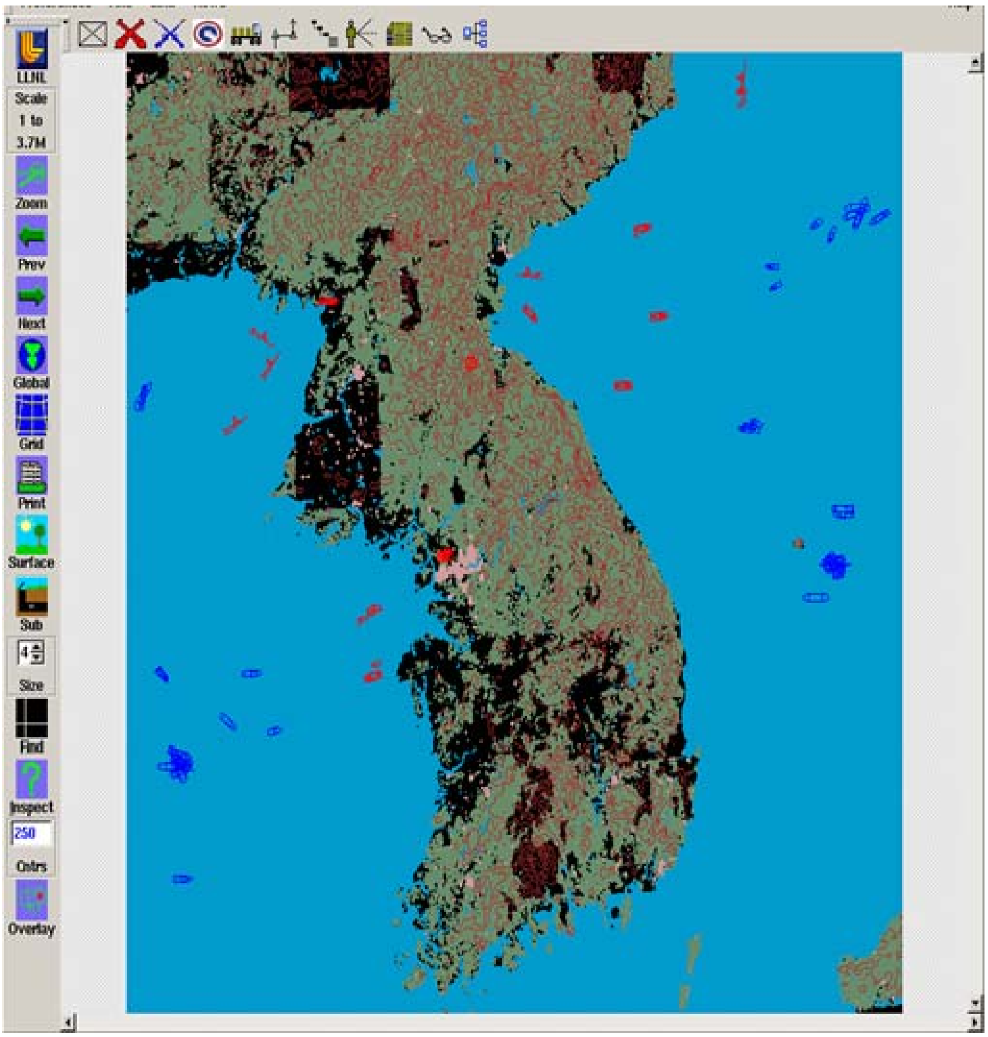


Figure 16. Jimenez Model Scenario at Simulation Start.

b. Design of Experiments

The Jimenez Scenario focused on employment of the joint force capability to project power from the sea to the shore. Attributes that were varied were environmental conditions and distance from shore landing sites. Table 7 illustrates the simulations configuration that was implemented by LT Jimenez.

Scenario / MOP	Scenario 1: East & West coast landings with 5 T-craft	Scenario 2: West coast landing with 10 T-craft
Mission Duration: Deploy 1 Marine Bridge within 8 to 10 hours	5 replications	5 replications
Survivability: 100 percent survivability of T-craft units	5 replications	5 replications

Table 7. JCATS Simulation Design of Experiments.

c. Data Analysis

The results of the Jimenez scenario showed the capability of JCATS to analyze the SBE scenario in a different way than other M&S tools used. The JCATS modeled the dual coastal approach of forces, which measured logistical elements automatically within the scenario. JCATS also represented environmental conditions differently than NSS that allowed for measurement of transit times. Specific data points were extracted on surface tactic implementation that were outside the scope of the Advanced Scenario but proved to show the flexibility of JCATS in the evaluation. Table 8 shows the results of the simulation runs conducted by LT Jimenez.

JCATS Simulation Results					
MOP	Scenario 1				Scenario 2
Mission Duration	West	East	West	East	West
Transit to shore landing site	*	*	7:58	9:05	9:48
Transit back to SBO	*	*	13:20	18:50	16:21
Survivability	West	East	West	East	West
Percent of T-craft survived complete runs	4 %	0 %	100 %	96 %	96 %
* No times recorded based on T-craft survival rate in transit to shore landing site.					

Table 8. JCATS Simulation Results.

2. Map Aware Non-Uniform Automata

MANA was developed by a New Zealand company Defense Technology Agency (DTA) in 2008 as an agent-based model with a bottom-up approach to warfare. DTA researched implications of chaos and complex theory in military applications and discovered that cellular automaton models produced results that were different that those of traditional models. The limitations of traditional models with areas like command and control, situational awareness (SA), and heterogeneous forces fell short of realistic results. The MANA program was designed to introduce certain functionalities to the current Complex Adaptive Systems (CAS) simulations. MANA integrates a memory map to allow for agents to have share SA and maneuver around the battle space (McIntosh, Anderson, & Lauren, 2007).

In 2000, MANA, with the Project Albert, a U.S. Marine Corp. research development program, introduced three agent-based models in succession: Irreducible Semi-Autonomous Adaptive Combat (ISAAC), Enhanced ISAAC Neural Simulation Tool (EINSTein), and Pythagoras (Bitinas, Henscheid, & Troung, 2003). The agent-based characteristics made MANA the most appealing of the AABM where results could be obtained. The bulk of the model settings were in the attributes of each entity. Event triggers were also implemented to assist in interactions of units to obtain the proper MOPs. The Advanced Scenario attempted to reflect controlling sea lanes of communications by defending against a hostile threat with varying forces. The sea lanes were limited to waypoints in the first phase of the scenario.

There were many assumptions in this scenario that allowed the SBE to be modeled. The fuel function in this study was used to model cargo transfer from the T-craft entity to landing sites. Refueling and logistic support were assumed to be adequate and not measured. The Advanced Scenario did not actively use coordinated tactics by either sides. The use of MANA produced stochastic results to answer survivability questions posed by scenario objectives. MANA has a number of available parameters like preference settings towards enemy and friendly units that were adjustable for modeling realistic interactions.

Resolution was an important aspect in MANA for MOP studies where cargo was the focus of a study. This research used MANA because of its resolution ability of combat forces. The Advanced Scenario was designed with opposing forces and one T-craft transiting to the SBO area. Future studies many be modeled with multiple SBE being used to transfer cargo. The last assumption that was made was the modeled capabilities of forces. The Scenarios depicted U.S. Naval Forces as escort elements and a generic third world naval force as the opposing force. All opposing forces were modeled with a limited offensive capability. Escort forces were modeled with a 2:1 advantage in the Advanced Scenario.

The results of the Basic Scenario were as expected; however, the Advanced Scenario introduced a higher degree of stochastic processes and did not clearly provide statistical MOPs for survivability. The AABM elements appeared to contain more randomness that could be accounted for in attribute settings. Another MOP was the number of escorts needed for T-craft defense. Based on the irregular results of the survivability measurement, the number of escorts did not correlate to the increase in opposing forces. A future consideration could be convoy tactics to ensure that the transfer of cargo is sufficient. The protection of cargo ships in naval history could have had applications in this scenario where the amount of supplies delivered was a measured factor.

a. Parameters

The scenario parameters in the MANA model are depicted in the following section. There were six attributes and one general setting tab within MANA that were used to set parameters for both the Basic and Advanced Scenarios. The tabs were Battlefield settings, General, Personality, Ranges, Sensors, Weapons, and Algorithm. Figures 25 through 43 show the SBE model set up in the MANA environment at the end of the chapter. Figure 17 is the generic model set up for the battle space configuration and a depiction of the Advanced Scenario. The model dimensions were configured to match the approximate area span of the geographical location; the scenario was based on a 500 x 500 nm area. The terrain parameter was kept as a simple line of sight model that provided the most general mode for evaluation purposes. The remaining settings were left as default.

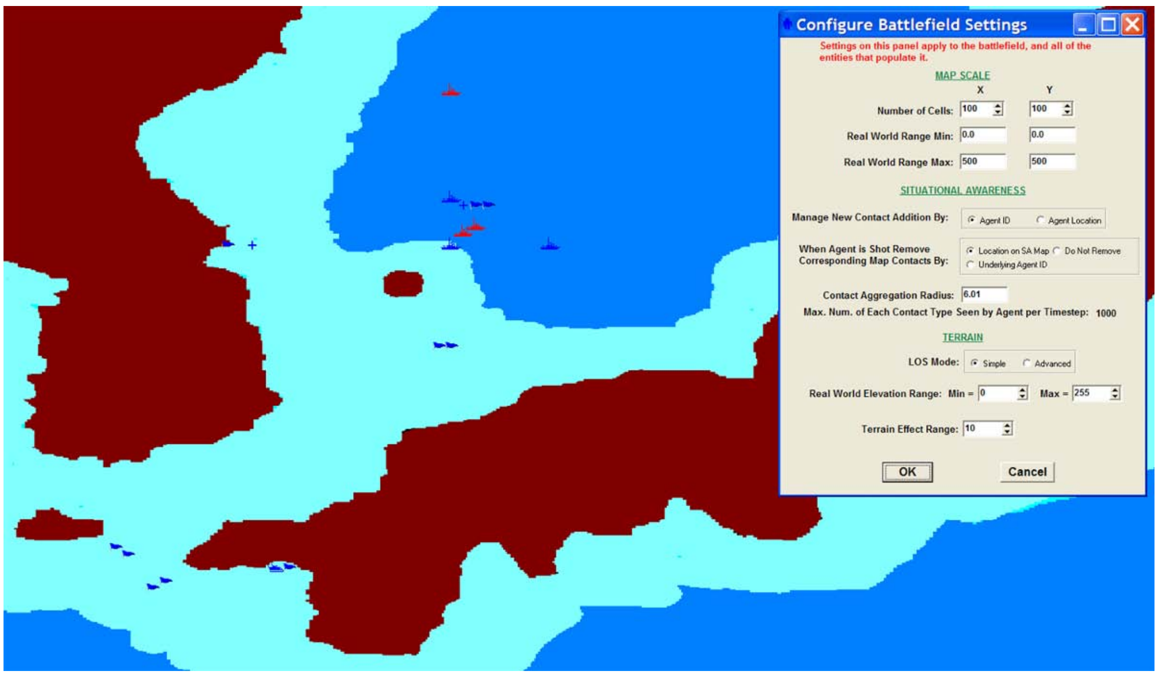


Figure 17. MANA Battlefield Settings.

The first unit instance defined in the Scenarios was the T-craft. Figures 25 through 29 show T-craft settings used in the Basic and Advance Scenarios. The number of T-craft units remained constant at one for all simulation runs. T-craft waypoint flags are seen in Figure 17. T-craft weapons tab was not provided due to the INP requirements that do not call for defense capabilities. The weapons tab had Master Enable deselected.

The second unit instance defined was the escort forces for T-craft's transit to the SBO in the first phase. The number of escort forces varied according to the design of experiments. The attribute settings were kept simple as well for the same reasons. Figures 30 through 33 show the escort parameter settings that were the same for each individual escort unit. The general configuration settings for escort units used the side name as Escorts, Squad #3, and varied the number of agents. The initial orientation was designed to remain constant for all entities.

The third unit instance was hostile surface forces, which are represented in Figures 34 through 38. The same general configuration was used as Escorts with the naming of hostile forces. The fourth unit instance was a hostile air threat that was modeled with considerable advanced capabilities over surface forces. This advantage was represented by increased speed capability. Figures 39 through 43 show the hostile air threat model parameters. Squad # 6 was used and the side options were selected to match those of the hostile surface forces. The last parameter that was selected was the simulation stopping criteria. This parameter was set to T-craft's end goal.

b. Design of Experiments

The solution space for the model was large and required extensive analysis of data to examine all possible combinations. According to Cioppa (2002), the concept of Latin hypercubes with orthogonality improved space filling properties of experimental design. The application of nearly orthogonal Latin hypercubes (NOLH) reduced experimental iterations to find key correlation elements of a simulation. The NOLH method was applied to decrease the number of iterations needed to determine relations between the three MOPs.

There were three factors in the Basic Scenario that were varied. The first variable was speed of the T-craft which was represented in MANA as an arbitrary factor within the model. MANA provided for the selection of two speeds for the T-craft entity. The second speed was double the first to show the capability T-craft had to achieve in capability 3. The additional factor was the number of transfer trips scripted to the shore with a maximum of three for the T-craft to delivery cargo in the second phase. Table 9 shows the NOLH design employed for the Basic Scenario. A single variable setting or trail was iterated for 50 replications.

Basic Scenario				
First Phase		Second Phase		
Speed	Cargo Rate	Speed	Cargo Rate	Trips to Shore
200/100	-20	200/100	-20	3
200/100	-10	200/100	-10	3
200/100	-10	200/100	-10	1
200/100	-15	200/100	-15	2
400/400	-20	400/400	-20	2
400/400	-10	400/400	-10	2
400/400	-10	400/400	-10	3
400/400	-20	400/400	-20	3
400/400	-15	400/400	-15	2
400/400	-5	400/400	-5	1
400/400	-15	400/400	-15	1
400/400	-15	400/400	-15	3
400/400	-10	400/400	-10	2
200/100	-5	200/100	-5	2
200/100	-15	200/100	-15	2
200/100	-15	200/100	-15	1
200/100	-5	200/100	-5	2

Table 9. NOLH Design of Experiments for Basic Scenario.

The Advanced Scenario introduced varying numbers of escort and opposing forces to T-craft’s transit. In an effort to counter the opposing forces, escort ships were positioned ahead of T-craft’s transit, which allowed for protection of the transit, as shown in Figure 17. Expanding on Table 9, Table 10 shows the factors used to simulate the SBE model in both phases.

Advanced Scenario					
Speed	**Cargo rate**	**Trips to shore**	**Escorts**	**Surface Threats**	**Air Threats**
200/100	-20	3	2	2	2
200/100	-10	3	2	1	1
200/100	-10	1	2	2	2
200/100	-15	2	3	2	1
400/400	-20	2	1	2	1
400/400	-10	2	3	1	2
400/400	-10	3	2	3	1
400/400	-20	3	3	3	2
400/400	-15	2	2	2	2
400/400	-5	1	2	3	1
400/400	-15	1	2	3	2
400/400	-15	3	3	2	1
400/400	-10	2	1	2	2
200/100	-5	2	3	2	2
200/100	-15	2	1	3	1
200/100	-15	1	2	1	2
200/100	-5	2	1	1	1

Table 10. NOLH Design of Experiments for Advanced Scenario.

The representation of transferred cargo was modeled in MANA by using triggers that simulated the increase of goods at the shore landing site. The shore landing site enabled a trigger when T-craft was within range and triggered the commencement of cargo transfer. My Fuel Usage Rate simulated large amounts of cargo transfer. These parameters were in shown in Ranges Settings when the Fuel Out trigger was selected.

c. Expected Results

The expected results in the Basic Scenario were predicted to be straight forward measuring the statistical outcomes of transit times and cargo transfer. The survivability of T-craft in the Advance Scenario was affected by the increased stochastic processes. The third measured value was the number of escorts needed to provide protection to the T-craft unit. This was proportional to the number of hostile forces in the area.

d. Data Analysis

MANA provided MOPs in generic terms, which allowed for a capabilities evaluation of the simulation to be made. The representations of time and cargo values did allow for a translation to various units and measures. The generic units were reported to illustrate the versatility of the simulation for combat models. The survivability factor of T-craft in the Advanced Scenario measured a probability of survival. The results were provided here to illustrate the capability of MANA to yield MOPs.

The following results were obtained from the Basic Scenario and list the average transits times with varied number of deliveries based on the design of experiments. The average amount of cargo transferred to the shore site was listed by varied rate transfers. Again, all trials conducted in MANA were replicated 50 times for statistical analysis. Table 11 shows the results from the Basic Scenario.

Basic Scenario Results			
Speed	**Cargo Rate**	**Time ± SD (sec)**	**Cargo ± SD (gal)**
200/100	5 (3 Trips)	457.84 ± 8.29	398.60 ± 177.27
200/100	10 (3 Trips)	445.38 ± 7.30	1173 ± 316.74
200/100	20 (3 Trips)	446.38 ± 8.48	2295.2 ± 780.76
400/100	10 (3 Trips)	200.04 ± 4.78	465.0 ± 148.07
400/100	15 (3 Trips)	201.20 ± 5.77	702.10 ± 253.51
400/100	20 (3 Trips)	200.5 ± 4.81	893.6 ± 253.51
200/100	5 (2 Trips)	347.76 ± 5.04	364.4 ± 110.3
200/100	5 (2 Trips)	336.4 ± 4.90	328.70 ± 108.78
200/100	15 (2 Trips)	338.36 ± 5.21	1001.4 ± 331.11
400/100	10 (2 Trips)	160.82 ± 3.55	295.8 ± 117.21
400/100	10 (2 Trips)	167.76 ± 4.52	325.2 ± 126.59
400/100	15 (2 Trips)	157.72 ± 3.50	441.6 ± 180.87
400/100	20 (2 Trips)	164.1 ± 3.94	558.0 ± 168.85
200/100	10 (1 Trips)	283.28 ± 13.81	331.2 ± 131.59
200/100	15 (1 Trips)	280.84 ± 13.17	542.4 ± 291.47
400/100	5 (1 Trips)	136.32 ± 1.63	97.6 ± 33.12
400/100	15 (1 Trips)	134.96 ± 2.09	307.20 ± 138.15

Table 11. Basic Scenario Results.

Table 12 shows the results from the Advanced Scenario which lists the distribution of survival percent for T-craft in the given replications. The distribution of Surface and Air threats represented the number of entities that were built into the scenario run for each category.

Advanced Scenario Results					
Speed	**Cargo Rate**	**Escorts**	**SURF Threat**	**AIR Threat**	**Survive %**
200/100	20	3	2	2	62
200/100	10	3	2	1	48
200/100	10	1	2	2	52
200/100	15	2	3	2	48
400/100	20	2	1	2	80
400/100	10	2	3	1	54
400/100	10	3	2	3	68
400/100	20	3	3	3	70
400/100	15	2	2	2	74
400/100	5	1	2	3	64
400/100	15	1	2	3	84
400/100	15	3	3	2	50
400/100	10	2	1	2	90
200/100	5	2	3	2	42
200/100	15	2	1	3	76
200/100	15	1	2	1	54
200/100	5	1	1	1	64

Table 12. Basic Scenario Results.

The mean probability of survival for T-craft was 63.53 $\pm$ 14.06%, which was less than 80 percent of an acceptable survivability rate.

e. Select Capabilities

Use of the MANA program showed that it was possible for the SBE Scenario to be represented in a computer-based model. MANA provided a set of characteristics and parameters in the form of personal settings that were used for modeling the T-craft to explore the capabilities that were desired for a SBE. Desired results were obtained from fairly simple agent settings, which made it user friendly. The graphical representation provided a powerful capability for visualization of the battle space. MANA was a stand-alone agent-based M&S tool that could be used in combination with a federation, for future T-craft simulation.

MANA was useful for collect data from the model. The data obtained from the replications of Scenarios were directly measured to determine statistical information. The results were used to show the presence of an accuracy functionality. The Basic Scenario results indicated an apparent relationship between the increased transfer rate and speed. One limitation to the MANA results was that for 11 of the 17 measurements, there was a large amount of variability among the cargo transfer time, such that the standard deviation values were as large as half of the mean values. Typically, a modest amount of variability would be indicated by a standard deviation that is less than 20 percent of the mean value.

MANA is not an open source program. A disadvantage of this was that documentation was not available to users. The MANA user manual was available within the downloaded source code, but was outdated for both MANA version 4 and version 5. There were several display and control settings that did match and were not explained in the user manual. This was only a minor inconvenience.

One difficulty to building the SBE scenarios was the determination of weapons effectiveness and defensives for forces that allowed for favorable exchange rates, while applied red force movements were realistic. The other difficulty was modeled T-craft capabilities had to be maintained to conform to desired ONR requirements. The T-craft speed was overly extended to illustrate the extreme advantage it had over conventional forces. This was done by setting T-craft’s speed to double that of hostile forces.

One disadvantage to the usability MANA was the inability to transfer created scenarios to other models. The TCP and UDP output streams were useful for combining simulation but did not allow analysis data to be collected in an effective way. In the Basic Scenario cargo measurement were made from multiple Excel spreadsheet entries taken from separate files across the multiple run output files. This was time consuming and not useful for quick and rapid analysis of key MOPs.

3. Pythagoras

Pythagoras was developed in conjunction with Project Albert in 2000 as previously discussed, in an attempt to model human factors in simulation environments. It introduced capabilities like soft decision rules for agents, dynamic "sidedness," alterations to behavior during run time, and nonlethal weapons (Bitinas, Henscheid, & Troung, 2003). A design criterion for Pythagoras was the ability to run the simulation in batch mode for data farming. The usability of Pythagoras extended over platforms because of its JAVA based software. It was offered soft decision rules that were adjustable by the users to input variation in agent actions. The agent’s processes did review their actions in a predetermined order, which allowed for some advantages and disadvantages to the agent interactions.

Pythagoras was included in this research for comparison of multiple AABM. It has differences that are discussed in this section. Replications of the SBE scenario were not needed for this model based on the similarity with MANA. Simulation results were predicted to match those of MANA. The SBE Scenario modeled was sufficient for comparison of the M&S capabilities in this research.

a. Parameters

The Pythagorus modeled scenario parameters are depicted in the following section. There were multiple attribute tabs that were used to set parameters for both the Basic and Advanced Scenarios. The tabs were Overview, Terrain, Weapon, "Sideness,” Sensor, Comms, Agent, Attribute Changer, Alternate Behavior, and MOE. Figures 44 through 57 show the SBE model basic model set up in the Pythagoras environment.

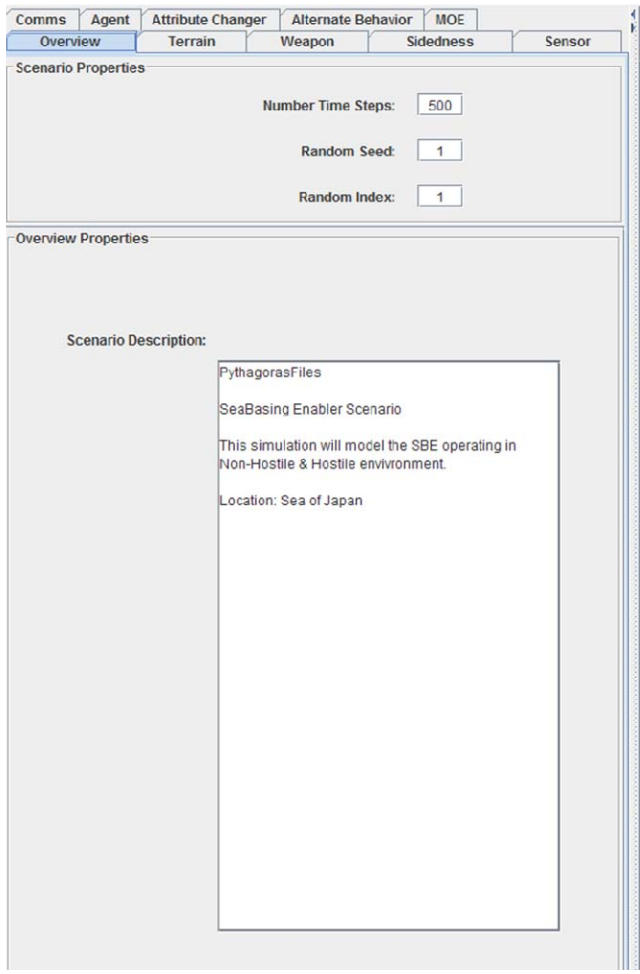


Figure 18. Pythagoras Model Overview.

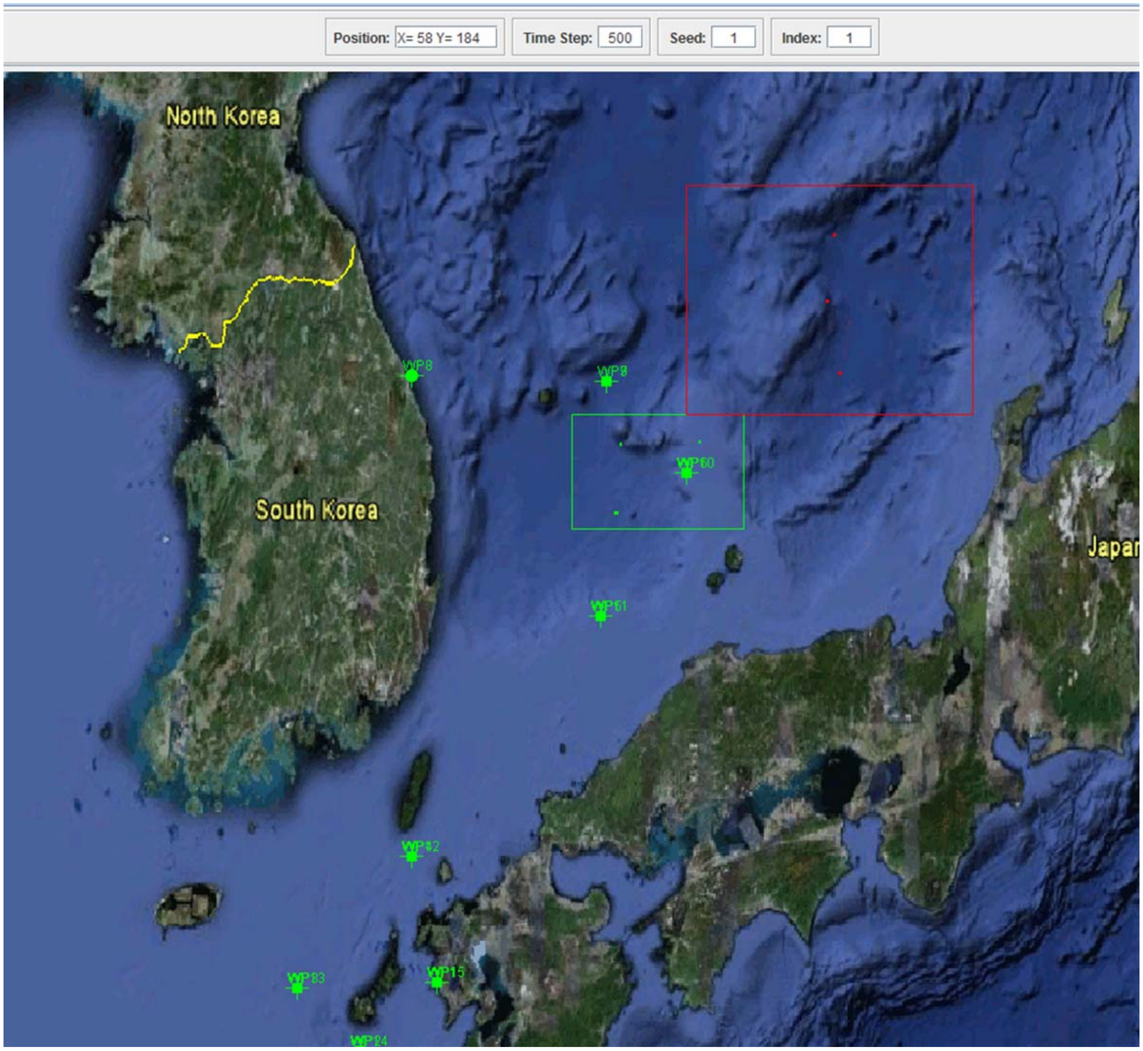
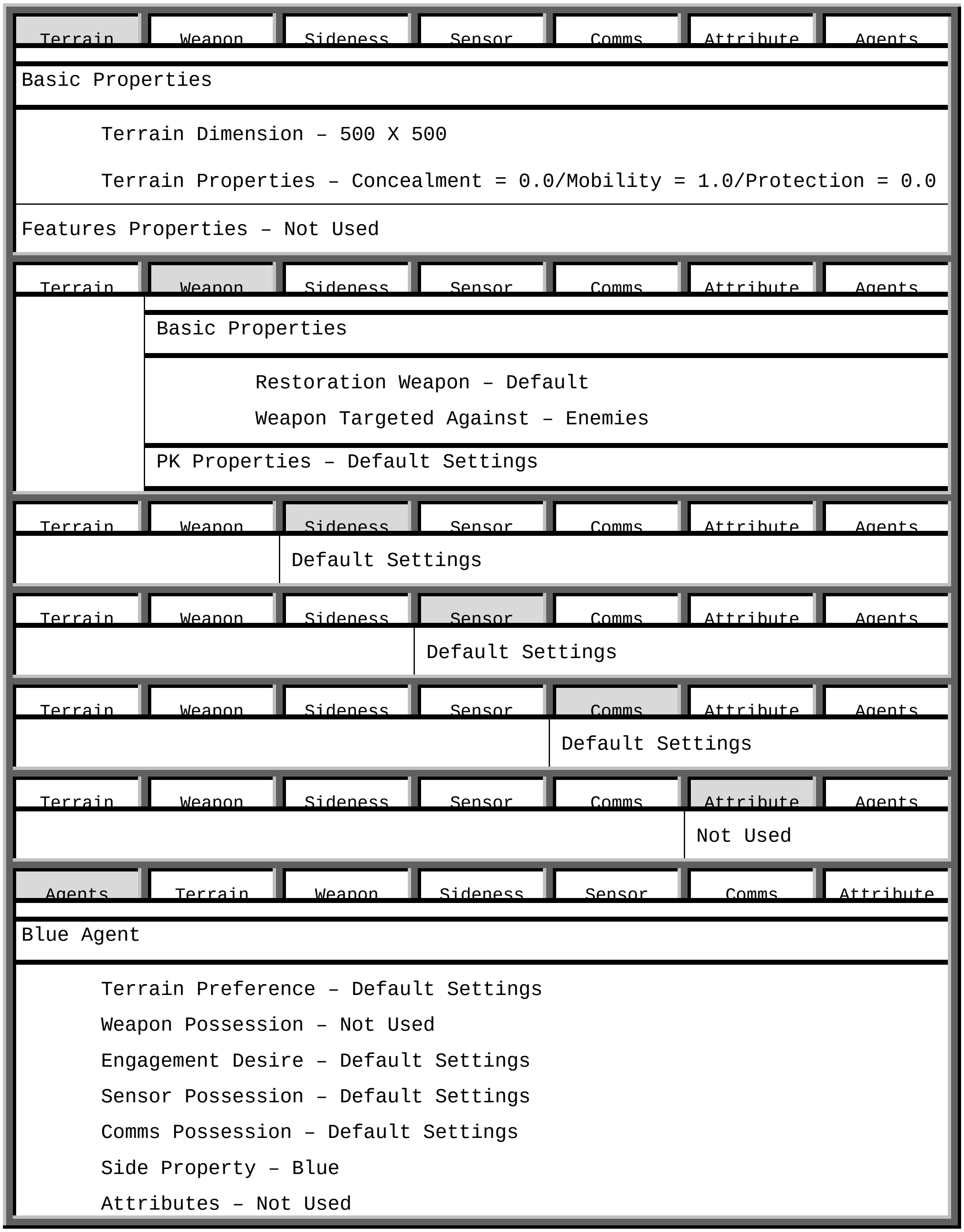


Figure 19. Pythagoras Map Overview.

There were three unit instances used in the Pythagoras model. The first was the blue agent that represented T-craft. The blue agent force parameters settings are shown in Figures 44 through 48. The second instance was red agent forces that are found in Figures 49 through 51. Shore, cargo, and MOE parameters are shown in Figures 52 through 57. These figures showed specific changes made to the default settings. A majority of the instance settings were similar for all units and remained constant. Figure 20 lists the minor settings that were not shown in the basic model figures and remain constant.



Resources   Fuel/Resource Y/Resource Z – Not Used Triggers – Detect Friend End of Run MOE - Default Settings
Red Agent
Other Properties – Default Settings Terrain Preference – Default Settings Weapon Possession – Basic Engagement Desire – Default Settings Sensor Possession – Universal Comms Possession – Not Used Side Property – Red Attributes – Not Used Resources – Not Used Triggers – Not Used End of Run MOE - Default Settings
Shore Agent
Other Properties – Default Settings Terrain Preference – Default Settings Weapon Possession – Not Used Engagement Desire – Default Settings Sensor Possession – Default Settings Comms Possession – Default Settings Side Property – Blue Attributes – Not Used Resources   Fuel/Resource Y/Resource Z – Not Used Triggers – Detect Friend End of Run MOE - Default Settings

Figure 20. Pythagoras Model Parameters.

b. Differences in Pythagoras

The differences between Pythagoras and MANA were not as dramatic as the differences between JCATS and Pythagoras. The first difference was the implementation of fuzzy logic or soft decision rules for agent actions. The concept of applied mathematics to decision making was used to better model the human factors as discussed above. The second difference was the representation of the battle space in Pythagoras, which lacked unit icons. This did not affect the simulation capabilities.

The third difference was use of the DOS command line to run the simulation. This took away the usability of the simulation and forced uncommon program language on novice users. The fourth difference was outputted data format. Where MANA produces Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) packets, Pythagoras used Extensible Markup Language to output data and scenario information. These methods both have their place in the M&S technology world and were accessible.

The fifth difference was the addition of resources that enabled measurements of multiple elements in the model. The fuel representation in MANA limited it to a single measurement where Pythagoras expanded the idea of MOPs and MOEs. The sixth difference addressed the capability of Pythagoras to change entity "sideness" of an agent if altered in the simulation. This option was not engineered into MANA and provided a more robust ability to model scenarios other than conventional warfare directly that could impact SBE Scenarios.

c. *Expected Results*

The SBE Scenario modeled in Pythagoras was not iterated for analysis purposes due to the amount of time needed for simulation iterations. It was also determined from single run iterations that the results obtained were similar to those of MANA and that multiple simulation replications were not required for evaluation the model. The limited number of simulations conducted showed similar survivability rates, transit times, and cargo transfers to those obtained in MANA. There were two additional results that were observed in Pythagoras that increased its scalability. The first was Battle Damage Assessment results that were recorded for simulation runs. The second was the recorded changes to agent attributes.

C. NEXT-EVENT BASED

Next-event or discrete event based models are based on the sequential events that happen within the simulation vice a given time interval. Next-event based models are notionally represented by event graphs that depict the elements, variables, and relationships of the simulation. The processing power of a next-event simulation is in the future event list and that no event can happen simultaneously with another. This makes DES more accurate than time-step based models. All models used have these basic elements and operate on these principles (Buss, 2002).

1. Naval Simulation System

NSS was developed by the Operations Analysis and Simulation Sciences (OASiS) Group of the Metron

Incorporation under Space and Naval Warfare Systems Command (SPAWAR) direction (PD-15). NSS is a model that utilizes a classified database in most cases and is property of the U.S. Government. NSS has had limited testing for VV&A due to lack of funding, however, contractor support and training is available upon request. NSS is an object orientated Monte Carlo M&S tool that provides up to theater level scenario application. It has been used in fleet exercises as well as war gaming to develop courses of actions for naval commands. NSS is designed to be use at the staff level (Metron, 2007).

NSS's capability to model the full spectrum of maritime, joint, and combined military operations made it well suited for the SBE Scenario. Similar to MANA, T-craft's track was used to model the sea lanes of communication. There were two assumptions made in modeling the SBE Scenario in NSS: (1) Monte Carlo features were sufficient to have results matched to AABM that enabled for stochastic processes. Initial simulation iterations of the Advance Scenario revealed stochastic survivability results. This was determined to fit into the capability hierarchy. (2) Logistical support was assumed to be present. NSS had the capability of initializing logistical support to units. The scenarios were simulated without the use of logistical functions. Logistical options were not used to maintain consistency among models used. Figure 21 presents the Basic Scenario map viewed in the input editor.

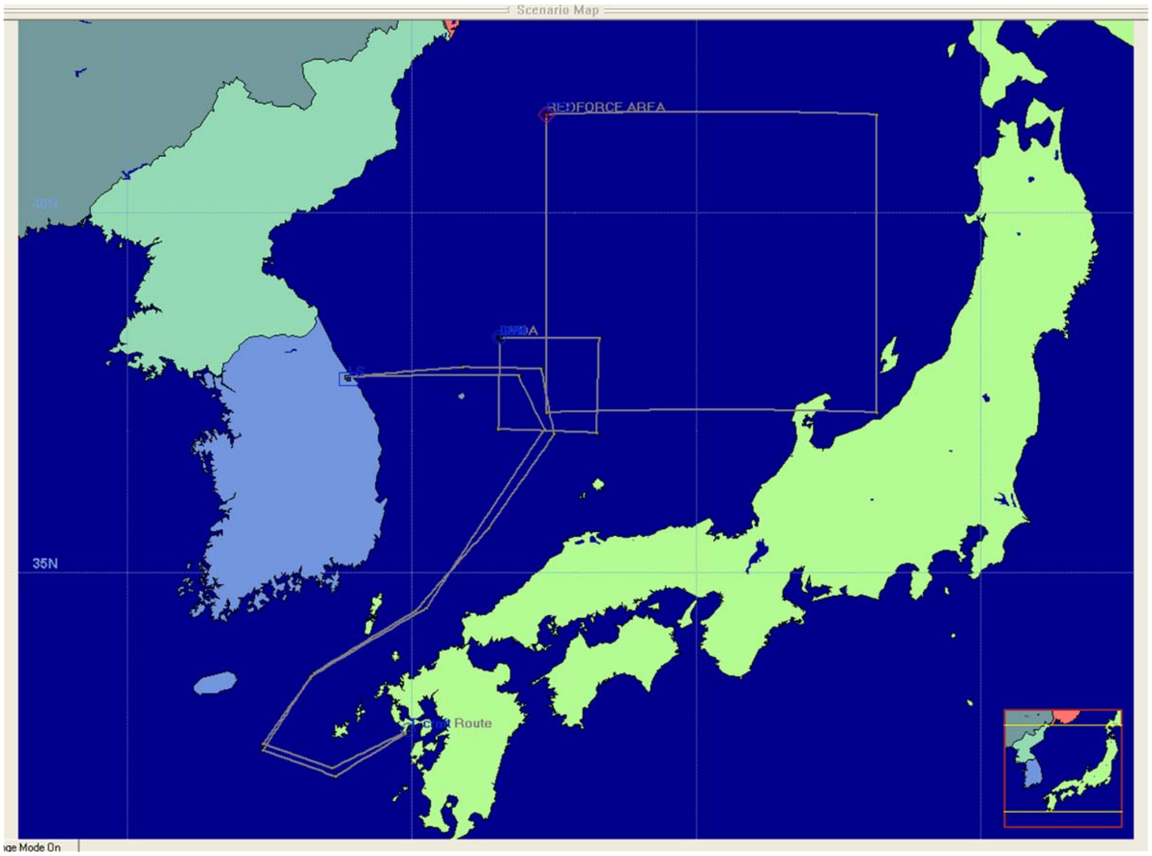


Figure 21. NSS Map Overview.

Analysis of the NSS simulation replications were not preformed on this model. There were multiple runs conducted on the Basic and Advanced Scenario for evaluation purposes due to time restriction. NSS has been an accredited M&S tool and extensively used by Commander Pacific Fleet, SPAWAR, naval air commands and operation offices. Scenario analysis in NSS was determined to not be needed, based on its accreditation.

a. Parameters

The NSS model was created through the use of five selection tabs in the input editor. The five tabs controlled forces, C2 plans, ops plans, mission plans, and track/region editor. The unit instances were retrieved from the NSS database their actions were altered in accordance with the SBE Scenario. Unit instance settings for escort forces and T-craft are listed in Figures 58 through 61, and hostile forces are contained in Figures 62 through 66. Figures 67 through 68 list blue force parameters used in the Advanced Scenario. The Basic Scenario was modeled with same parameters as the Advanced Scenario with the exception of escort and hostile forces, where red forces are shown in Figures 61 and 65 through 66. There were controls like communication networks and warfare commander plans that attempted to persuade entity actions. The default settings were retained for sensor, signature, and weapons for unit instances.

The commander warfare plans selection tabs are shown in Figures 69 and 70. These figures grouped the operational, C2, and mission settings in one figure to show the default settings for all controls. Blue and red force settings were identical and based on the instance generated from the NSS database. One variation from default settings was the all unit check box was selected in the communications tab to assist in scenario speed. The time duration of the SBE Scenario was entered as 9 hours to facilitate sufficient time for T-craft to complete a successful mission. The Advanced Scenario incorporated hostile air forces depicted as MIG 23s and SU-24s and introduced the design element used in the other M&S tools of hostile air threats.

b. Expected Results

NSS was determined to yield two of the three MOPs based on limited runs performed. The MOE selection was limited to model defined parameters that were not flexible for SBE Scenarios. Transit time of T-craft was presented in the application of MOE to the scenario; survivability was selected as a second MOP to be recorded. The third MOP was not measurable in NSS due to the lack of functionality in entities to carry and transfer cargo. The MOP did not fit into the logistical support functionality. A functionality that was added to MOP selection that was not initially considered was the use of confidence intervals. This was integrated into the accuracy functionality under replication.

2. Simkit

Simkit was created at the NPS in 1996 by professor Arnold Buss and graduate student Kirk Stork to represent sensor oriented objects in a model and simulation environment to better model processes that provided alternatives to expense processes. The concept of discrete event simulation (DES) was centered on modeled abstract objects in a computer program that used event graph logic. Simkit was originally implemented in the Java computer language by Sun Microsystems. DES can widely be applied to other computer languages, but the Basic and Advanced Scenario were both written in Java based on the reusability of predefined object classes in the Simkit library at the NPS (Stork, 1996). The user interface was at the

Application Programmer Interface (API) level that required extensive modeling and use of the libraries (Buss, 2002).

The advantage of modeling abstract objects in DES was the use of the Listener Event Graph Objects (LEGO) component framework that enabled T-craft to be specifically modeled and not the scenario processes. Cargo transfer and logistical processes were modeled in extensive detail to account for all aspects of the SBE Scenario. This allowed for powerful modeling of the SBE Scenario processes, for example, all three MOPs were implemented and measured with more accuracy than time-step based models (Buss, 2002). Simkit has a wide variety of uses and the NPS studies that have used Simkit included port usage, sonar process, and security issue models to show the versatility of the M&S tool.

Deterministic and stochastic models depend on input parameters. The use of an API allowed for the use of random processes and slightly stochastic models to be generated for the SBE Scenarios. The reason for this was the pseudo random nature of the variant generation factory within Simkit. The advantage of using a Java based program was that a robust statistical analysis capability was available. The data analysis tools embedded in Simkit produced user defined analyzed results from multiple simulation runs at the end of run time.

Figures 22 and 23 are the simple flow diagrams that represent the Basic and Advanced Scenario implemented with the Simkit API. The detailed event graphs for the Simkit model are shown in Figures 71 through 77. The detailed model illustrates the conditions and parameters used to model the SBE Scenario. The model represented the interaction stations as states that indicated to the T-craft platform object what action to perform. MOPs were state variables that were linked to the platform objects and used property change functions to account for the change over a single iteration and not over the total number of replications.

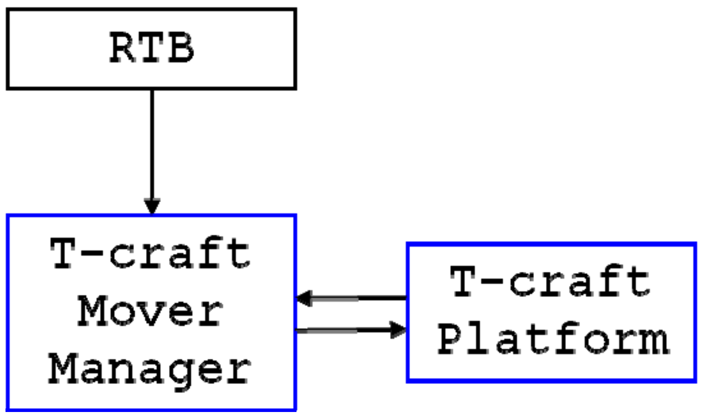


Figure 22. Event Graph for Basic Scenario.

There were two assumptions used in the T-craft Mover Manager. The first assumption was that T-craft proceed back to debarkation point and not repaired once the mission was successful. The reality was that T-craft could stop for repairs at the SBO, but was not modeled to in Simkit. Time limitations did not allow for debugging and revision of the code. The second assumption was that T-craft departed the SBO with cargo greater than or equal to the minimum load requirement of the scenarios. This was defined in the parameters section and required for T-craft to transit to the shore landing site when cargo was needed for the mission objective. Real-world application of T-craft could allow transit to the shore with any amount of cargo.

In addition to the above assumptions there was a repair facility implemented in the Advanced Scenario. The repair facility was located in the SBO state in an attempt to model the SBO capability for repairs of T-craft during mission execution. An Arena model created by Mary McDonald, a research associate of the SEED center at the NPS, was the basis for evaluation of the Arena M&S tool used as the sixth model for evaluation. Other work included a SBE model that was created by Major Sebastian Scheibe from the Germany Army at the NPS. The purpose of the Scheibe model was to determine critical capabilities of T-craft listed in BAA (05-020). One major MOP that Major Scheibe concentrated on was survivability when a repair factor was introduced to an Arena model (Scheibe, 2010). This was the basis for the added repair station in the Advanced Scenario. Figure 23 shows the Advanced Scenario modeled in Simkit.

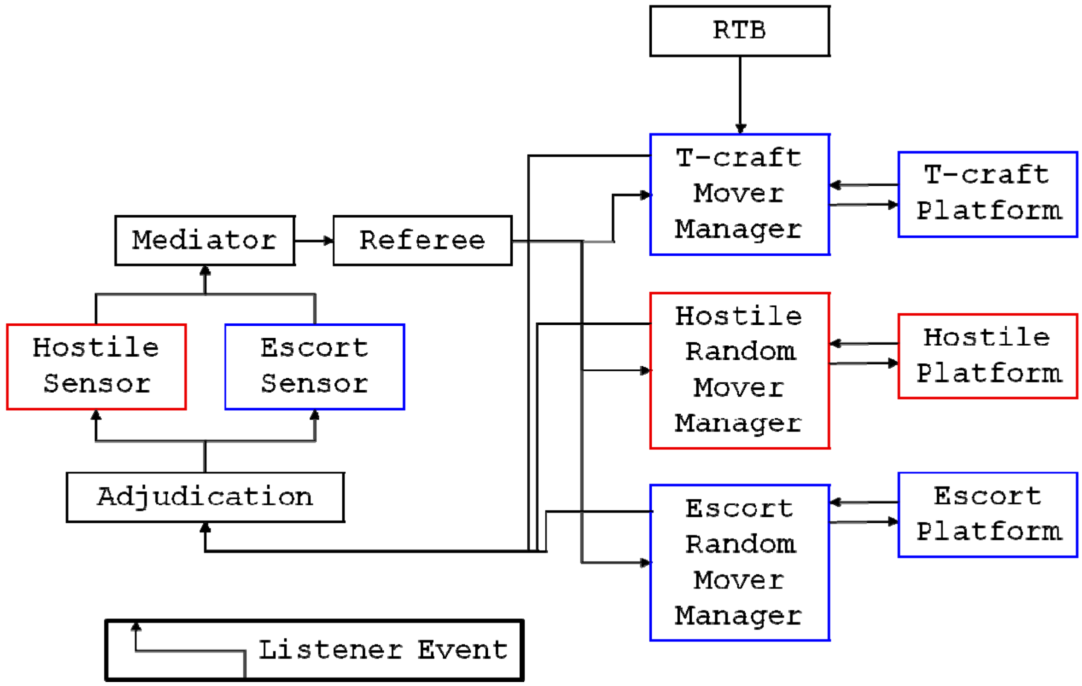


Figure 23. Event Graph for Advanced Scenario.

a. *Parameters*

There were two types of variables used in Simkit that were used as measurements in the scenario models. The first was a set of State variables that were defined as variables that change at least once during simulation. Table 13 lists the state variables used in the Basic and Advanced Scenario. The variables represented states and input parameters.

State Variables		
Label	Definition	Value
C	Cargo carried in T-craft (Tons)	< 750
D	Damage taken by T-craft	(0 – 1)
S	State Variable (Debarkation, SBO, Shore)	2D Point
X	Survivability rate of T-craft	(0 | 1)
SC	Shore landing site Cargo received (Tons)	ST
M	Mission status Flag	(0 | 1)
t_X	Delay Time for transit time of T-craft	Triangle (0, 90, 180)
t_L	Delay Time for loading time of T-craft	Exp (λ)
t_R	Delay Time for repair time of T-craft	Exp (λ)
t_U	Delay Time for unloading time of T-craft	Exp (λ)
t_D	Delay Time for detection time of hostile sensor	Triangle (0, 10, 20)
t_M	Delay Time for movement time of unit	Un (100, 1).
t_E	Delay Time for End of Service	waitDelay = 1.0
t_V	Delay Time for Entering Range	N (10, 1)
t_G	Delay Time for Exit Range	N (10, 1)
u_C	Random amount of cargo loaded on to T-craft	U ~ Un(0,750)

Table 13. Simkit State Variables.

The second type of variable is the set of Parameter variables. The Parameters variables represented constant values in scenario used to determine damage and cargo thresholds. Table 14 lists the Parameters used in the Basic and Advanced Scenario. The damage threshold (DT) was used to determine when entities reached critical points of sustained damage. The repair threshold (RT) indicated the need for repairs based on sustained damaged. Along with threshold settings, there were queues size parameters, which defined t-craft force levels, repair facilities, and shore landing sites. Shore landing site (SL), repair facility (R), and loading stations (L) were set to one. The last parameter used was a two dimensional point vector parameter that represented a geo-graphical location in the environment that was used for movement and modeled physics.

Parameters		
Label	Definition	Value
MinLD	Minimum Load for T-craft (Tons)	min = 300
MaxLD	Maximum Load for T-craft (Tons)	max <= 750
DT	Damage threshold	dt = 0.8
RT	Repair Threshold	rt = 0.3
CT	Cargo Threshold	ct = 750
SL	Number of shore landing sites	1
R	Number of Repair Facilities	1
L	Number of Loading Facilities	1
UL	Number of Unloading Facilities	1
ST	Shore landing site cargo threshold	2000
G	Debarkation Point	2D Point
H	SBO Point	2D Point
I	Shore landing site Point	2D Point

Table 14. Simkit Parameters.

The detailed Simkit model depicted the algorithm used for logic problem solving that made the T-craft model object change states and transfer cargo to the shore landing site. This was fundamentally different that AABM that used waypoints to direct motion and actions of agents. The DES relied heavily on user defined methods to guide the course of actions for the scenario. The methods used to create randomness in the simulation were distributions curves.

There are three basic distributions that were used in Simkit. The first distribution was a Uniform (Un) that provided random motion of hostile and escorts forces in the defined battle space of the SeaBase. Time-step model's random movement was arbitrarily to an image, where DES required correct physical interactions and placement. Uniform distributions were used to model the randomness of a ship's movement in the operation area (t_M) and for cargo load rates (u_C).

The second was a Triangle distribution that was based on the knowledge of limits to the distribution but no evidence recorded to validate. Given the transit time results from the MANA simulation, a rough gage of the time needed to transit the distance in the scenario was taken from Table 13 to define transit (t_X), enter (t_V), and exit range (t_G) times. The last was an Exponential (Exp) distribution that described rates of a process. The distribution selected for loading, unloading, and repair delays can be based on historical logistic mean times of completion. Generic place holders were used for the Simkit model.

b. Design of Experiments

The iteration of the Simkit model over a design space was based on the need to test the model prior to extensive simulation runs in the Simkit environment and to determine the number of runs needed that would produce sufficient trials for statistical results. Event graph models allowed for the user to hand simulate the model. This function was used to test the range of the model prior to replication. It also allowed for debugging of the algorithms prior to code generation. The idea behind the hand simulation was to test the model for all possible states and situation T-craft transitioned to. Table 15 shows the design of experiments for the hand simulation method. The two factors that were varied are cargo load outs and starting location. This also showed that three starting states were not possible in a SBE Scenario based on earlier assumptions. For example, the T-craft could not start from the SBO without cargo loaded; otherwise, the mission would be satisfied. The other starting states that were not possible were departing the shore landing site with cargo. The T-craft was designed to unload all cargo at the shore landings site. An important consideration in the verification of the model's predicted outcome was the use of non random delay times. Each hand simulation had similar even delay times that enabled low computational stress in carrying out the calculations.

Hand Simulation Design of Experiments		
Design Point	Starting State	Initial Cargo Load
1	Debarkation	0
2	Debarkation	300
3	Debarkation	750
4	SBO	0
5	SBO	300
6	SBO	750
7	SHO	0
8	SHO	300
9	SHO	750
	Note: Not a possible starting state for a SBE Scenario.	

Table 15. Hand Simulation Design of Experiments.

The second design question was determining the number of simulation runs required to obtain statistical significant results. The number of simulation iterations was set at 10,000 replications. Given the starting states in Table 15, 10,000 replications were conducted at each starting point to collect data on the three MOPs.

c. Expected Results

The expected results of the Simkit model were originally assumed to match the characteristics of the distributions chosen for the inputted values. The triangle distribution of the transit and detection delays coupled to the exponential rates of the loading states produced a mean that was translatable to real-world processes. This research was not directed at validating the results of Simkit but merely to evaluate obtained results. It did seem to be highly likely that the model, developed with actual data to model the SBE Scenario, increased its usability.

d. Data Analysis

The results of the hand simulation are listed in Table 16. The results did show the full range of expected outcomes needed to model the Advanced Scenario. The survivability rate of the T-craft indicated that further simulation in Simkit should provide sufficient results for analysis. The transit times and cargo delivered results of the hand simulation are also comparable to those of MANA. The hand simulation calculations are shown in Figures 78 through 83.

Hand Simulation Results				
Initial State	Initial Cargo	Cargo	Time	Survivability
Debarkation	0	1060	82	X = 0
Debarkation	300	2260	181	X = 1
Debarkation	750	360	62	X = 0
SBO	0			
SBO	300	2030	122	X = 0
SBO	750	2480	126	X = 1
SHO	0	1060	92	X = 0
SHO	300			
SHO	750			

Table 16. Hand Simulation Results.

The results from the Simkit simulation of the SBE Scenario are listed in Table 17 through 19. The Basic Scenario illustrated the capability of statistical analysis of Simkit and measured the processes to enable optimization. The Simkit model in Appendix C represented the Advanced Scenario and was configured for measuring MOPs. The results showed that Simkit was affected by distributions in the modeling of T-craft in a pseudo stochastic environment.

Simkit Simulation Results								
Replications {100} Trips (1)		Measures of Performance						
Distribution	Parameters	Shore Cargo Transferred (LT)			Survivabillity Rate (%)	Transit Times (sec)		
Uniform	[0, 750]	450.79	±	266.95	54.0	5.38	±	2.92
Normal	[525, 200]	440.11	±	283.91	44.0	5.76	±	5.25
Exponential	[300]	457.54	±	281.95	52.0	5.93	±	4.31

Replications {1000} Trips (1)		Measures of Performance						
Distribution	Parameters	Shore Cargo Transferred (LT)			Survivabillity Rate	Transit Times (sec)		
Uniform	[0, 750]	436.29	±	266.25	48.2	5.83	±	5.02
Normal	[525, 200]	440.09	±	286.60	49.6	5.74	±	4.68
Exponential	[300]	433.43	±	293.63	49.2	5.32	±	3.53

Replications {10000} Trips (1)		Measures of Performance						
Distribution	Parameters	Shore Cargo Transferred (LT)			Survivabillity Rate	Transit Times (sec)		
Uniform	[0, 750]	435.31	±	271.69	49.3	5.51	±	4.19
Normal	[525, 200]	441.33	±	290.69	49.3	5.50	±	4.03
Exponential	[300]	441.33	±	287.81	49.6	5.52	±	4.30

Table 17. Simkit Results (One Trip to Shore).

Simkit Simulation Results								
Replications {100} Trips (2)		Measures of Performance						
Distribution	Parameters	Shore Cargo Transferred (LT)			Survivabillity Rate (%)	Transit Times (sec)		
Uniform	[0, 750]	637.42	±	475.05	24.0	6.10	±	3.60
Normal	[525, 200]	665.20	±	486.42	30.0	6.50	±	4.63
Exponential	[300]	529.94	±	484.77	36.0	7.65	±	6.31

Replications {1000} Trips (2)		Measures of Performance						
Distribution	Parameters	Shore Cargo Transferred (LT)			Survivabillity Rate (%)	Transit Times (sec)		
Uniform	[0, 750]	702.31	±	456.86	30.9	6.79	±	4.53
Normal	[525, 200]	703.11	±	483.12	30.4	6.84	±	4.80
Exponential	[300]	452.62	±	405.61	30.5	6.72	±	4.35

Replications {10000} Trips (2)		Measures of Performance						
Distribution	Parameters	Shore Cargo Transferred (LT)			Survivabillity Rate (%)	Transit Times (sec)		
Uniform	[0, 750]	702.54	±	462.63	31.2	6.85	±	4.74
Normal	[525, 200]	703.11	±	483.12	30.4	6.84	±	4.80
Exponential	[300]	460.46	±	405.61	30.9	6.73	±	4.66

Table 18. Simkit Results (Two Trips to Shore).

Simkit Simulation Results								
Replications Trips	{100} (3)	Measures of Performance						
Distribution	Parameters	Shore Cargo Transferred (LT)			Survivabillity Rate (%)	Transit Times (sec)		
Uniform	[0, 750]	676.28	±	537.54	14.0	7.28	±	4.81
Normal	[525, 200]	706.21	±	551.46	17.0	7.30	±	4.67
Exponential	[300]	549.19	±	489.62	19.0	7.44	±	4.67

Replications Trips	{1000} (3)	Measures of Performance						
Distribution	Parameters	Shore Cargo Transferred (LT)			Survivabillity Rate (%)	Transit Times (sec)		
Uniform	[0, 750]	781.62	±	498.04	15.4	7.82	±	5.25
Normal	[525, 200]	776.14	±	527.92	14.3	7.44	±	4.66
Exponential	[300]	521.23	±	480.42	19.2	7.42	±	4.95

Replications Trips	{10000} (3)	Measures of Performance						
Distribution	Parameters	Shore Cargo Transferred (LT)			Survivabillity Rate (%)	Transit Times (sec)		
Uniform	[0, 750]	744.37	±	518.41	14.7	7.44	±	5.24
Normal	[525, 200]	752.62	±	530.71	14.4	7.34	±	5.06
Exponential	[300]	540.61	±	484.60	17.6	7.44	±	5.08

Table 19. Simkit Results (Three Trips to Shore).

Simkit Raw Data (Exert)		
Number of Replications = 100 Number of Trips = 1 Uniform Distribution Parameters are [0,750]		
Shore Cargo	Survivability	Time
469.28	1	5.40
0.00	0	1.26
738.82	1	7.17
381.89	0	5.66
391.23	1	6.12
441.07	1	9.42
405.54	0	6.77
740.65	1	6.88
836.81	1	3.90
511.24	1	9.07
320.83	1	5.25
621.89	1	5.08
456.55	1	6.09
561.93	0	19.78
665.75	1	7.90
0.00	0	2.56
740.77	1	7.10
575.28	0	8.81
669.77	0	6.46
970.78	1	7.30
0.00	0	0.88
703.29	1	6.37
505.16	1	5.76
713.77	0	8.25
346.44	1	6.56
605.55	0	5.37
566.33	0	4.19
835.02	0	4.03
742.18	1	4.41
0.00	0	0.69
0.00	0	2.07
640.07	1	3.68
885.71	1	4.85
352.59	1	7.98
675.01	1	6.32
0.00	0	1.56
0.00	0	2.16
359.51	1	7.30
0.00	0	0.74
586.05	1	8.72

Table 20. Simkit Data Collection Excerpt.

Simkit results behaved similarly to those of MANA, in that when more trips to the shore were implemented, cargo transfer increased at the shore landing site. The confidence interval magnitudes from the Simkit simulation were larger, giving a wider range for the actual value to be in. This meant that the cargo transfer rates modeled within the simulations were subjective to the developer of the simulation and the modeler of T-craft and yielded results similar but not realistic to actual cargo transfer rates.

3. Arena Simulation

The Rockwell Automation Arena software M&S tool is primarily designed for business process applications. Arena's main versatility is based on converting flowchart process in a model that can be simulated for analysis. Arena was developed by the Rockwell Automation Technologies Incorporated in 2007. The Arena M&S tool is recommended for uses in (1) documenting, visualizing, and demonstrating processes with animation, (2) predicting system performance, (3) identifying system choke points, and (4) planning requirements. (RA, 2007) Arena is designed for use in the business environment and is less capable than Simkit for military operations.

As mentioned earlier, the evaluation of the Arena M&S tool was based on a model created by Mary McDonald, a research associate of the NPS. The McDonald model implemented the second phase of the SBE Scenario where the scenario starts at the SBO and SBEs transit to and from the shore landings site transferring cargo. It was a basic model that focused on the cargo measurement and not survivability. An extrapolation in areas relating to the

MOPs of the McDonald model was the focus of this research. As with Pythagoras, simple testing was conducted with Arena to determine the presence of functionalities in the Arena model and evaluate the capabilities of the M&S tool. The Arena model was iterated over multiple runs to determine the transfer patterns and survivability rates similar to other M&S tools in this study.

a. Parameters

The McDonald model imported values from a database that runs the model. The database consisted of 14 independent variables that are listed below. The model also created multiple T-craft objects for transferring cargo. The time delay was a random exponential distribution with the process containing 51 T-craft entities. T-craft entities conducted transfer of cargo in batches to the shore landing site and were then disposed of once a threshold of cargo was reached. The McDonald model replicated the process 512 times. The McDonald model did not implement the return transit to the debarkation point, but did input attack probabilities into the transit processes. Figure 24 shows the McDonald model in Arena and illustrates the generation process of the entities from the database with a separate block for reading input from a designated file.

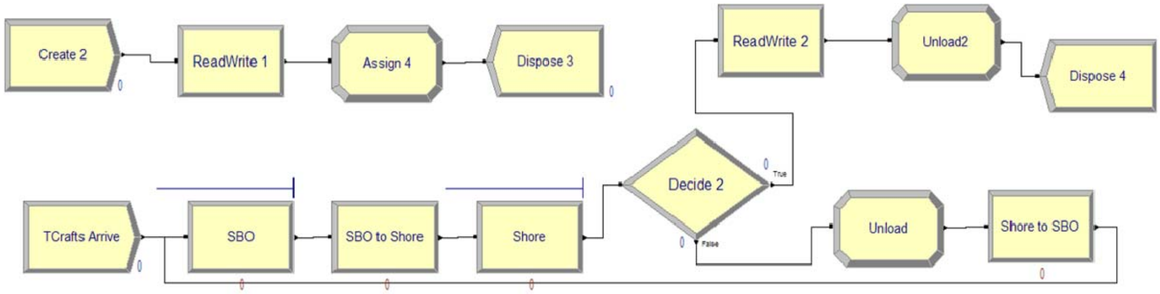


Figure 24. McDonald Arena Model Overview.

The following is a listing of the variables that were parameter settings in the McDonald model. The database was divided into 14 different independent variables that were used to then calculate 12 dependent variables. The dependent variables were calculated outside the model and then used as input parameters for model simulation.

- Cargo Payload Weight (Long Tons)
- Cargo Deck Size (Square Feet)
- Speed in Knots
- Loading Time in hours
- Unloading Time in hours
- Number of T-craft
- Number of Sea Spots for Loading
- Refueling during Loading (Boolean Value)
- Refueling Rates (Tons/hour)
- Cargo Capacities (Long Tons)
- Fuel Consumption while Loaded (Long Tons)
- Fuel Consumption while Unloaded (Long Tons)

- Batch Size
- Number of Hits until Repair needed

b. Differences in Arena

The most notable difference in Arena from Simkit was the GUI that was available in Arena. However, the GUI presence did not overcome certain short comings that an object orientated M&S tool supports. Arena was able to display models graphically, but lacked the computational power. The lack of versatile variables and extensive random numbers separated Arena from the Simkit that has robust methods for stochastic processes. The results from an Arena model were simple and not as robust as the statistical calculation in the Simkit API. The Arena GUI was not open sourced and reduced user capability to model complex interactions with logic programming. These factors, coupled with limited combat modeling capabilities made Arena distinctively different.

Arena and Simkit shared one similarity. The capability of waiting queues to be used for measuring logistics provided information in analysis on force factors and composition. Arena was specifically designed for business-like applications to optimize processes and determine the best combination of factors. Waiting queues were the basis for selecting both Simkit and Arena M&S tools in this research.

c. *Expected Results*

The SBE Scenario modeled in the McDonald model was not iterated for analysis purposes in this study. Instead, the McDonald model was used as a comparison mechanism to evaluate Arena's simulation capabilities. It was apparent from initial simulation runs that the primary results obtained from provided databases were comparable with Simkit results. The determination was made that extensive simulation of the McDonald model, like that of MANA, would not be necessary due to time restriction and the clear presence of M&S capabilities. Limited simulations iterations conducted by Mary McDonald did show similar survivability rates, transit times, and cargo transfers compared to Simkit, which indicated the model was a viable SBE Scenario. Selection of MOPs were also similar to those of Simkit, therefore, high replications of Arena was not needed for evaluation purposes.

M&S tools used in this study were selected base on capabilities to model a SBE and availability at NPS. The two types of models kept within the constructive realm of M&S. Each M&S tool possessed capabilities and limitations that made them differently suited for modeling a naval problem, but still usable to apply to the SBE Scenario broadly for measuring performance characteristics. The results collected in this chapter were too used to illustrate obtainable results and that each M&S tool evaluated by subjectively observed functionalities within the capability Hierarchy.

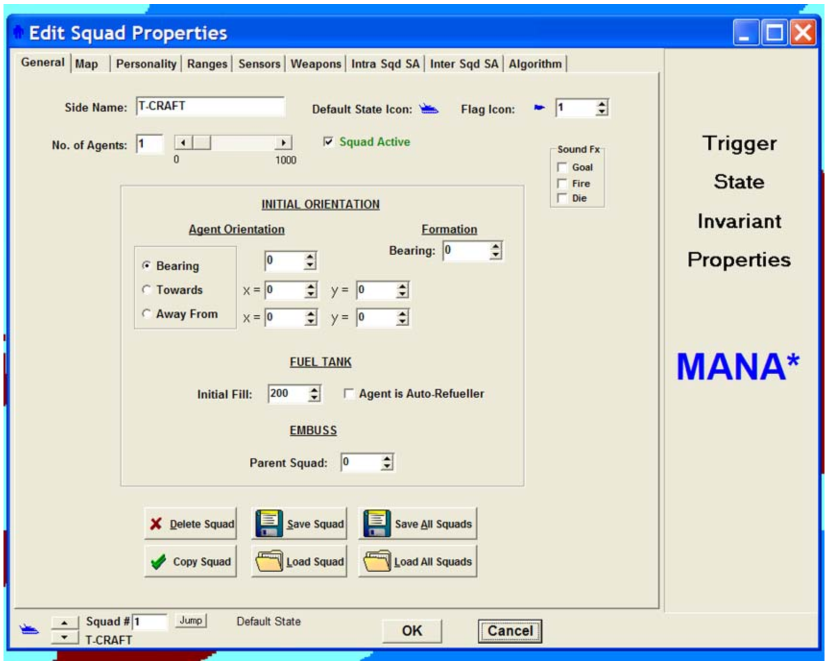


Figure 25. T-craft General Configuration.

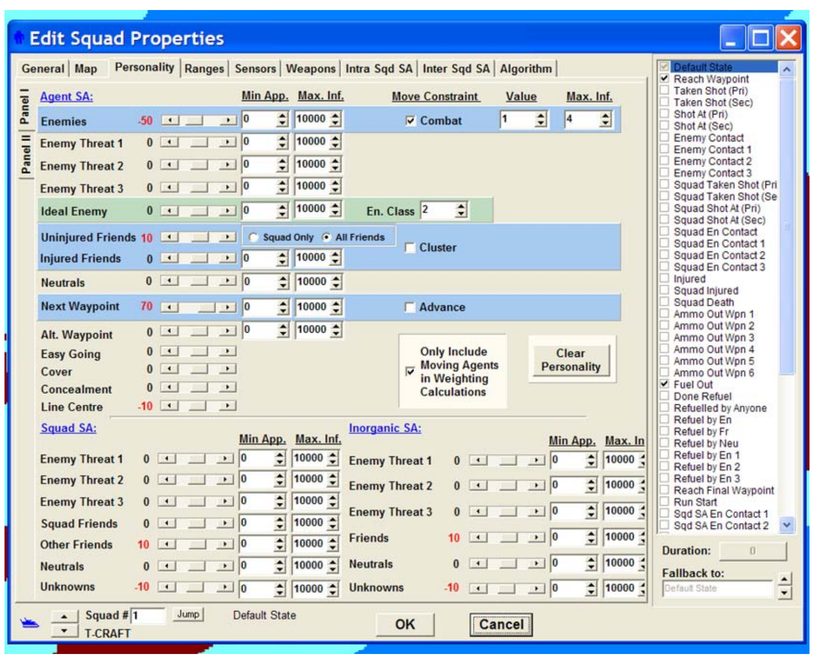


Figure 26. T-craft Personal Settings.

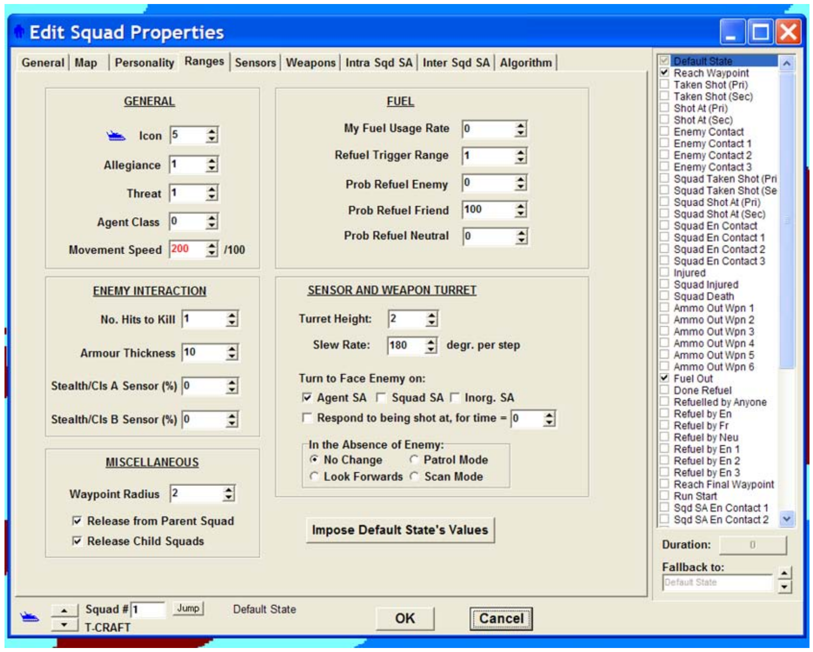


Figure 27. T-craft Ranges Settings.

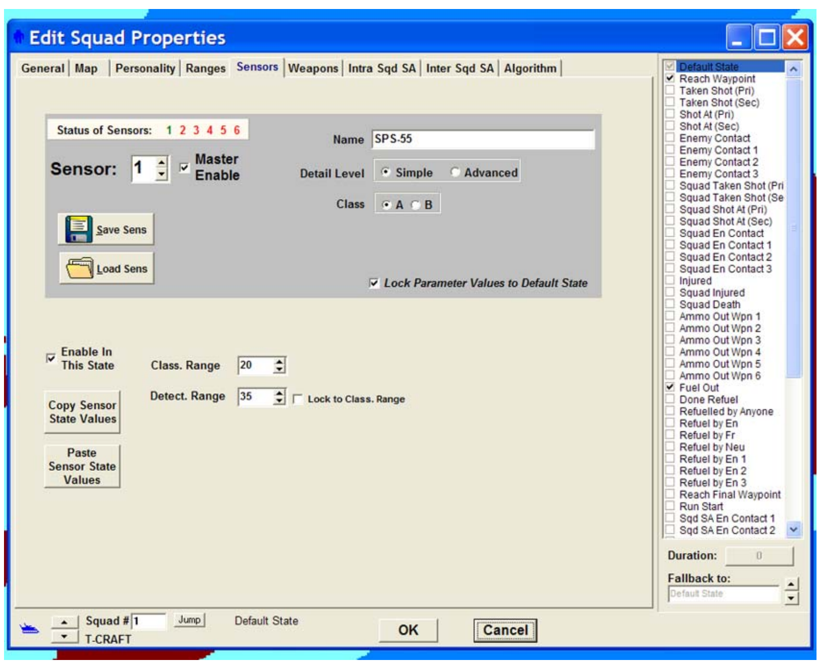


Figure 28. T-craft Sensors Settings.

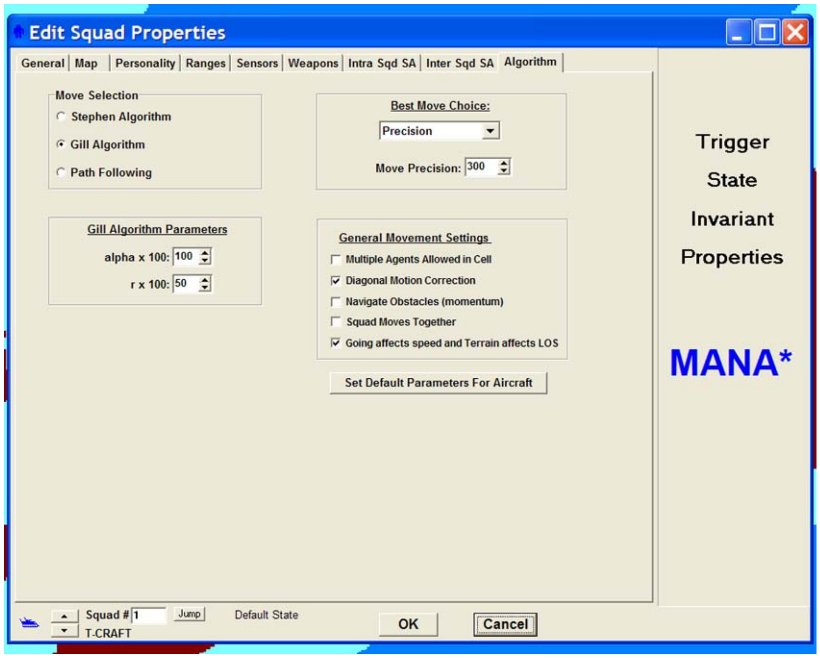


Figure 29. T-craft Algorithm Settings.

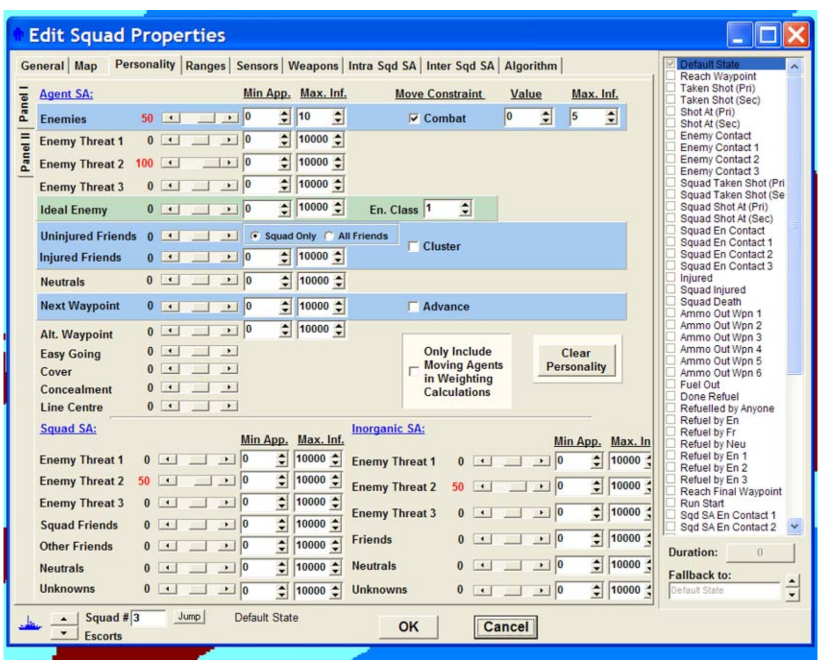


Figure 30. Escort Personal Settings.

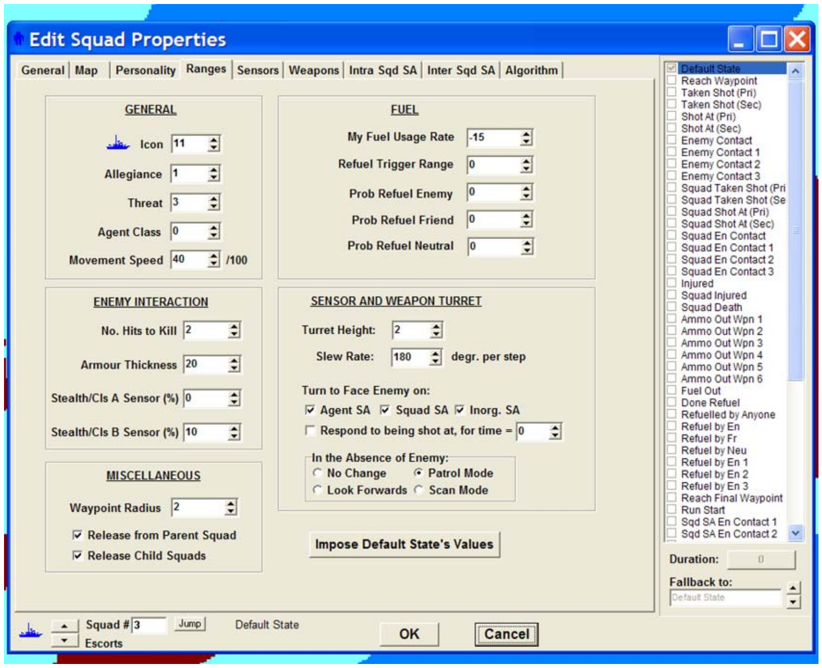


Figure 31. Escort Ranges Settings.

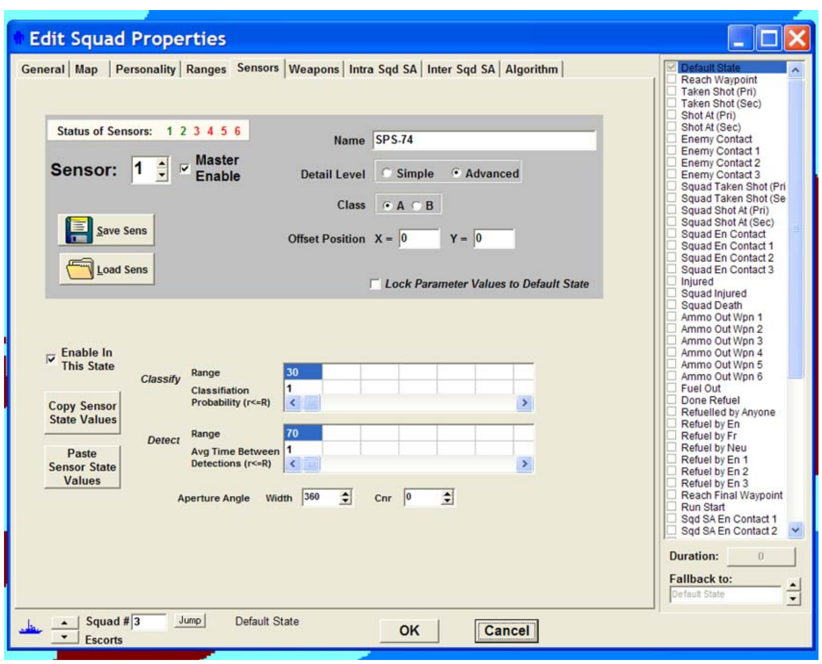


Figure 32. Escort Sensors Settings.

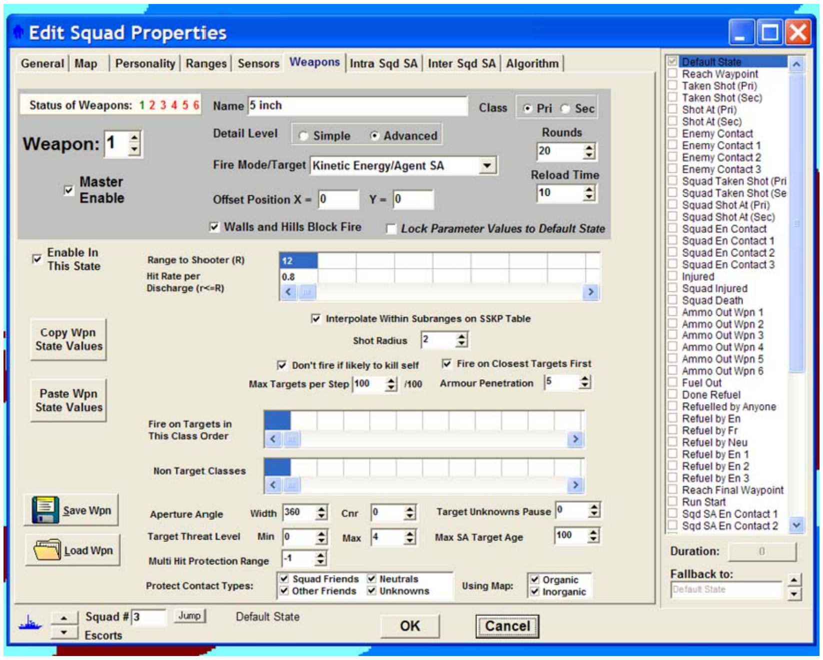


Figure 33. Escort Weapons Settings.

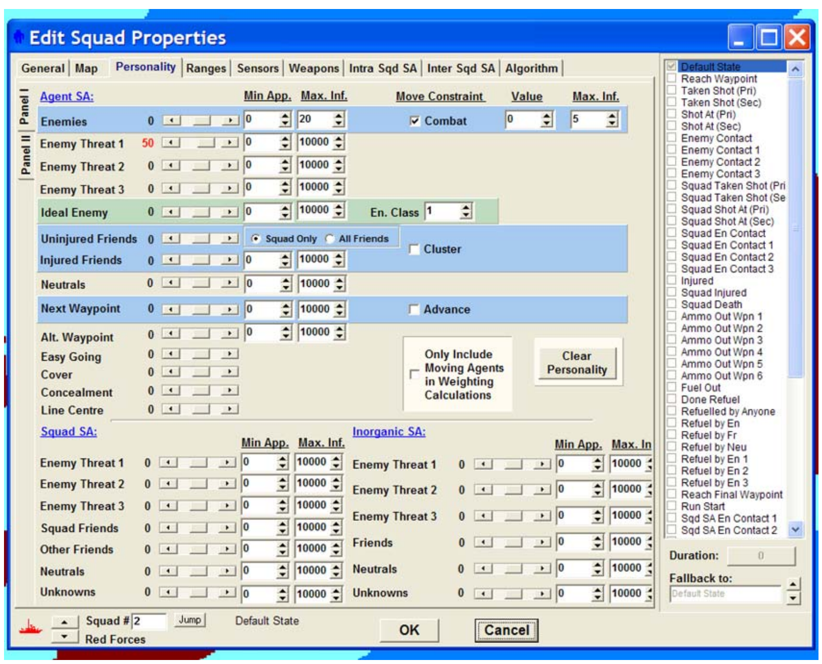


Figure 34. Hostile Personal Settings.

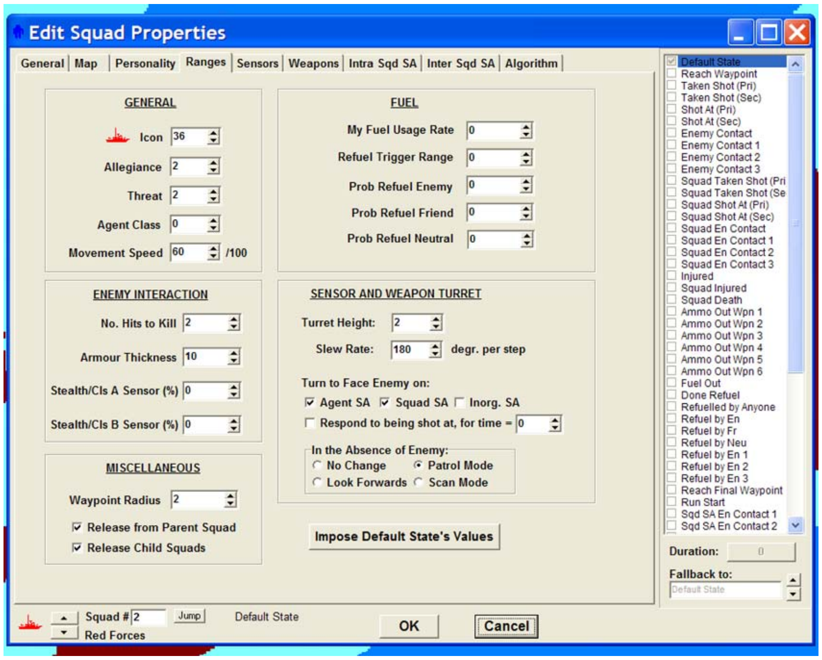


Figure 35. Hostile Ranges Settings.

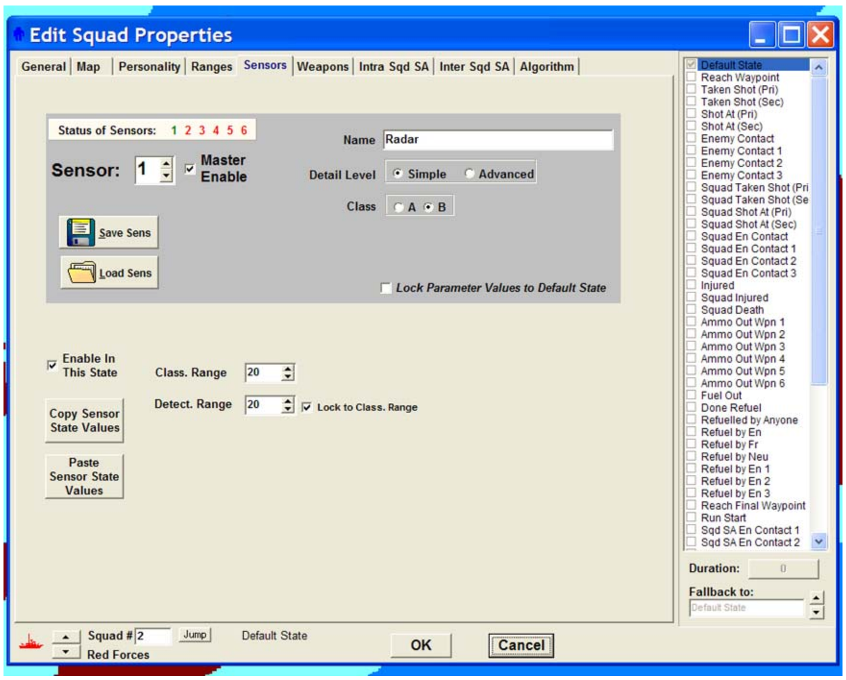


Figure 36. Hostile Sensors Settings.

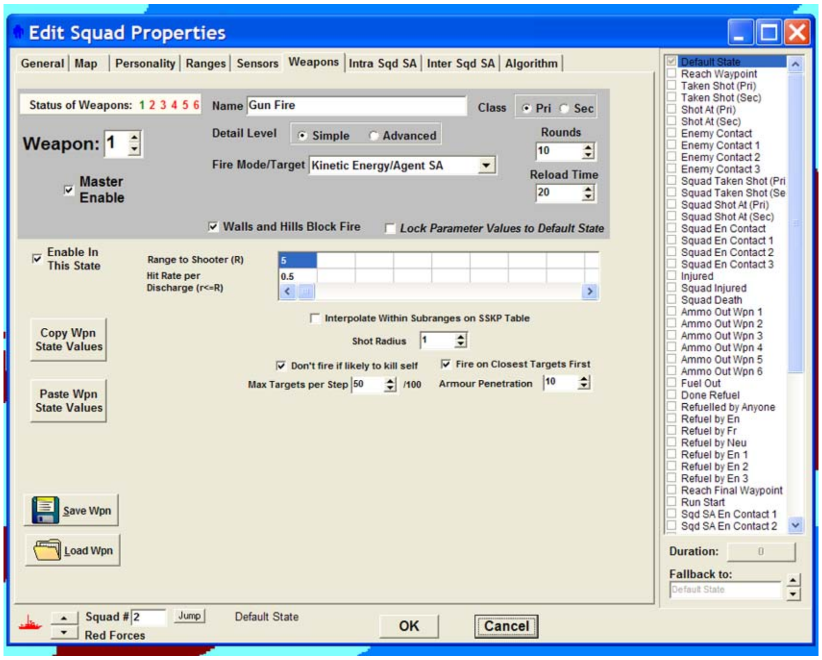


Figure 37. Hostile Weapons Settings.

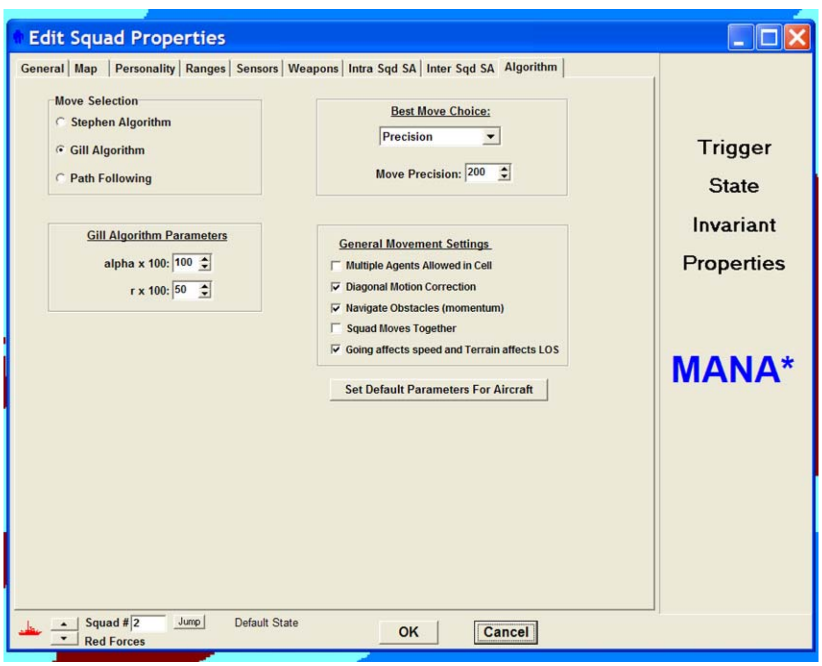


Figure 38. Hostile Algorithm Settings.

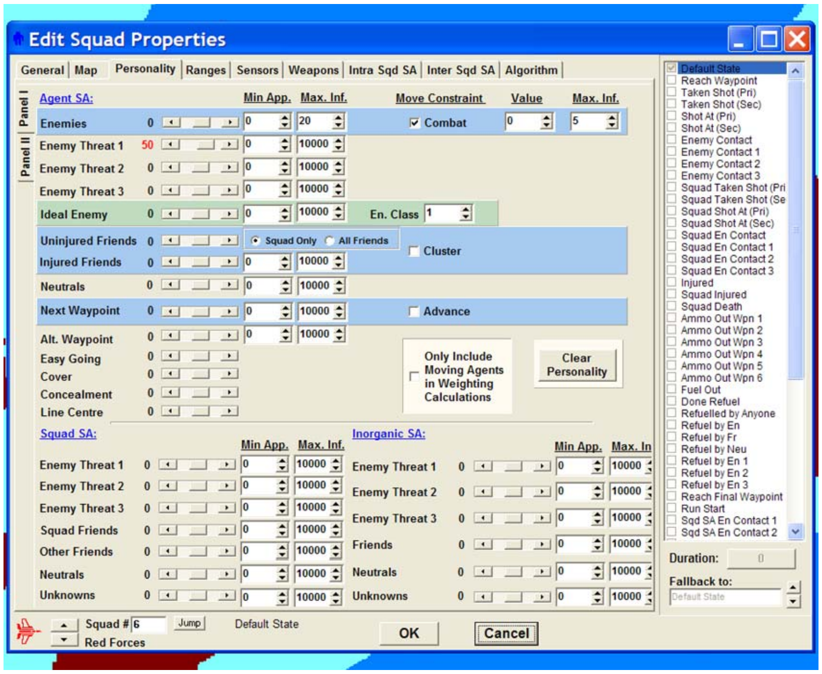


Figure 39. Hostile Air Personal Settings.

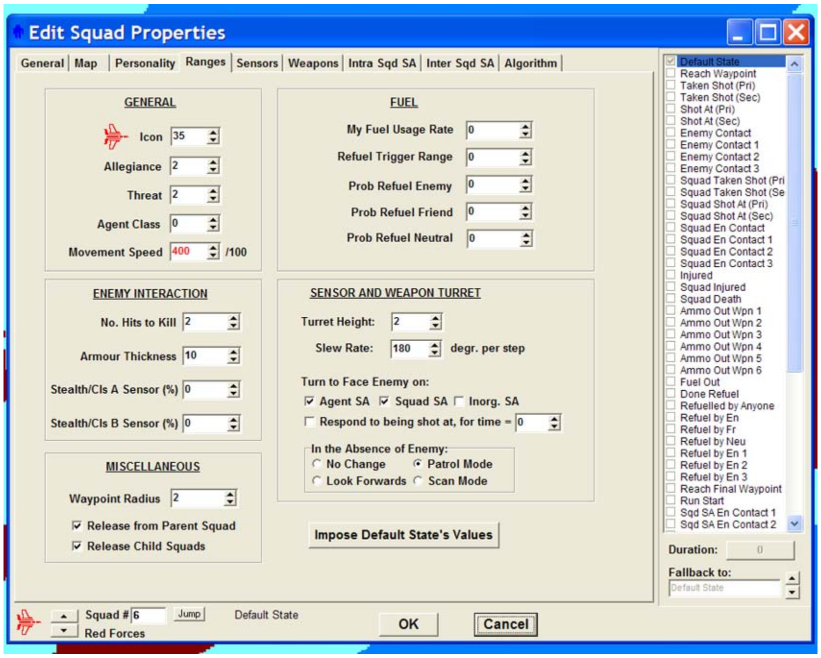


Figure 40. Hostile Air Ranges Settings.

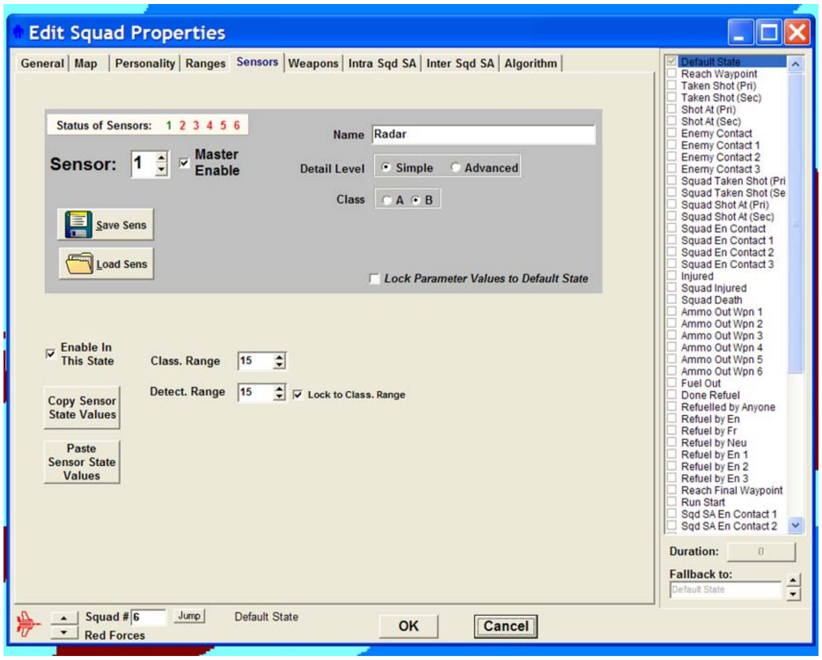


Figure 41. Hostile Air Sensors Settings.

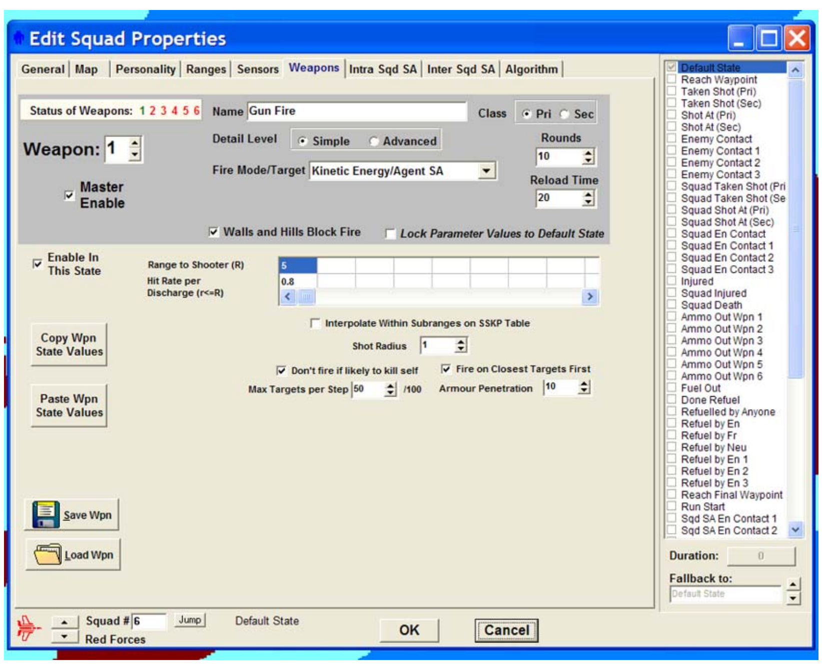


Figure 42. Hostile Air Weapons Settings.

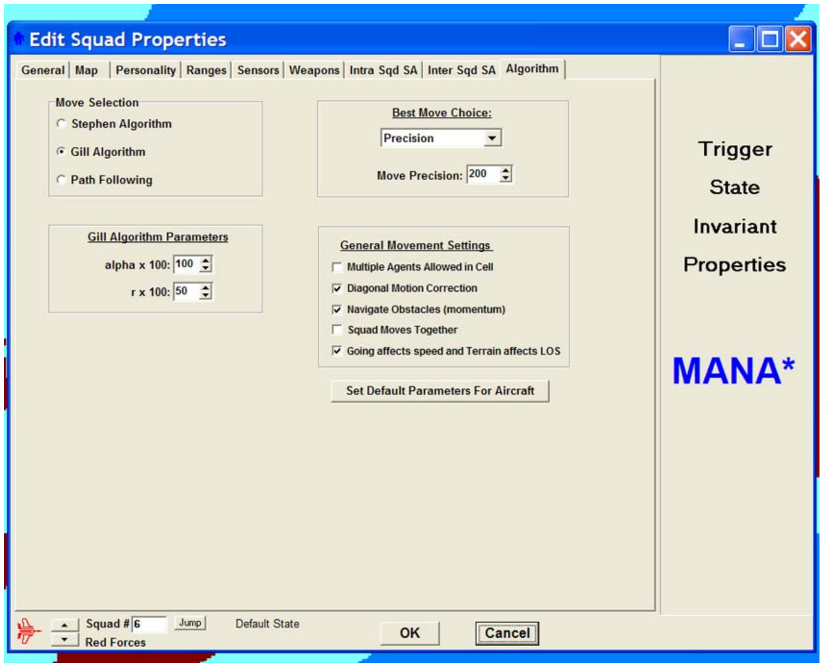


Figure 43. Hostile Air Algorithm Settings.

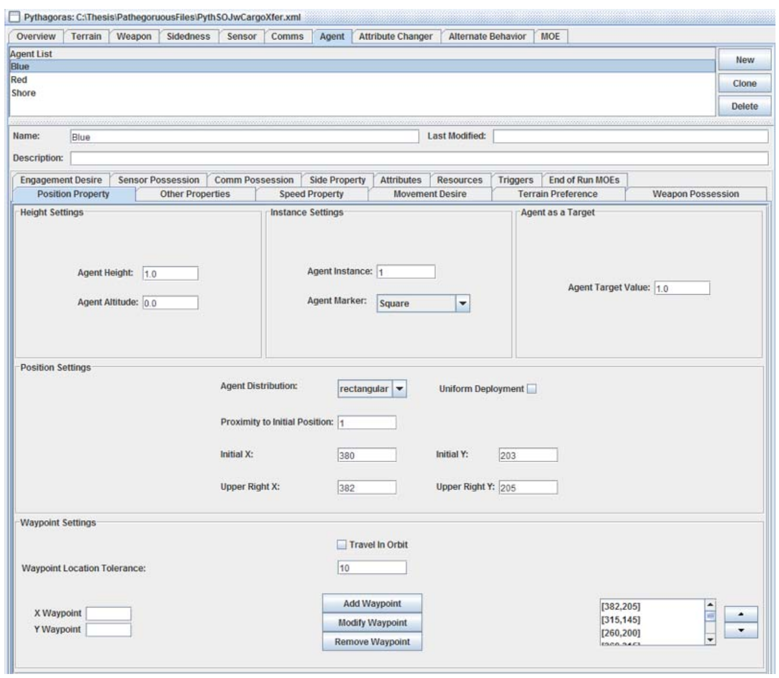


Figure 44. Blue Agent Position Property.

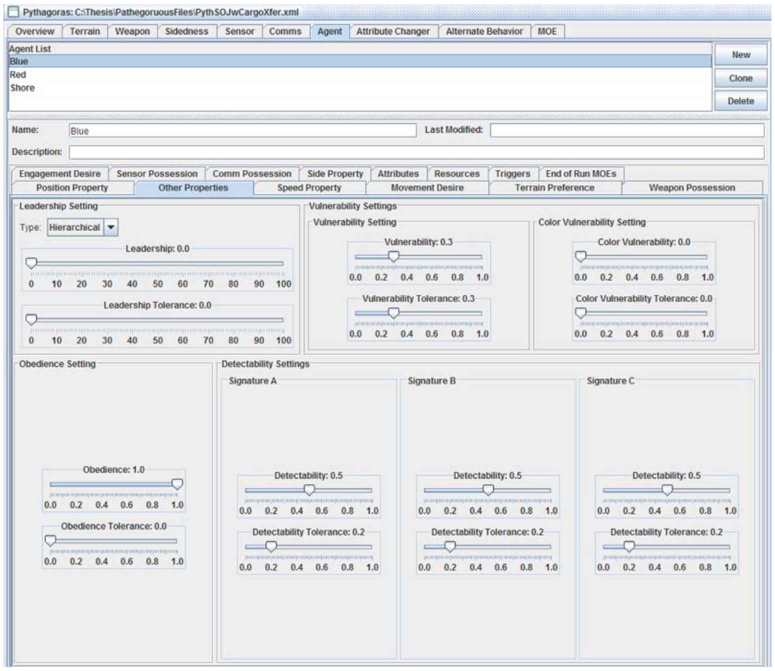


Figure 45. Blue Agent Other Property.

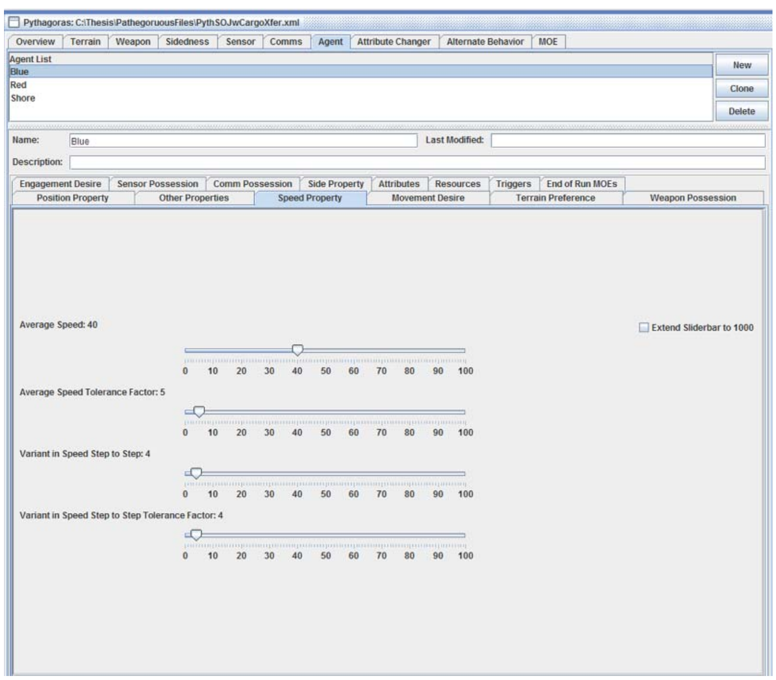
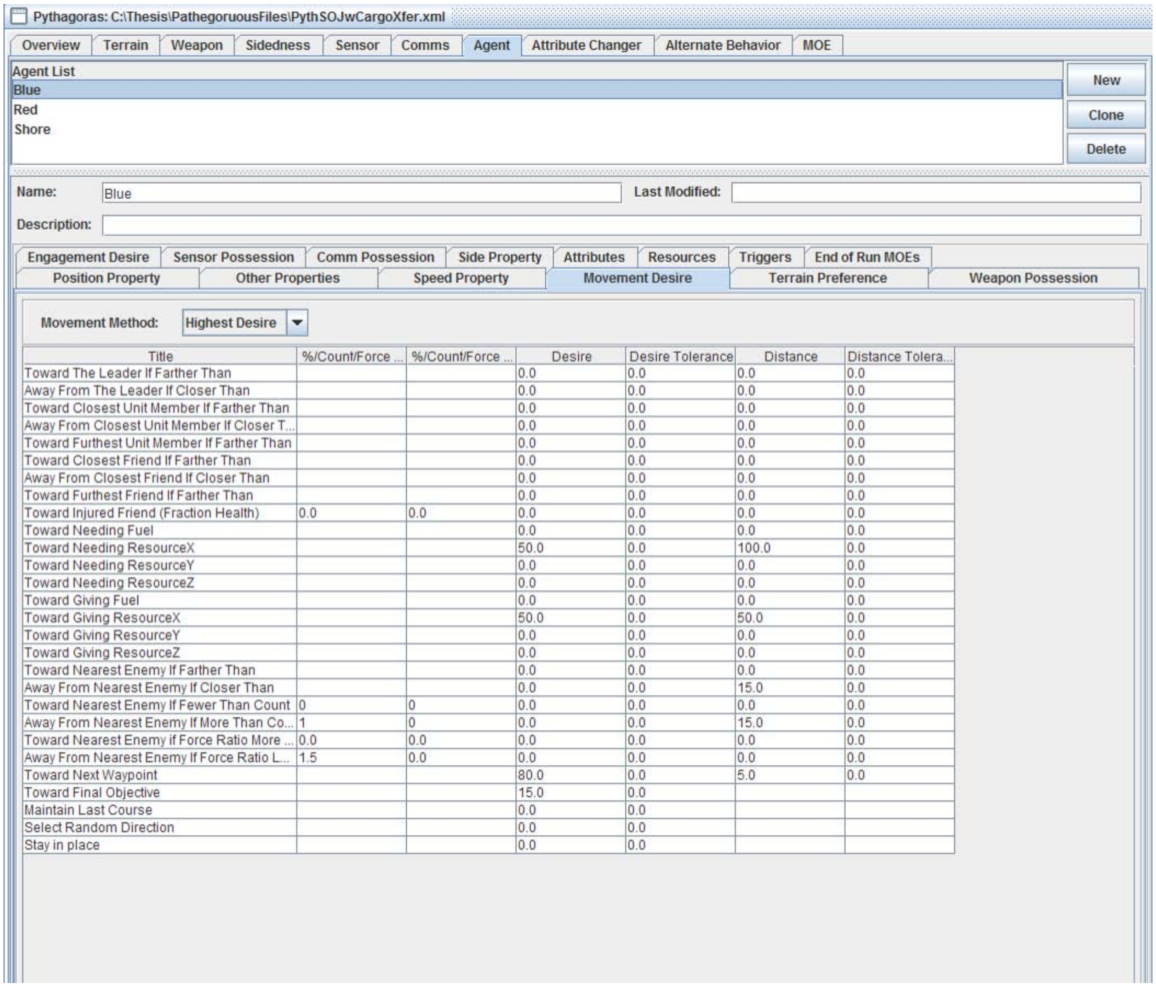


Figure 46. Blue Agent Speed Property.



Title	%/Count/Force ...	%/Count/Force ...	Desire	Desire Tolerance	Distance	Distance Tolera...
Toward The Leader If Farther Than			0.0	0.0	0.0	0.0
Away From The Leader If Closer Than			0.0	0.0	0.0	0.0
Toward Closest Unit Member If Farther Than			0.0	0.0	0.0	0.0
Away From Closest Unit Member If Closer T...			0.0	0.0	0.0	0.0
Toward Furthest Unit Member If Farther Than			0.0	0.0	0.0	0.0
Toward Closest Friend If Farther Than			0.0	0.0	0.0	0.0
Away From Closest Friend If Closer Than			0.0	0.0	0.0	0.0
Toward Furthest Friend If Farther Than			0.0	0.0	0.0	0.0
Toward Injured Friend (Fraction Health)	0.0	0.0	0.0	0.0	0.0	0.0
Toward Needing Fuel			0.0	0.0	0.0	0.0
Toward Needing ResourceX			50.0	0.0	100.0	0.0
Toward Needing ResourceY			0.0	0.0	0.0	0.0
Toward Needing ResourceZ			0.0	0.0	0.0	0.0
Toward Giving Fuel			0.0	0.0	0.0	0.0
Toward Giving ResourceX			50.0	0.0	50.0	0.0
Toward Giving ResourceY			0.0	0.0	0.0	0.0
Toward Giving ResourceZ			0.0	0.0	0.0	0.0
Toward Nearest Enemy If Farther Than			0.0	0.0	0.0	0.0
Away From Nearest Enemy If Closer Than			0.0	0.0	15.0	0.0
Toward Nearest Enemy If Fewer Than Count	0	0	0.0	0.0	0.0	0.0
Away From Nearest Enemy If More Than Co...	1	0	0.0	0.0	15.0	0.0
Toward Nearest Enemy if Force Ratio More ...	0.0	0.0	0.0	0.0	0.0	0.0
Away From Nearest Enemy If Force Ratio L...	1.5	0.0	0.0	0.0	0.0	0.0
Toward Next Waypoint			80.0	0.0	5.0	0.0
Toward Final Objective			15.0	0.0		
Maintain Last Course			0.0	0.0		
Select Random Direction			0.0	0.0		
Stay in place			0.0	0.0		

Figure 47. Blue Agent Movement Desire.

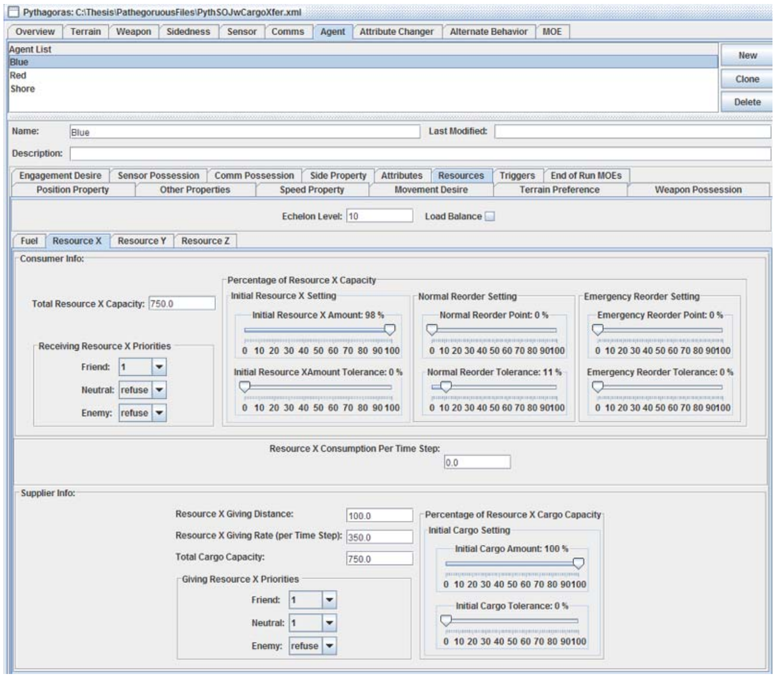


Figure 48. Blue Agent Resource.

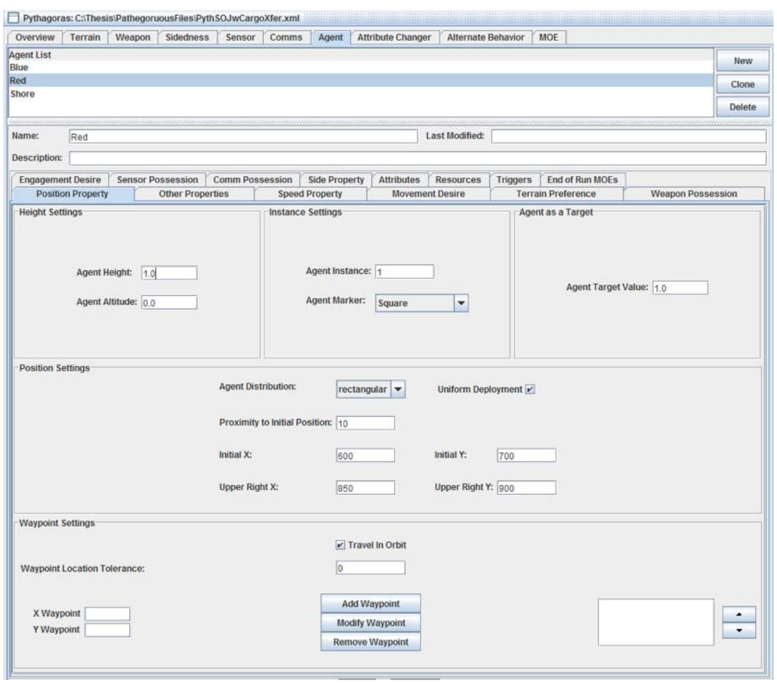


Figure 49. Red Agent Position Property.

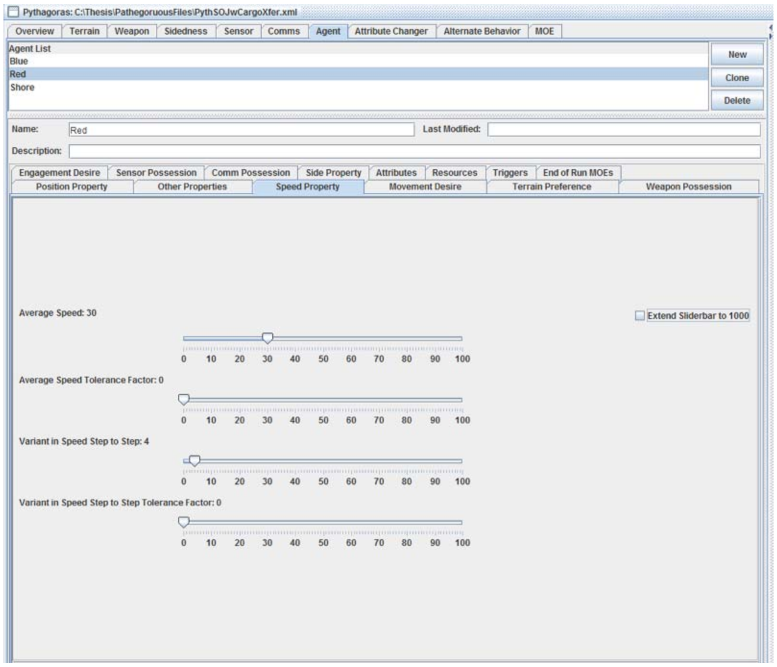


Figure 50. Red Agent Speed Property.

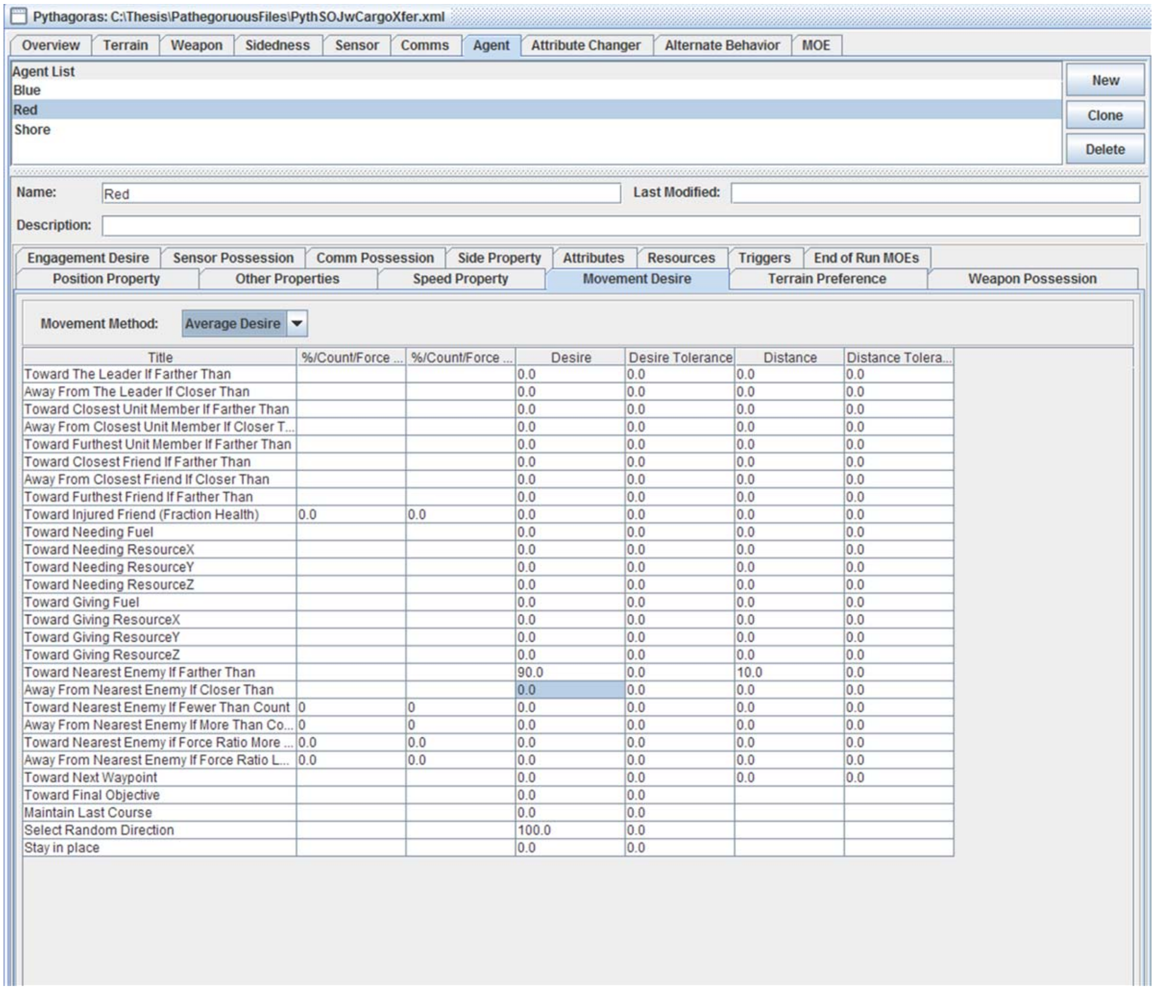


Figure 51. Red Agent Movement Desire.

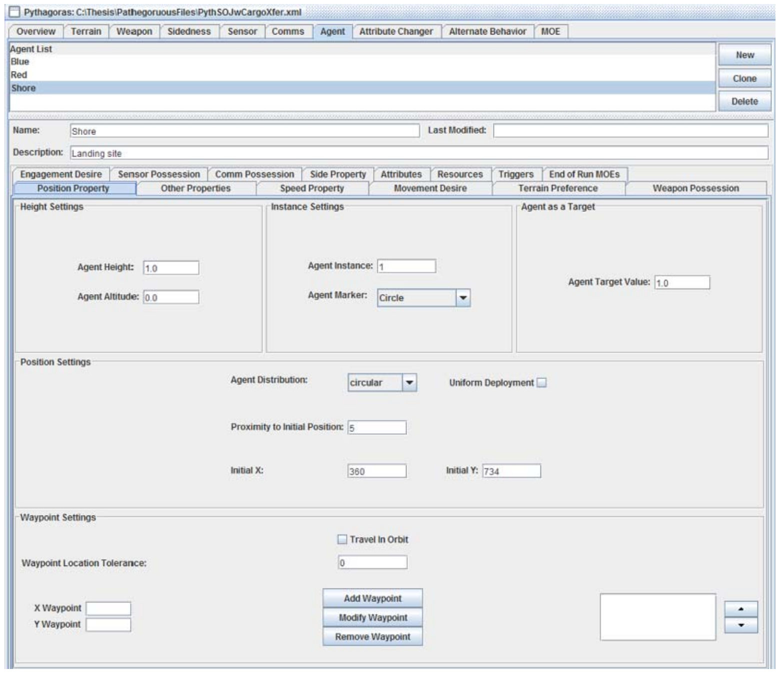


Figure 52. Shore Agent Position Property.

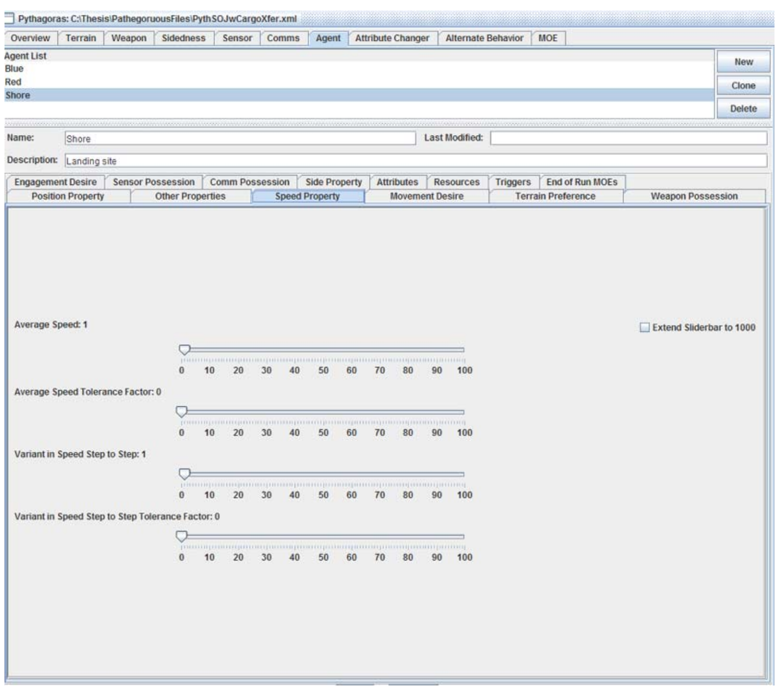


Figure 53. Shore Agent Speed Property.

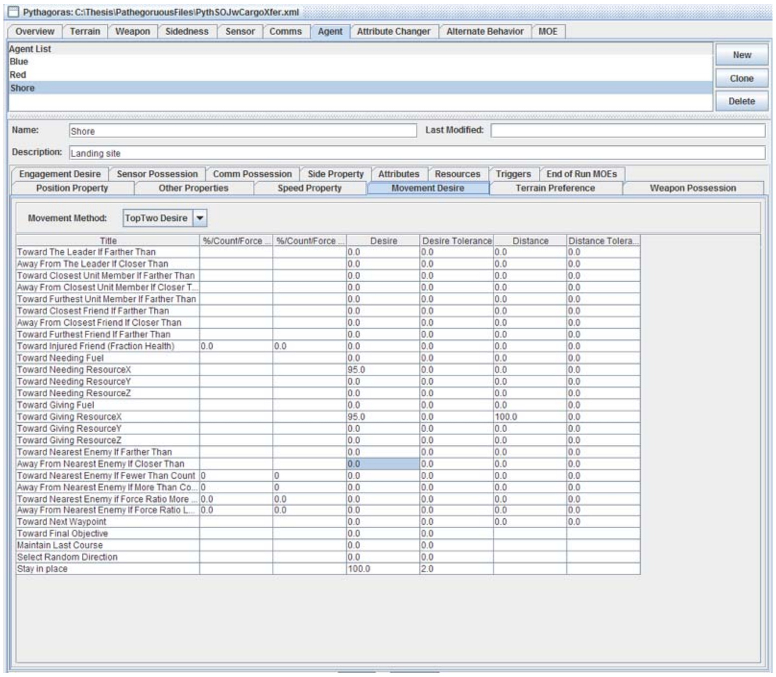


Figure 54. Shore Agent Movement Desire.

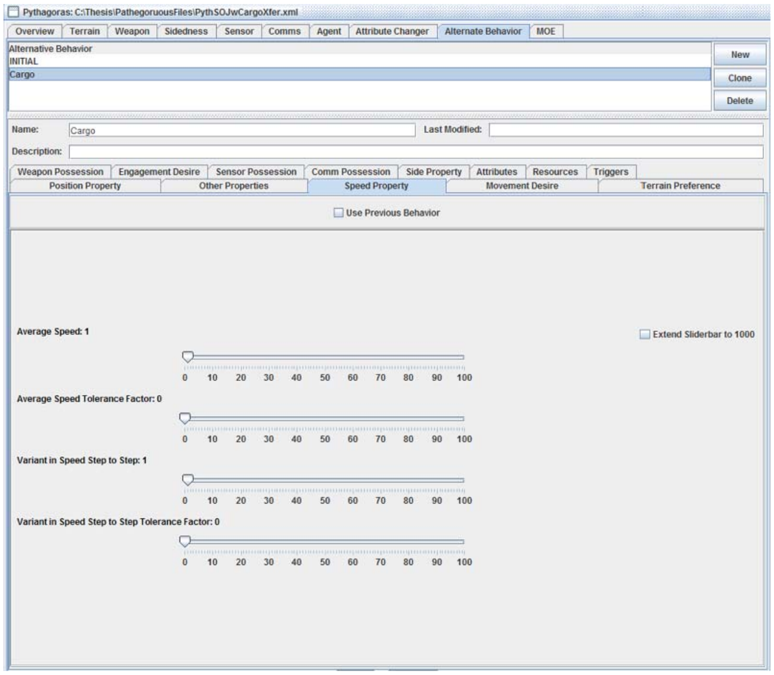


Figure 55. Cargo Alternate Behavior Speed Property.

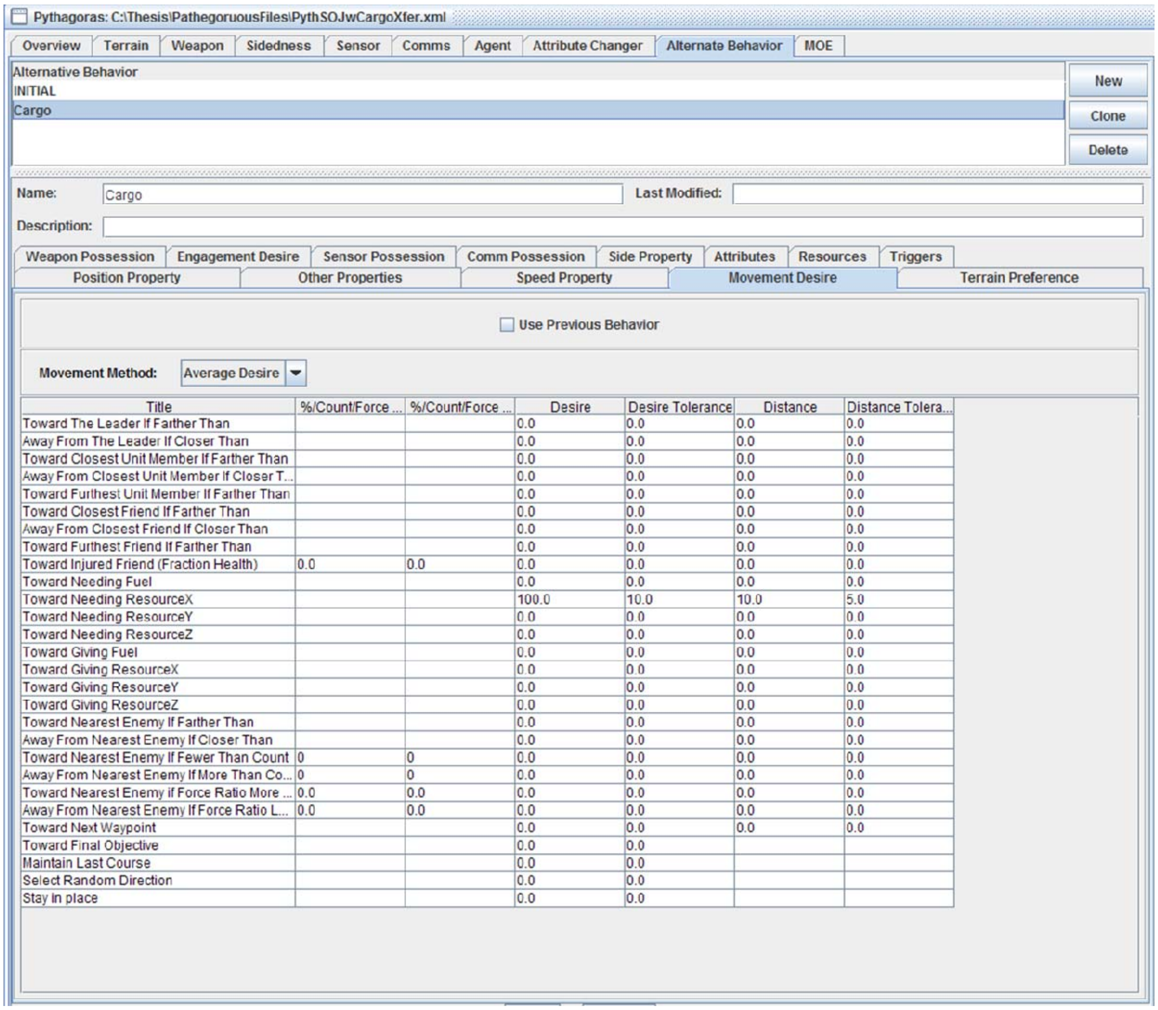


Figure 56. Cargo Alternate Behavior Movement Desire.

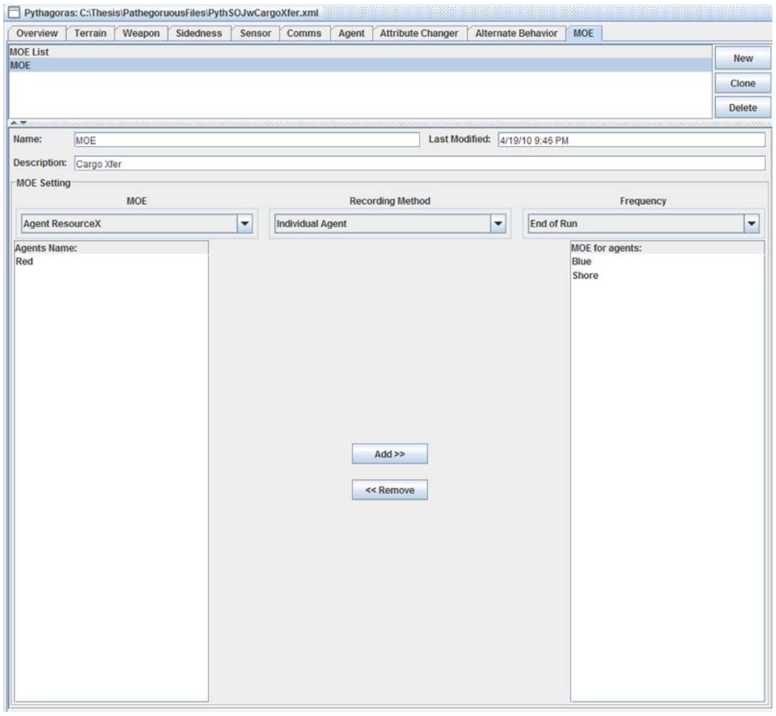


Figure 57. MOE for Model Iterations.

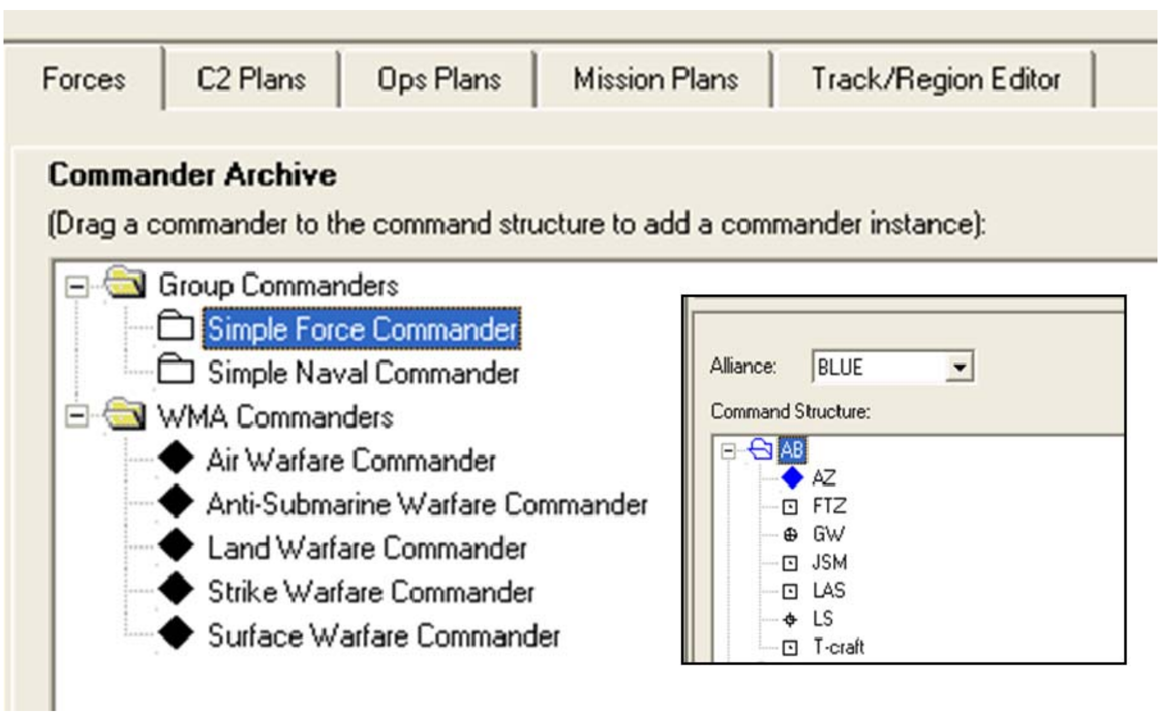


Figure 58. Blue Force and Warfare Commanders Structure.

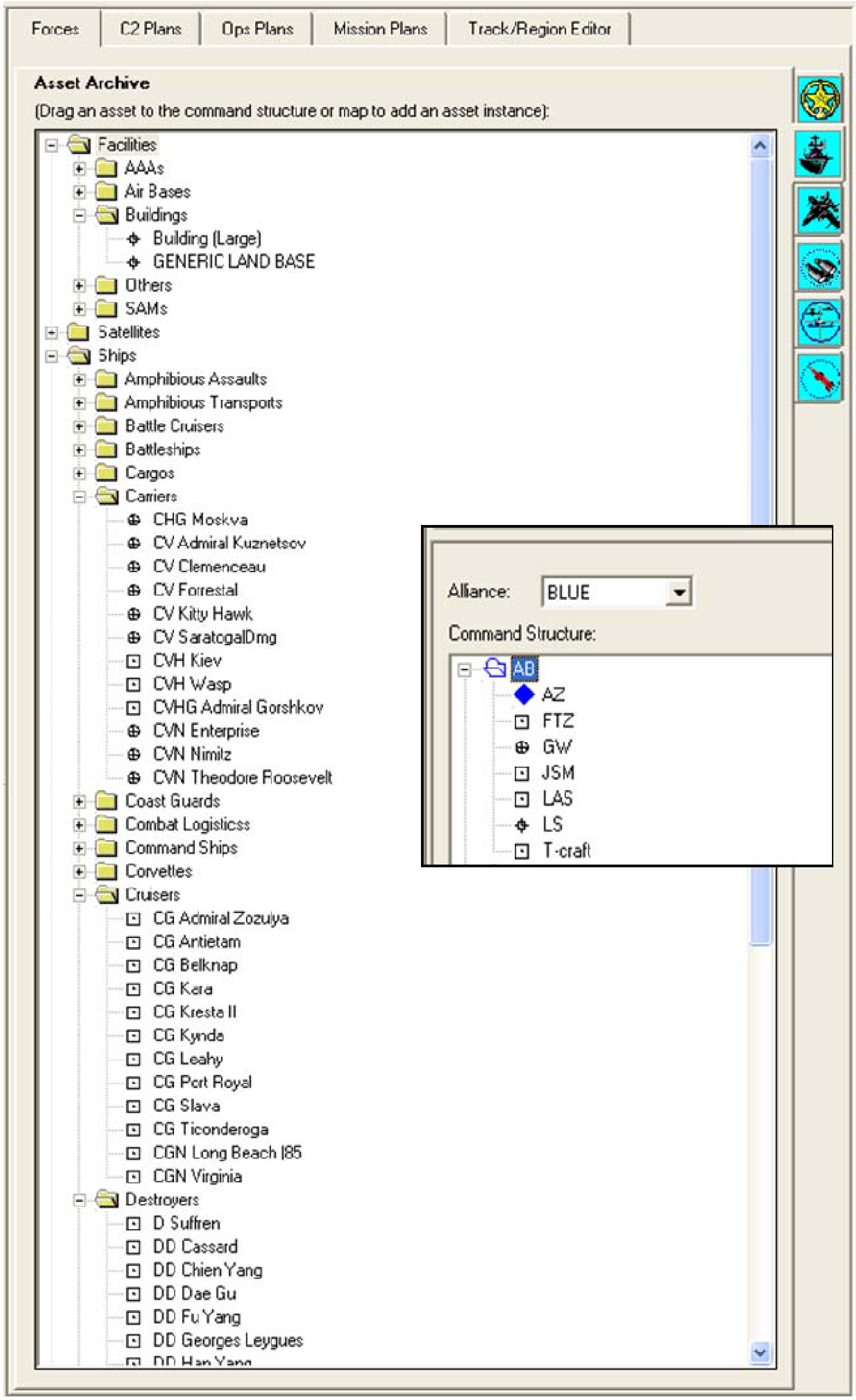


Figure 59. Blue Unit Level Structure.

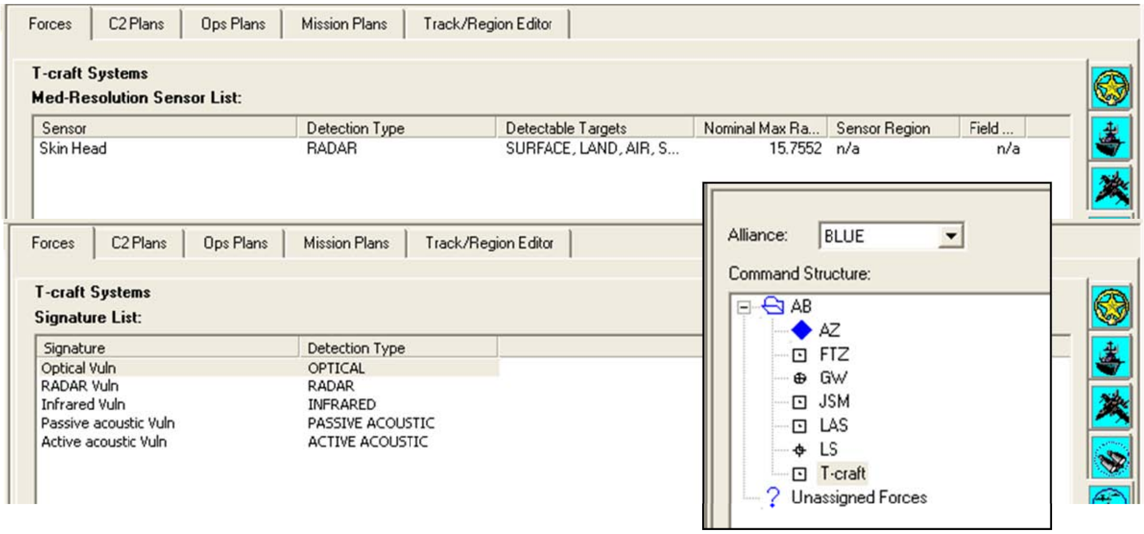


Figure 60. T-craft Instance Settings.

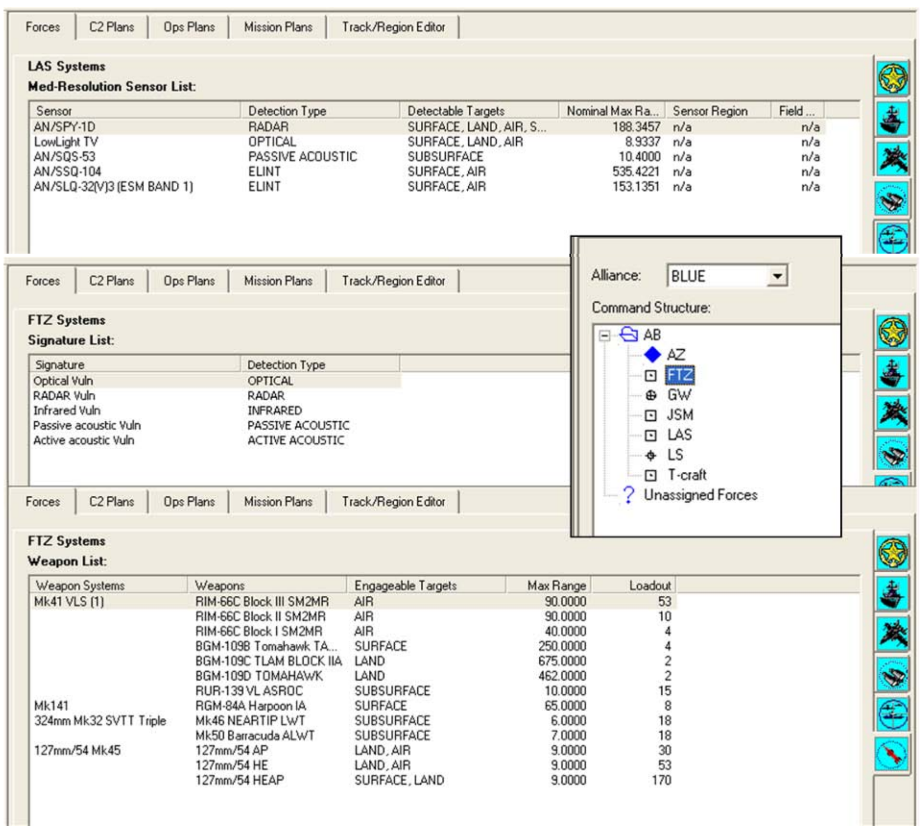


Figure 61. Escort Instance Settings.

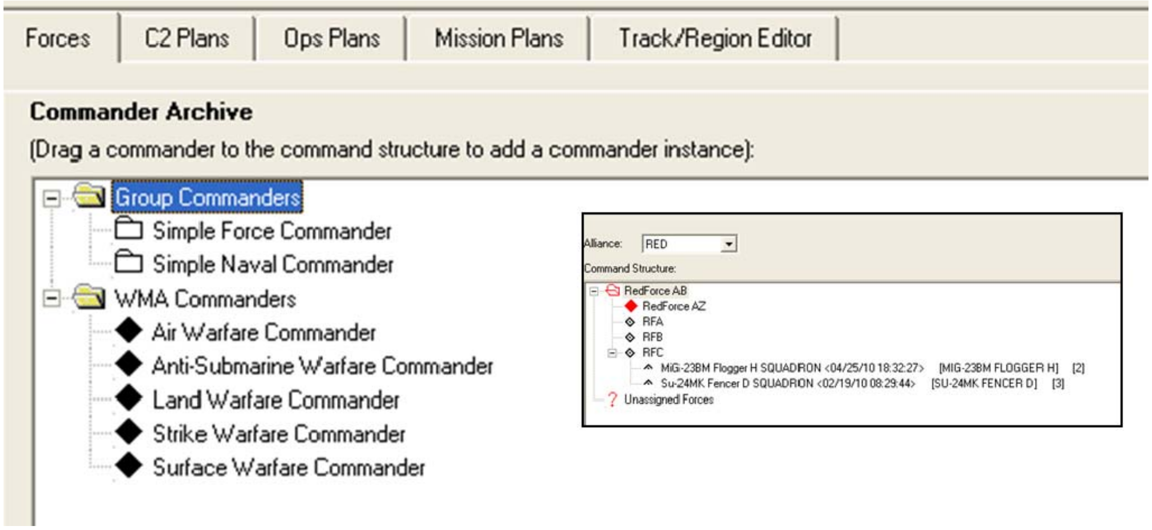


Figure 62. Red Force and Warfare Commanders Structure.

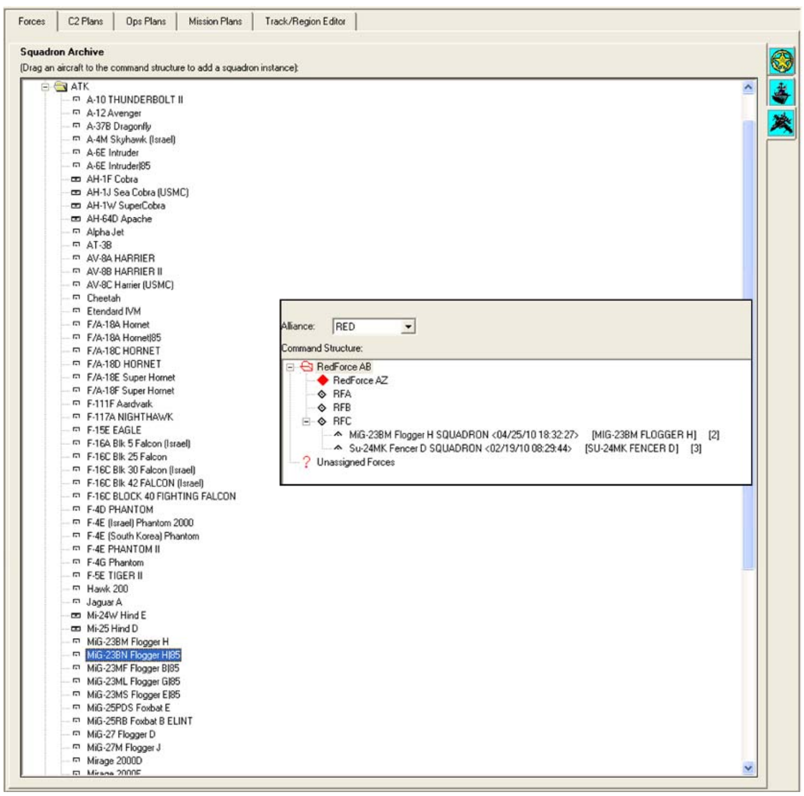


Figure 63. Red Unit Level Structure.

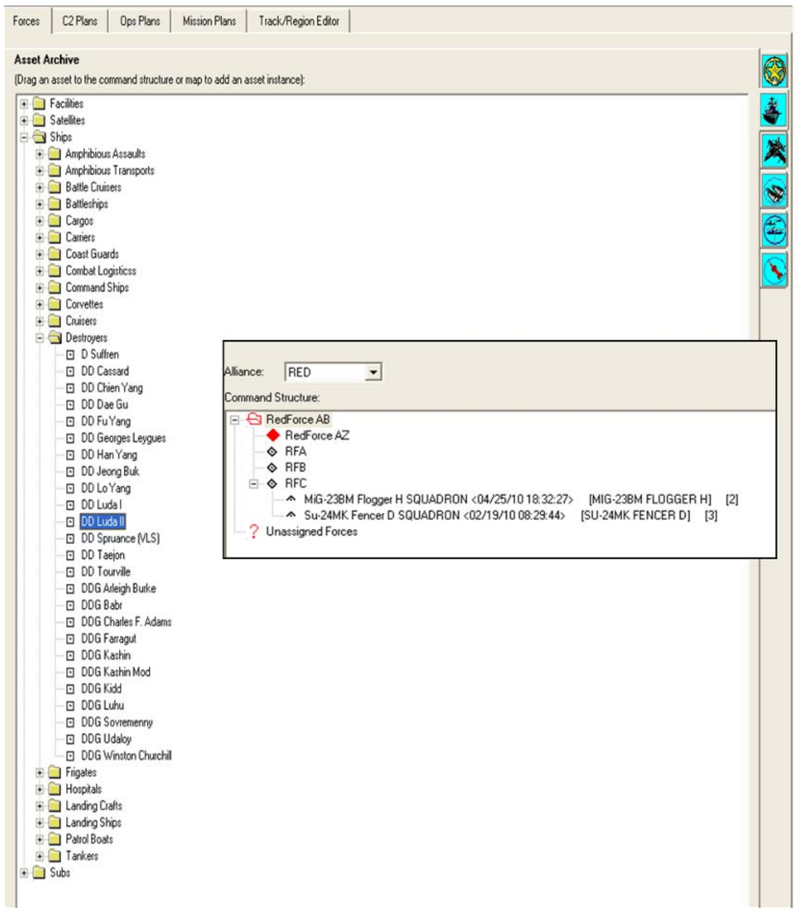


Figure 64. Red Unit Level Structure (cont.).

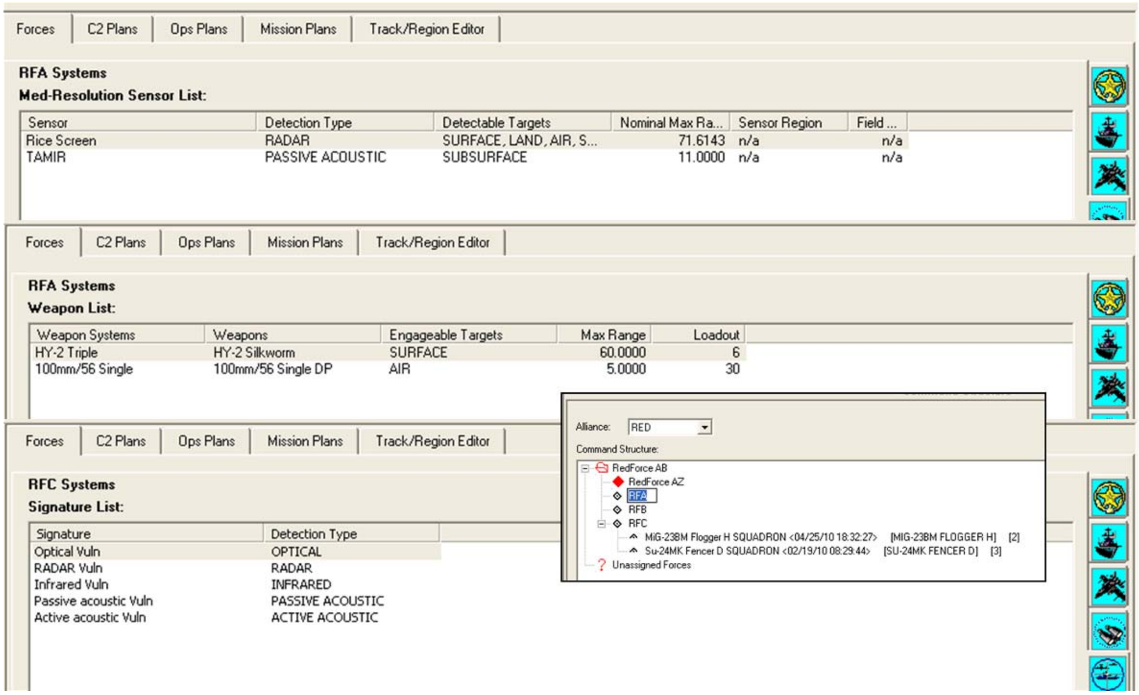


Figure 65. Hostile Force Instance Settings.

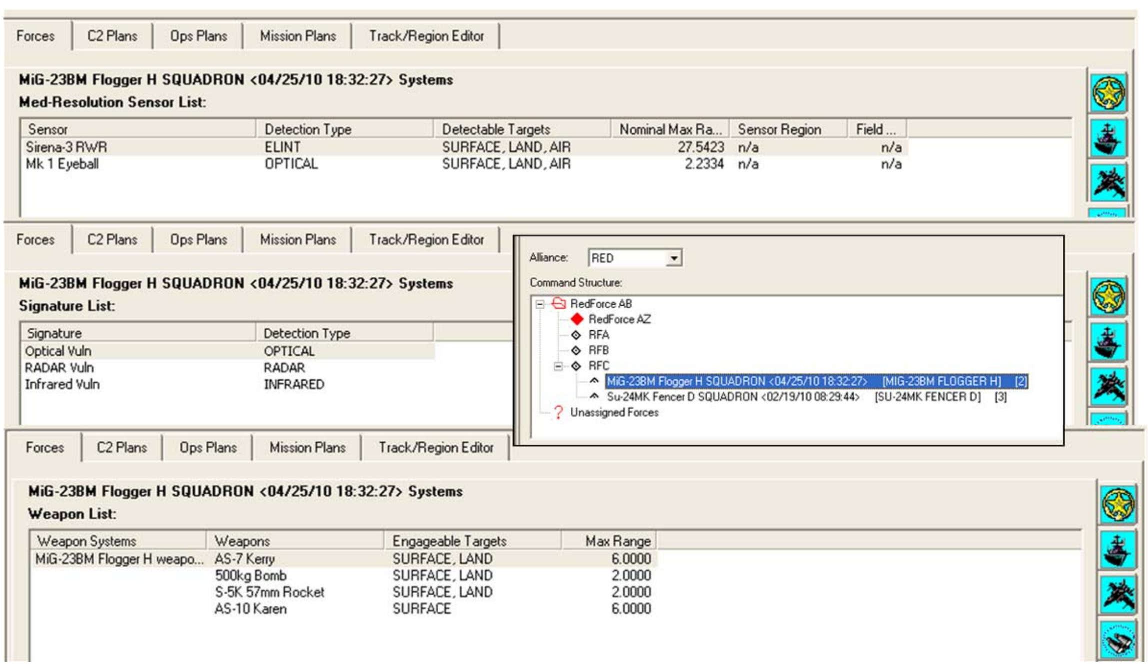


Figure 66. Hostile Force Instance Settings (cont.).

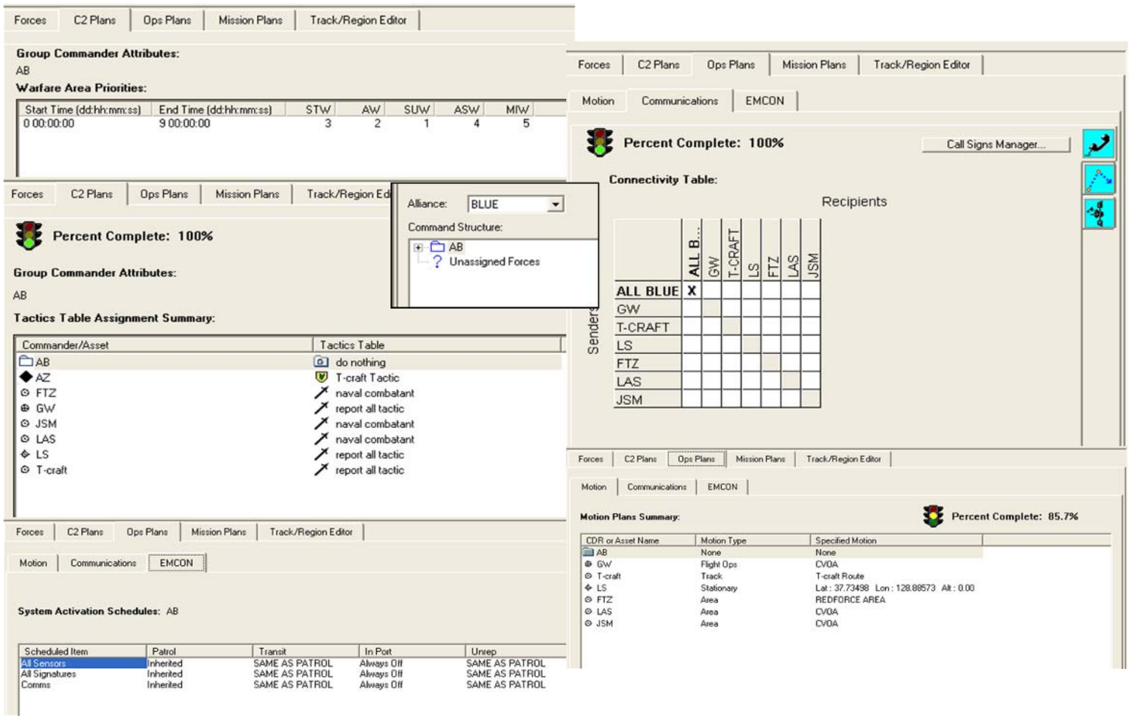


Figure 67. Blue Force Commander Settings.

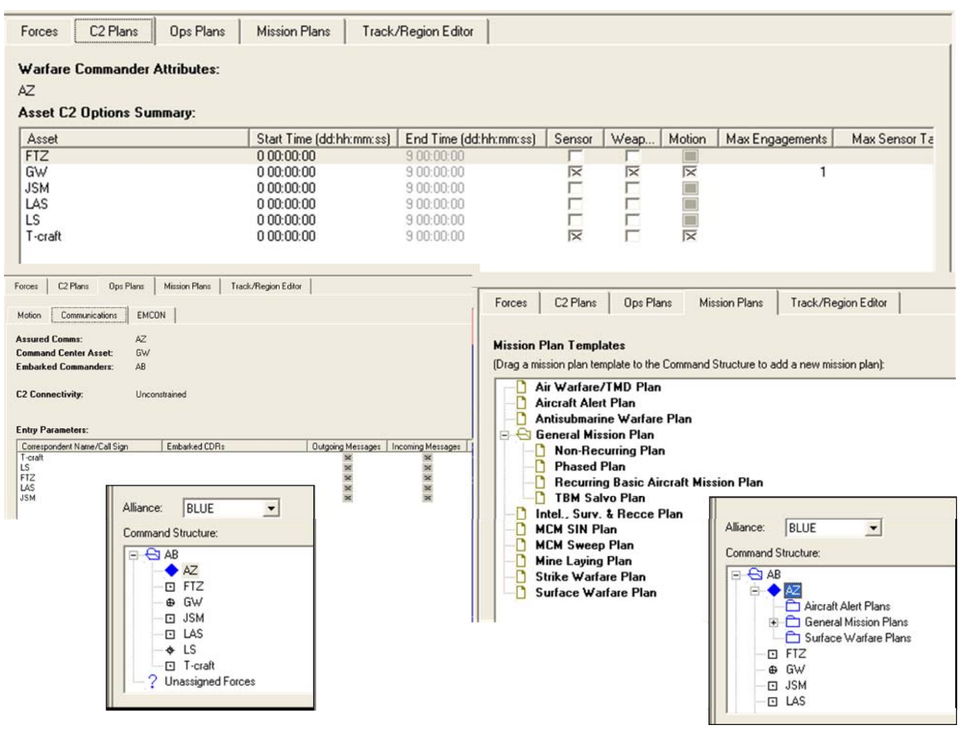


Figure 68. Blue Warfare Commander Settings.

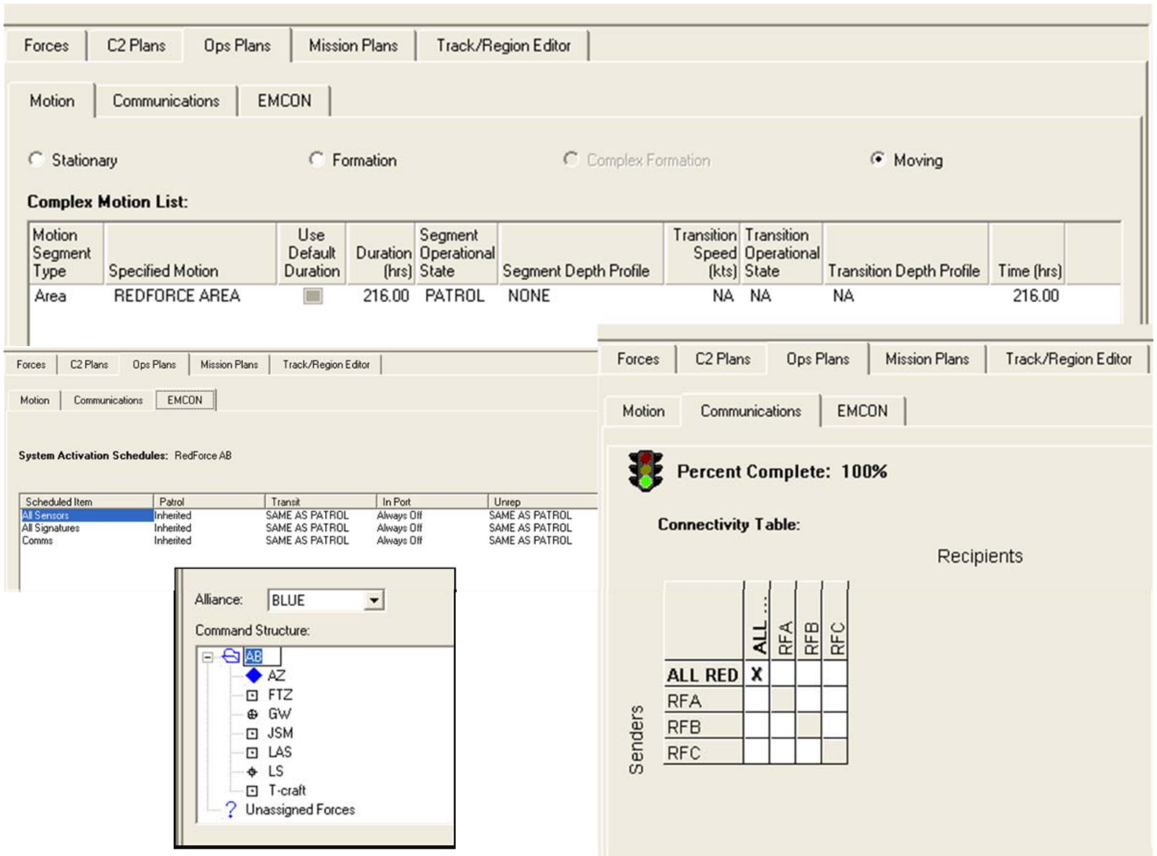


Figure 69. Warfare Commander Settings (cont.).

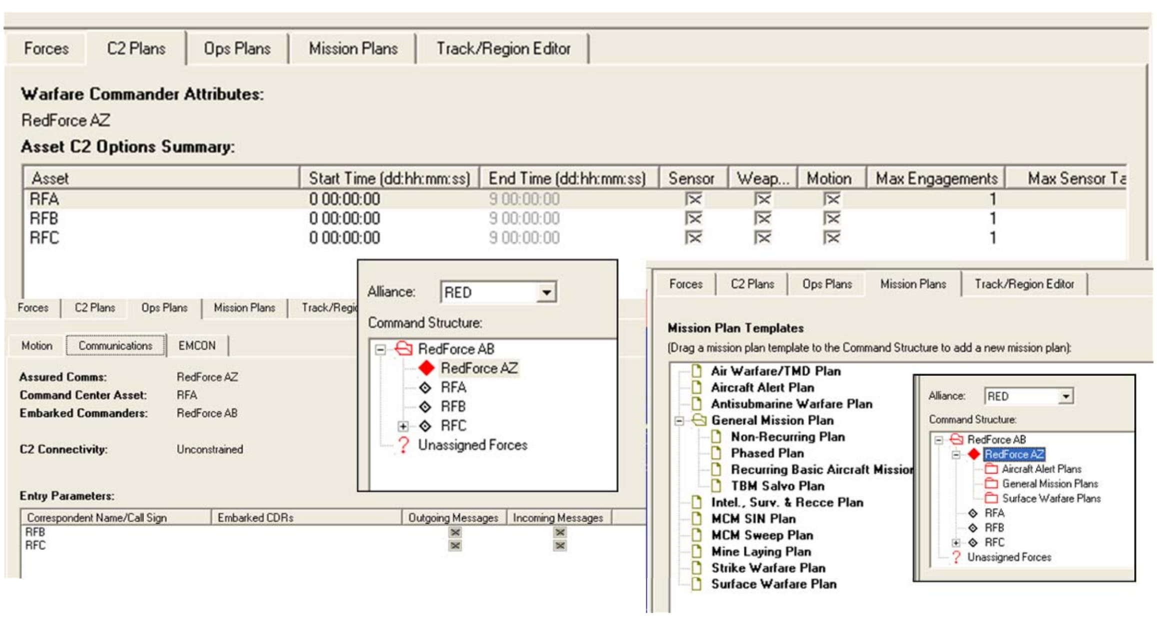


Figure 70. Red Warfare Commander Settings.

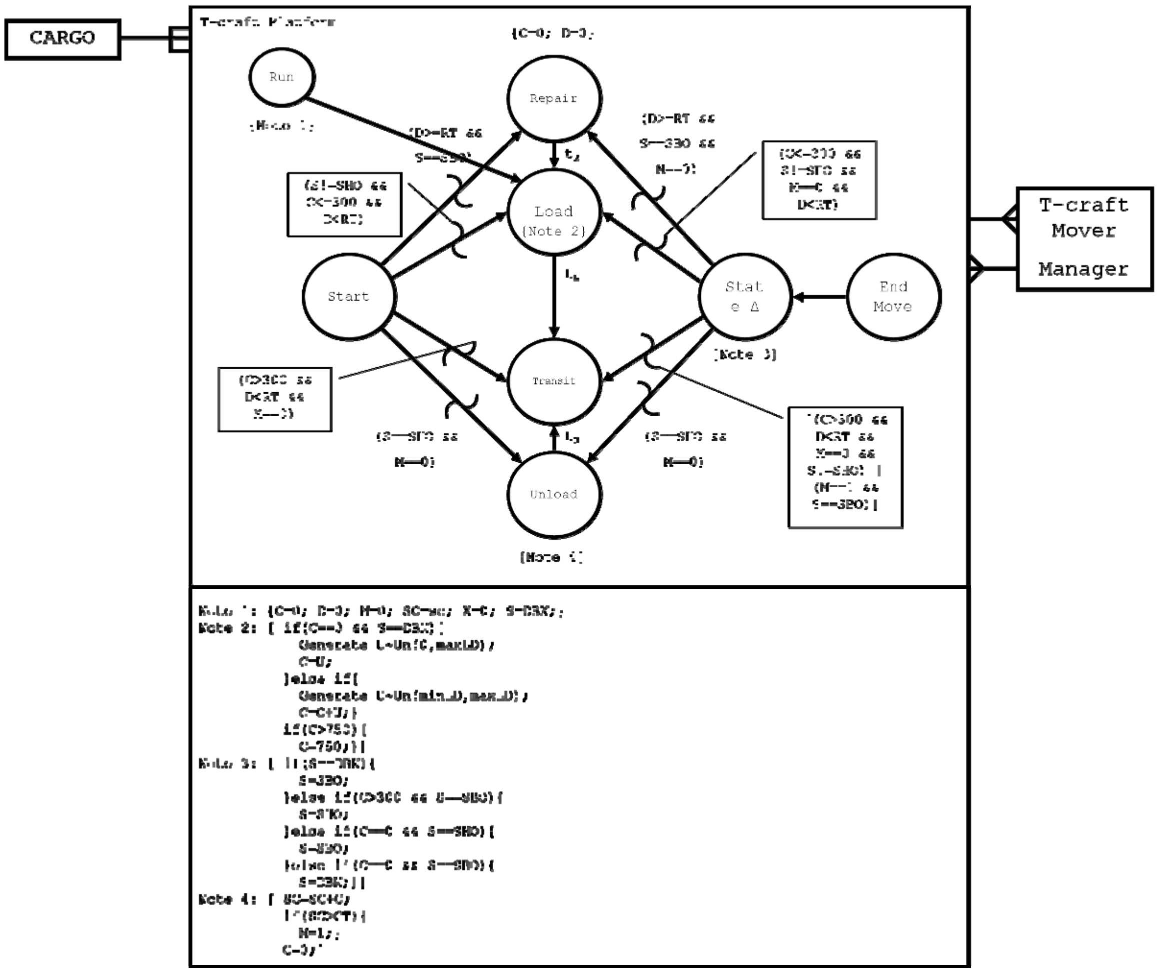


Figure 71. T-craft Platform Event Graph Object.

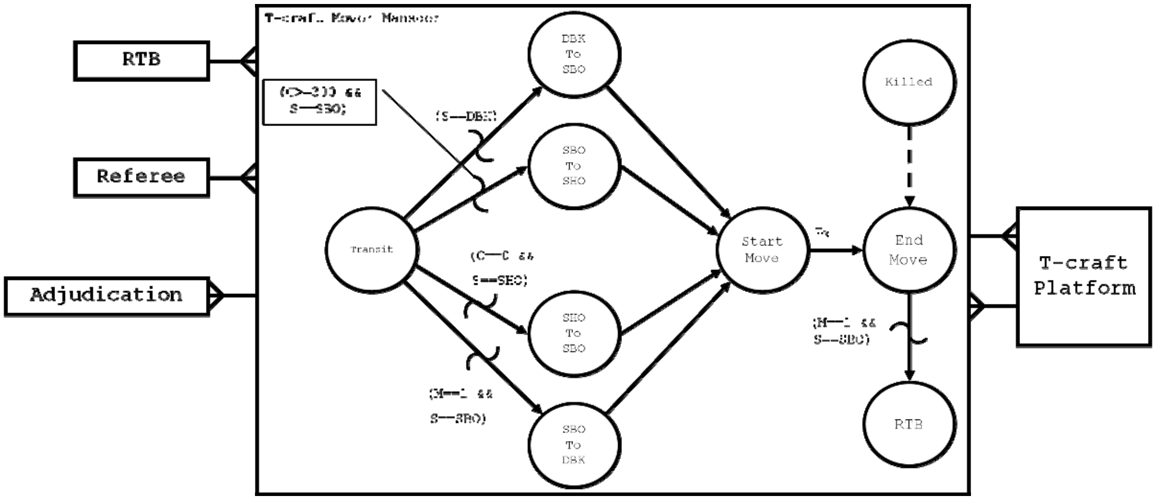


Figure 72. T-craft Mover Manager Event Graph Object.

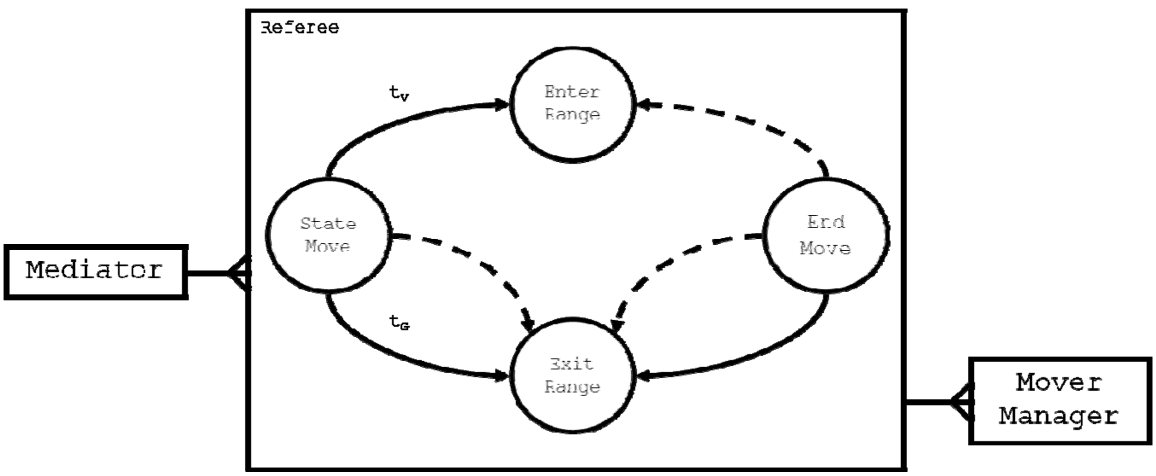


Figure 73. Generic Referee Event Graph Object.

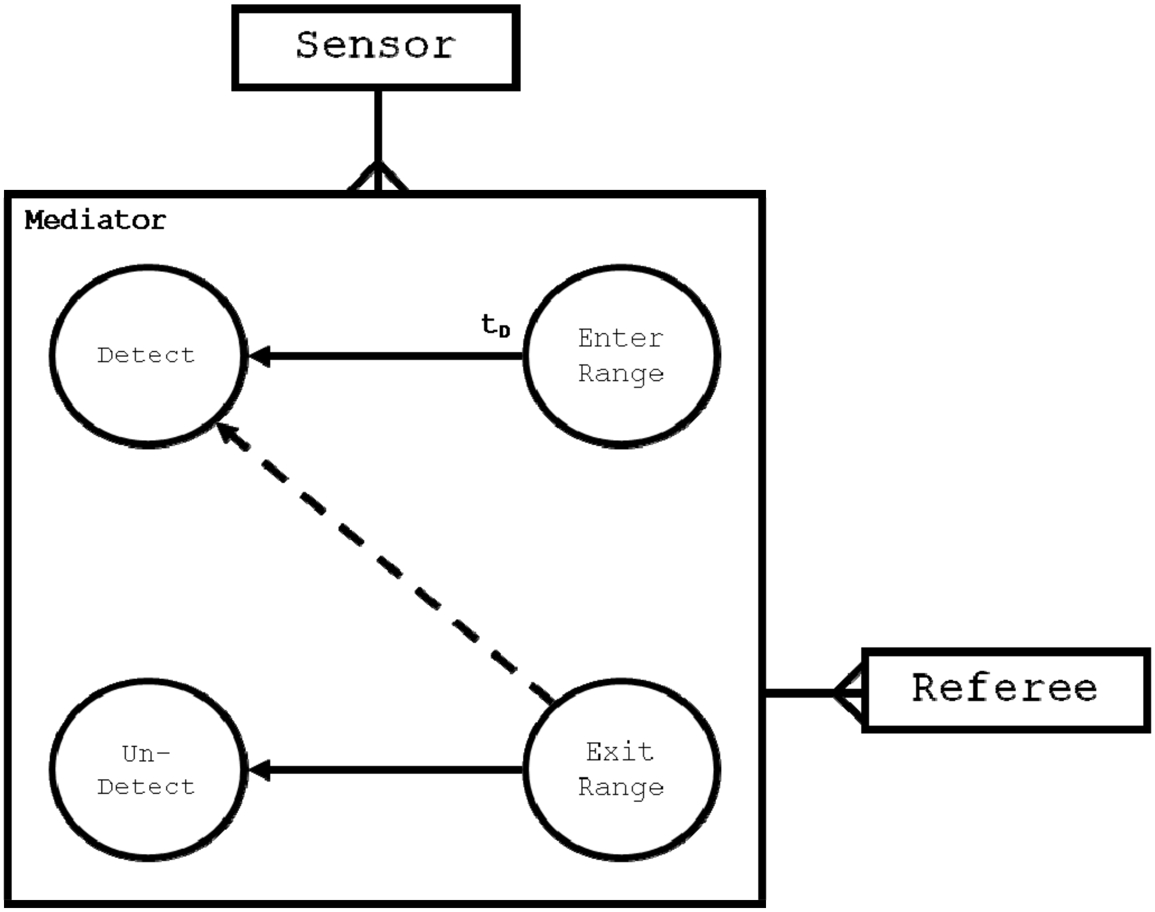


Figure 74. Generic Mediator Event Graph Object.

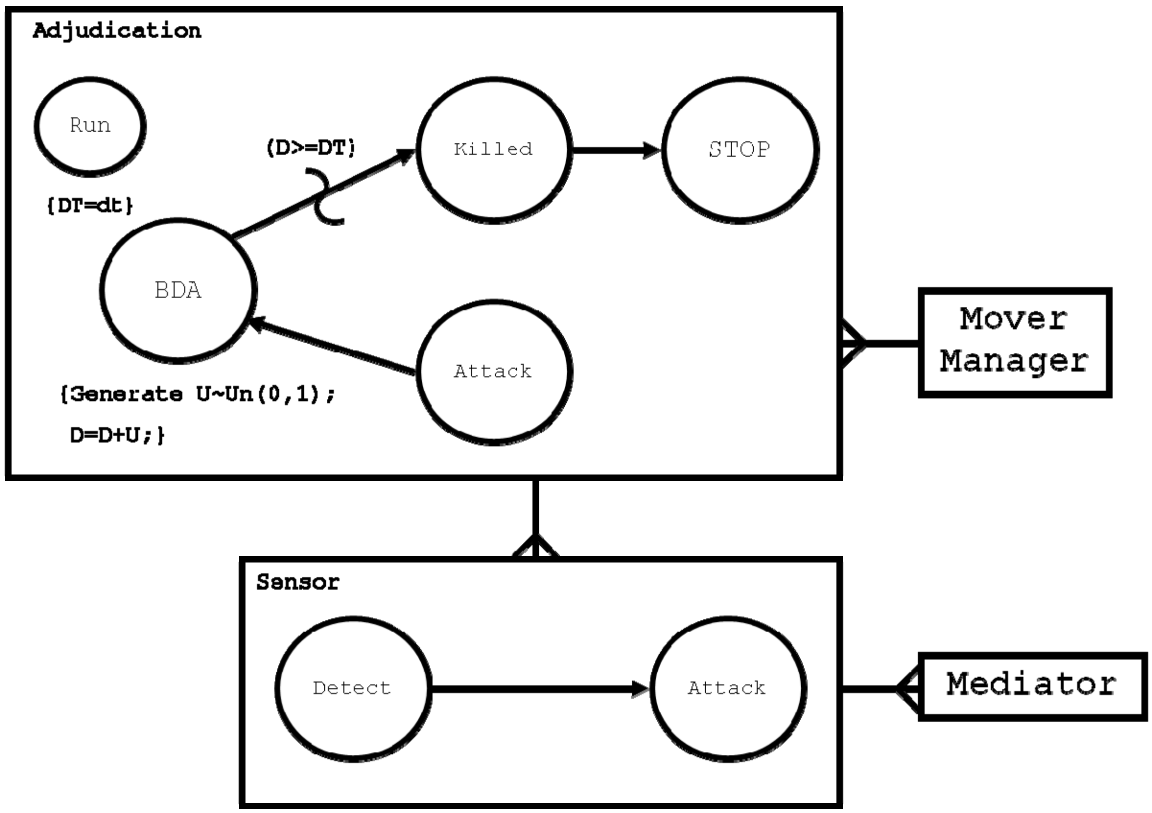


Figure 75. Sensor and Adjudication Event Graph Objects.

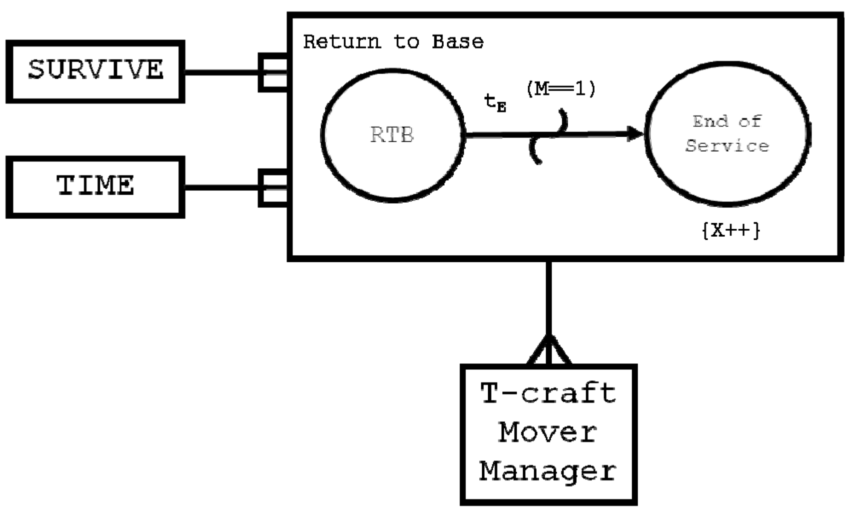


Figure 76. Return to Base Event Graph Object.

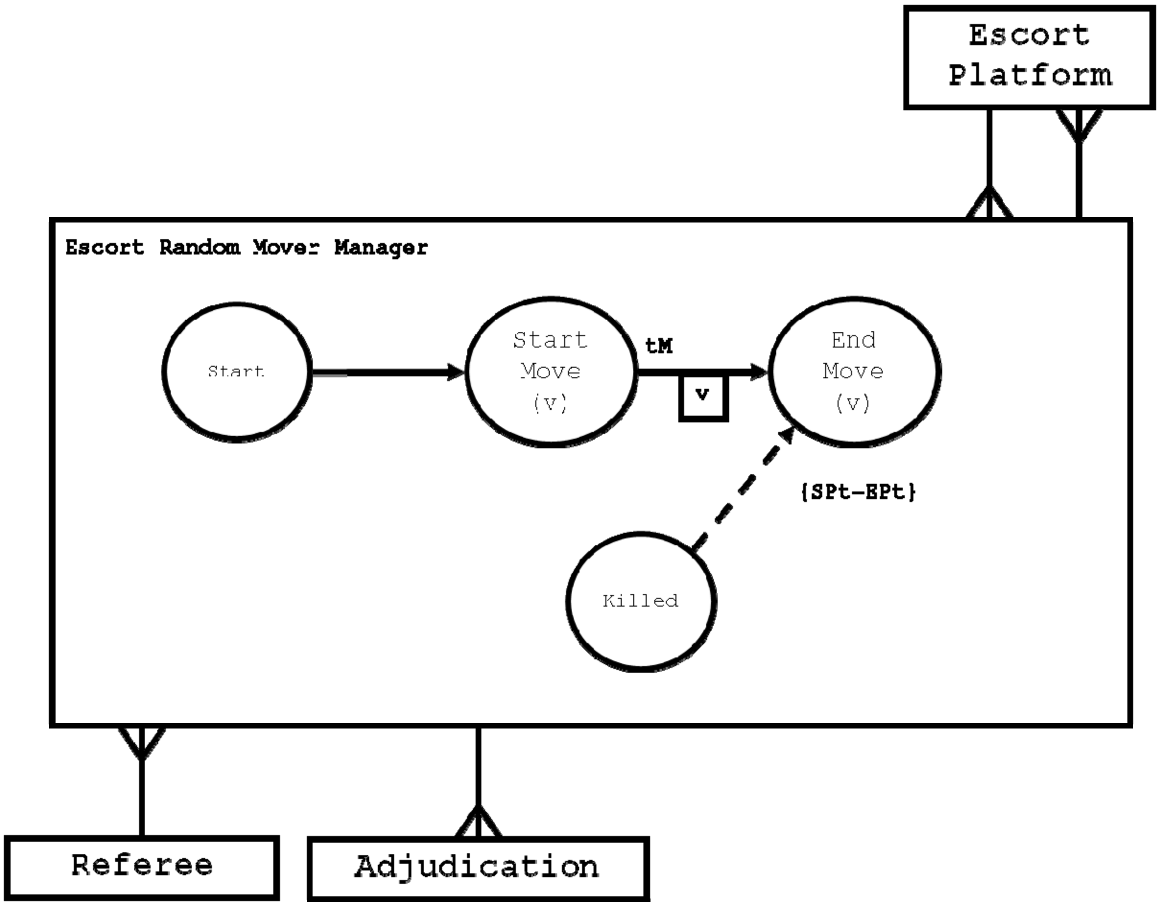


Figure 77. Escort Random Mover Manager Event Graph Object.

SimTime	Event	State (S)	Cargo (S)	Damage (D)	Mission Flag (M)	Shore Cargo (SC)	[Next Event]
0.00	Run	DBK	0.00	0.00	0	0.00	[0, Load]
0.00	Load	DBK	0.00	0.00	0	0.00	[0, Transit]
0.00	Transit	DBK	0.00	0.00	0	0.00	[0, DBK to SBO]
0.00	DBK to SBO	DBK	0.00	0.00	0	0.00	[0, Start Move]
0.00	Start Move	DBK	0.00	0.00	0	0.00	[5, End Move; 1 Enter Range; 5 Exit Range]
1.00	Enter Range	DBK	0.00	0.00	0	0.00	[5, End Move; 5 Exit Range; 2 Detect]
2.00	Detect	DBK	0.00	0.00	0	0.00	[5, End Move; 5 Exit Range; 2 Attack]
2.00	Attack	DBK	0.00	0.00	0	0.00	[5, End Move; 5 Exit Range; 2 BDA]
2.00	BDA	DBK	0.00	0.00	0	0.00	[5, End Move; 5 Exit Range]
5.00	End Move	DBK	0.00	0.00	0	0.00	[5, State; 5 Exit Range]
5.00	State Δ	SBO	0.00	0.00	0	0.00	[5, Exit Range; 5 Load]
5.00	Load	SBO	360.00	0.00	0	0.00	[5, Exit Range; 15, Transit]
5.00	Exit Range	SBO	360.00	0.00	0	0.00	[5, Un-Detect; 15, Transit]
5.00	Un-Detect	SBO	360.00	0.00	0	0.00	[15, Transit]
15.00	Transit	SBO	360.00	0.00	0	0.00	[15, SBO to SHO]
15.00	SBO to SHO	SBO	360.00	0.00	0	0.00	[15, Start Move]
15.00	Start Move	SBO	360.00	0.00	0	0.00	[20, End Move; 20 ,Exit Range; 16, Enter Range]
16.00	Enter Range	SBO	360.00	0.00	0	0.00	[20, End Move; 20, Exit Range; 17, Detect]
17.00	Detect	SBO	360.00	0.00	0	0.00	[20, End Move; 20, Exit Range; 17, Attack]
17.00	Attack	SBO	360.00	0.00	0	0.00	[20, End Move; 20, Exit Range; 17, BDA]
17.00	BDA	SBO	360.00	0.30	0	0.00	[20, End Move; 20, Exit Range]
20.00	End Move	SBO	360.00	0.30	0	0.00	[20, State; 20, Exit Range]
20.00	Exit Range	SBO	360.00	0.30	0	0.00	[20, State; 20, Un-Detect]
20.00	Un-Detect	SBO	360.00	0.30	0	0.00	[20, State]
20.00	State Δ	SHO	360.00	0.30	0	0.00	[20, Unload]
20.00	Unload	SHO	0.00	0.30	0	360.00	[30, Transit]
30.00	Transit	SHO	0.00	0.30	0	360.00	[30, SHO to SBO]
30.00	SHO to SBO	SHO	0.00	0.30	0	360.00	[30, Start Move]
30.00	Start Move	SHO	0.00	0.30	0	360.00	[35, End Move; 35 Exit Range; 31 Enter Range]
31.00	Enter Range	SHO	0.00	0.30	0	360.00	[35, End Move; 35, Exit Range; 32, Detect]
32.00	Detect	SHO	0.00	0.30	0	360.00	[35, End Move; 35, Exit Range; 32, Attack]
32.00	Attack	SHO	0.00	0.30	0	360.00	[35, End Move; 35, Exit Range; 32, BDA]
32.00	BDA	SHO	0.00	0.30	0	360.00	[35, End Move; 35, Exit Range]
35.00	End Move	SHO	0.00	0.30	0	360.00	[35, State; 35, Exit Range]
35.00	State Δ	SBO	0.00	0.30	0	360.00	[35, Exit Range; 35, Repair]
35.00	Repair	SBO	0.00	0.00	0	360.00	[35, Exit Range; 55, Load]
35.00	Exit Range	SBO	0.00	0.00	0	360.00	[55, Load; 35 Un-Detect]
35.00	Un-Detect	SBO	0.00	0.00	0	360.00	[55, Load]
55.00	Load	SBO	700.00	0.00	0	360.00	[65, Transit]
65.00	Transit	SBO	700.00	0.00	0	360.00	[65, SBO to SHO]
65.00	SBO to SHO	SBO	700.00	0.00	0	360.00	[65, Start Move]
65.00	Start Move	SBO	700.00	0.00	0	360.00	[70, End Move; 70 ,Exit Range; 66, Enter Range]
66.00	Enter Range	SBO	700.00	0.00	0	360.00	[70, End Move; 70, Exit Range; 67, Detect]
67.00	Detect	SBO	700.00	0.00	0	360.00	[70, End Move; 70, Exit Range; 67, Attack]
67.00	Attack	SBO	700.00	0.00	0	360.00	[70, End Move; 70, Exit Range; 67, BDA]
67.00	BDA	SBO	700.00	0.12	0	360.00	[70, End Move; 70, Exit Range]
70.00	End Move	SBO	700.00	0.12	0	360.00	[70, State; 70, Exit Range]
70.00	Exit Range	SBO	700.00	0.12	0	360.00	[70, State; 70, Un-Detect]
70.00	Un-Detect	SBO	700.00	0.12	0	360.00	[70, State]
70.00	State Δ	SHO	700.00	0.12	0	360.00	[70, Unload]
70.00	Unload	SHO	0.00	0.12	0	1060.00	[80, Transit]
80.00	Transit	SHO	0.00	0.12	0	1060.00	[80, SHO to SBO]
80.00	SHO to SBO	SHO	0.00	0.12	0	1060.00	[80, Start Move]
80.00	Start Move	SHO	0.00	0.12	0	1060.00	[85, End Move; 85 Exit Range; 81 Enter Range]
81.00	Enter Range	SHO	0.00	0.12	0	1060.00	[85, End Move; 85, Exit Range; 82, Detect]
82.00	Detect	SHO	0.00	0.12	0	1060.00	[85, End Move; 85, Exit Range; 82, Attack]
82.00	Attack	SHO	0.00	0.12	0	1060.00	[85, End Move; 85, Exit Range; 82, BDA]
82.00	BDA	SHO	0.00	1.02	0	1060.00	[85, End Move; 85, Exit Range; 82, Killed]
82.00	Killed	SHO	0.00	1.02	0	1060.00	[~~85, End Move~~; 85, Exit Range; 82, STOP]
82.00	STOP	SHO	0.00	1.02	0	1060.00	X = 0

MinLD	300.00	
MaxLD	750.00	
DT	0.80	
RT	0.30	
CT	750.00	
SL	1.00	
R	1.00	
L	1.00	
UL	1.00	
ST	2000.00	
G	20.00	20.00
H	0.00	0.00
I	-30.00	-30.00
SPt	20.00	20.00
EPt	19.39	196.23

t_E	1										
t_X	5										
t_L	10										
t_R	20										
t_U	10										
t_D	1										
u_C	0	160	400	500	350	700	120	330	750	0	0
u_C	360	700	400	500	350	700	550	330	750	300	300
d	0	0.3	0.12	0.9	0.5	0.44	0.12	0.21	0.4	0.88	0.31

Figure 78. Hand Simulation Design Point 1.

SimTime	Event	State (S)	Cargo (S)	Damage (D)	Mission Flag (M)	Shore Cargo (SC)	[Next Event]
0.00	Run	**DBK**	**0.00**	**0.00**	0	0.00	[0, Load]
0.00	Load	**DBK**	**300.00**	**0.00**	0	0.00	[0, Transit]
0.00	Transit	**DBK**	**300.00**	**0.00**	0	0.00	[0, DBK to SBO]
0.00	DBK to SBO	**DBK**	**300.00**	**0.00**	0	0.00	[0, Start Move]
0.00	Start Move	**DBK**	**300.00**	**0.00**	0	0.00	[5, End Move; 1 Enter Range; 5 Exit Range]
1.00	Enter Range	**DBK**	**300.00**	**0.00**	0	0.00	[5, End Move; 5 Exit Range; 2 Detect]
2.00	Detect	**DBK**	**300.00**	**0.00**	0	0.00	[5, End Move; 5 Exit Range; 2 Attack]
2.00	Attack	**DBK**	**300.00**	**0.00**	0	0.00	[5, End Move; 5 Exit Range; 2 BDA]
2.00	BDA	**DBK**	**300.00**	**0.00**	0	0.00	[5, End Move; 5 Exit Range]
5.00	End Move	**DBK**	**300.00**	**0.00**	0	0.00	[5, State; 5 Exit Range]
5.00	State Δ	**SBO**	**300.00**	**0.00**	0	0.00	[5, Exit Range; 5 Load]
5.00	Load	**SBO**	**660.00**	**0.00**	0	0.00	[5, Exit Range; 15, Transit]
5.00	Exit Range	**SBO**	**660.00**	**0.00**	0	0.00	[5, Un-Detect; 15, Transit]
5.00	Un-Detect	**SBO**	**660.00**	**0.00**	0	0.00	[15, Transit]
15.00	Transit	**SBO**	**660.00**	**0.00**	0	0.00	[15, SBO to SHO]
15.00	SBO to SHO	**SBO**	**660.00**	**0.00**	0	0.00	[15, Start Move]
15.00	Start Move	**SBO**	**660.00**	**0.00**	0	0.00	[20, End Move; 20 ,Exit Range; 16, Enter Range]
16.00	Enter Range	**SBO**	**660.00**	**0.00**	0	0.00	[20, End Move; 20, Exit Range; 17, Detect]
17.00	Detect	**SBO**	**660.00**	**0.00**	0	0.00	[20, End Move; 20, Exit Range; 17, Attack]
17.00	Attack	**SBO**	**660.00**	**0.00**	0	0.00	[20, End Move; 20, Exit Range; 17, BDA]
17.00	BDA	**SBO**	**660.00**	**0.30**	0	0.00	[20, End Move; 20, Exit Range]
20.00	End Move	**SBO**	**660.00**	**0.30**	0	0.00	[20, State; 20, Exit Range]
20.00	Exit Range	**SBO**	**660.00**	**0.30**	0	0.00	[20, State; 20, Un-Detect]
20.00	Un-Detect	**SBO**	**660.00**	**0.30**	0	0.00	[20, State]
20.00	State Δ	**SHO**	**660.00**	**0.30**	0	0.00	[20, Unload]
20.00	Unload	**SHO**	**0.00**	**0.30**	0	660.00	[30, Transit]
30.00	Transit	**SHO**	**0.00**	**0.30**	0	660.00	[30, SHO to SBO]
30.00	SHO to SBO	**SHO**	**0.00**	**0.30**	0	660.00	[30, Start Move]
30.00	Start Move	**SHO**	**0.00**	**0.30**	0	660.00	[35, End Move; 35 Exit Range; 31 Enter Range]
31.00	Enter Range	**SHO**	**0.00**	**0.30**	0	660.00	[35, End Move; 35, Exit Range; 32, Detect]
32.00	Detect	**SHO**	**0.00**	**0.30**	0	660.00	[35, End Move; 35, Exit Range; 32, Attack]
32.00	Attack	**SHO**	**0.00**	**0.30**	0	660.00	[35, End Move; 35, Exit Range; 32, BDA]
32.00	BDA	**SHO**	**0.00**	**0.30**	0	660.00	[35, End Move; 35, Exit Range]
35.00	End Move	**SHO**	**0.00**	**0.30**	0	660.00	[35, State; 35, Exit Range]
35.00	State Δ	**SBO**	**0.00**	**0.30**	0	660.00	[35, Exit Range; 35, Repair]
35.00	Repair	**SBO**	**0.00**	**0.00**	0	660.00	[35, Exit Range; 55, Load]
35.00	Exit Range	**SBO**	**0.00**	**0.00**	0	660.00	[55, Load; 35 Un-Detect]
35.00	Un-Detect	**SBO**	**0.00**	**0.00**	0	660.00	[55, Load]
55.00	Load	**SBO**	**700.00**	**0.00**	0	660.00	[65, Transit]
65.00	Transit	**SBO**	**700.00**	**0.00**	0	660.00	[65, SBO to SHO]
65.00	SBO to SHO	**SBO**	**700.00**	**0.00**	0	660.00	[65, Start Move]
65.00	Start Move	**SBO**	**700.00**	**0.00**	0	660.00	[70, End Move; 70 ,Exit Range; 66, Enter Range]
66.00	Enter Range	**SBO**	**700.00**	**0.00**	0	660.00	[70, End Move; 70, Exit Range; 67, Detect]
67.00	Detect	**SBO**	**700.00**	**0.00**	0	660.00	[70, End Move; 70, Exit Range; 67, Attack]
67.00	Attack	**SBO**	**700.00**	**0.00**	0	660.00	[70, End Move; 70, Exit Range; 67, BDA]
67.00	BDA	**SBO**	**700.00**	**0.12**	0	660.00	[70, End Move; 70, Exit Range]
70.00	End Move	**SBO**	**700.00**	**0.12**	0	660.00	[70, State; 70, Exit Range]
70.00	Exit Range	**SBO**	**700.00**	**0.12**	0	660.00	[70, State; 70, Un-Detect]
70.00	Un-Detect	**SBO**	**700.00**	**0.12**	0	660.00	[70, State]
70.00	State Δ	**SHO**	**700.00**	**0.12**	0	660.00	[70, Unload]
70.00	Unload	**SHO**	**0.00**	**0.12**	0	1360.00	[80, Transit]
80.00	Transit	**SHO**	**0.00**	**0.12**	0	1360.00	[80, SHO to SBO]
80.00	SHO to SBO	**SHO**	**0.00**	**0.12**	0	1360.00	[80, Start Move]
80.00	Start Move	**SHO**	**0.00**	**0.12**	0	1360.00	[85, End Move; 85 Exit Range; 81 Enter Range]
81.00	Enter Range	**SHO**	**0.00**	**0.12**	0	1360.00	[85, End Move; 85, Exit Range; 82, Detect]
82.00	Detect	**SHO**	**0.00**	**0.12**	0	1360.00	[85, End Move; 85, Exit Range; 82, Attack]
82.00	Attack	**SHO**	**0.00**	**0.12**	0	1360.00	[85, End Move; 85, Exit Range; 82, BDA]
82.00	BDA	**SHO**	**0.00**	**0.72**	0	1360.00	[85, End Move; 85, Exit Range; 82, Killed]
85.00	End Move	**SHO**	**0.00**	**0.72**	0	1360.00	[85, State; 85, Exit Range]
85.00	State Δ	**SBO**	**0.00**	**0.72**	0	1360.00	[85, Exit Range; 85, Repair]
85.00	Repair	**SBO**	**0.00**	**0.00**	0	1360.00	[85, Exit Range; 105, Load]
85.00	Exit Range	**SBO**	**0.00**	**0.00**	0	1360.00	[105, Load; 85 Un-Detect]
85.00	Un-Detect	**SBO**	**0.00**	**0.00**	0	1360.00	[105, Load]
105.00	Load	**SBO**	**400.00**	**0.00**	0	1360.00	[115, Transit]
115.00	Transit	**SBO**	**400.00**	**0.00**	0	1360.00	[115,SBO to SHO]
115.00	SBO to SHO	**SBO**	**400.00**	**0.00**	0	1360.00	[115, Start Move]
115.00	Start Move	**SBO**	**400.00**	**0.00**	0	1360.00	[120, End Move; 120 ,Exit Range; 116, Enter Range]
116.00	Enter Range	**SBO**	**400.00**	**0.00**	0	1360.00	[120, End Move; 120, Exit Range;117, Detect]
117.00	Detect	**SBO**	**400.00**	**0.00**	0	1360.00	[120, End Move; 120, Exit Range;117, Attack]
117.00	Attack	**SBO**	**400.00**	**0.00**	0	1360.00	[120, End Move; 120, Exit Range; 117, BDA]
117.00	BDA	**SBO**	**400.00**	**0.32**	0	1360.00	[120, End Move; 120, Exit Range]
120.00	End Move	**SBO**	**400.00**	**0.32**	0	1360.00	[120, State; 120, Exit Range]
120.00	Exit Range	**SBO**	**400.00**	**0.32**	0	1360.00	[120, State; 120, Un-Detect]

MinLD	300.00	
MaxLD	750.00	
DT	0.80	
RT	0.30	
CT	750.00	
SL	1.00	
R	1.00	
L	1.00	
UL	1.00	
ST	2000.00	
G	20.00	20.00
H	0.00	0.00
I	-30.00	-30.00
SPt	20.00	20.00
EPt	300.41	431.74

t_E	1										
t_X	5										
t_L	10										
t_R	20										
t_U	10										
t_D	1										
u_C	300	160	400	500	350	700	120	330	750	0	0
u_C	360	700	400	500	350	700	550	330	750	300	300
d	0	0.3	0.12	0.6	0.32	0.11	0.05	0.69	0.4	0.88	0.31

Figure 79. Hand Simulation Design Point 2.

SimTime	Event	State (S)	Cargo (S)	Damage (D)	Mission Flag (M)	Shore Cargo (SC)	[Next Event]
0.00	Run	DBK	0.00	0.00	0	0.00	[0, Load]
0.00	Load	DBK	750.00	0.00	0	0.00	[0, Transit]
0.00	Transit	DBK	750.00	0.00	0	0.00	[0, DBK to SBO]
0.00	DBK to SBO	DBK	750.00	0.00	0	0.00	[0, Start Move]
0.00	Start Move	DBK	750.00	0.00	0	0.00	[5, End Move; 1 Enter Range; 5 Exit Range]
1.00	Enter Range	DBK	750.00	0.00	0	0.00	[5, End Move; 5 Exit Range; 2 Detect]
2.00	Detect	DBK	750.00	0.00	0	0.00	[5, End Move; 5 Exit Range; 2 Attack]
2.00	Attack	DBK	750.00	0.00	0	0.00	[5, End Move; 5 Exit Range; 2 BDA]
2.00	BDA	DBK	750.00	0.00	0	0.00	[5, End Move; 5 Exit Range]
5.00	End Move	DBK	750.00	0.00	0	0.00	[5, State; 5 Exit Range]
5.00	State Δ	SBO	750.00	0.00	0	0.00	[5, Exit Range; 5 Transit]
5.00	Exit Range	SBO	750.00	0.00	0	0.00	[5, Transit; 5, Un-Detect]
5.00	Transit	SBO	750.00	0.00	0	0.00	[5, SBO to SHO]
5.00	SBO to SHO	SBO	750.00	0.00	0	0.00	[5, Start Move]
5.00	Start Move	SBO	750.00	0.00	0	0.00	[10, End Move; 10 ,Exit Range; 6, Enter Range]
6.00	Enter Range	SBO	750.00	0.00	0	0.00	[10, End Move; 10, Exit Range; 7, Detect]
7.00	Detect	SBO	750.00	0.00	0	0.00	[10, End Move; 10, Exit Range; 7, Attack]
7.00	Attack	SBO	750.00	0.00	0	0.00	[10, End Move; 10, Exit Range; 17, BDA]
7.00	BDA	SBO	750.00	0.30	0	0.00	[10, End Move; 10, Exit Range]
10.00	End Move	SBO	750.00	0.30	0	0.00	[10, State; 10, Exit Range]
10.00	Exit Range	SBO	750.00	0.30	0	0.00	[10, State; 10, Un-Detect]
10.00	Un-Detect	SBO	750.00	0.30	0	0.00	[10, State]
10.00	State Δ	SBO	750.00	0.30	0	0.00	[10, Repair]
10.00	Repair	SBO	0.00	0.00	0	0.00	[30, Load]
30.00	Load	SBO	360.00	0.00	0	0.00	[30, Transit]
30.00	Transit	SBO	360.00	0.00	0	0.00	[30, SBO to SHO]
30.00	SBO to SHO	SBO	360.00	0.00	0	0.00	[30, Start Move]
30.00	Start Move	SBO	360.00	0.00	0	0.00	[35, End Move; 35 ,Exit Range; 31, Enter Range]
31.00	Enter Range	SBO	360.00	0.00	0	0.00	[35, End Move; 35, Exit Range; 32, Detect]
32.00	Detect	SBO	360.00	0.00	0	0.00	[35, End Move; 35, Exit Range; 32, Attack]
32.00	Attack	SBO	360.00	0.00	0	0.00	[35, End Move; 35, Exit Range; 32, BDA]
32.00	BDA	SBO	360.00	0.12	0	0.00	[35, End Move; 35, Exit Range]
35.00	End Move	SBO	360.00	0.12	0	0.00	[35, State; 35, Exit Range]
35.00	Exit Range	SBO	360.00	0.12	0	0.00	[35, State; 35, Un-Detect]
35.00	Un-Detect	SBO	360.00	0.12	0	0.00	[35, State]
35.00	State Δ	SHO	360.00	0.12	0	0.00	[35, Unload]
35.00	Unload	SHO	0.00	0.12	0	360.00	[45, Transit]
45.00	Transit	SHO	0.00	0.12	0	360.00	[45, SHO to SBO]
45.00	SHO to SBO	SHO	0.00	0.12	0	360.00	[45, Start Move]
45.00	Start Move	SHO	0.00	0.12	0	360.00	[50, End Move; 50, Exit Range; 46, Enter Range]
46.00	Enter Range	SHO	0.00	0.12	0	360.00	[50, End Move; 50, Exit Range; 47, Detect]
47.00	Detect	SHO	0.00	0.12	0	360.00	[50, End Move; 50, Exit Range; 47, Attack]
47.00	Attack	SHO	0.00	0.12	0	360.00	[50, End Move; 50, Exit Range; 47, BDA]
47.00	BDA	SHO	0.00	0.12	0	360.00	[50, End Move; 50, Exit Range]
50.00	End Move	SHO	0.00	0.12	0	360.00	[50, State; 50, Exit Range]
50.00	State Δ	SBO	0.00	0.12	0	360.00	[50, Exit Range; 50, Load]
50.00	Exit Range	SBO	0.00	0.12	0	360.00	[50, Load, 50, Un-Detect]
50.00	Un-Detect	SBO	0.00	0.12	0	360.00	[50, Load]
50.00	Load	SBO	700.00	0.12	0	360.00	[60, Transit]
60.00	Transit	SBO	700.00	0.12	0	360.00	[60, SBO to SHO]
60.00	SBO to SHO	SBO	700.00	0.12	0	360.00	[60, Start Move]
60.00	Start Move	SBO	700.00	0.12	0	360.00	[65, End Move; 65 ,Exit Range; 61, Enter Range]
61.00	Enter Range	SBO	700.00	0.12	0	360.00	[65, End Move; 65, Exit Range; 62, Detect]
62.00	Detect	SBO	700.00	0.12	0	360.00	[65, End Move; 65, Exit Range; 62, Attack]
62.00	Attack	SBO	700.00	0.12	0	360.00	[65, End Move; 65, Exit Range; 62, BDA]
62.00	BDA	SBO	700.00	1.02	0	360.00	[65, End Move; 65, Exit Range; 62, Killed]
62.00	Killed	SBO	700.00	1.02	0	360.00	[~~65, End Move~~; 65, Exit Range; 65, Un-Detect; 62, STOP]
62.00	STOP	SBO	700.00	1.02	0	360.00	[~~125, Exit Range; 125, Un-Detect~~] (X = 0)

MinLD	300.00	
MaxLD	750.00	
DT	0.80	
RT	0.30	
CT	750.00	
SL	1.00	
R	1.00	
L	1.00	
UL	1.00	
ST	2000.00	
G	20.00	20.00
H	0.00	0.00
I	-30.00	-30.00
SPt	20.00	20.00
EPt	587.60	17.47

t_X	5
t_L	10
t_R	20
t_U	10
t_D	1

u_c	750	160	400	500	350	700	120	330	750	0	0
u_c	360	700	400	500	350	700	550	330	750	300	300
d	0	0.3	0.12	0	0.9	0.44	0.12	0.21	0.4	0.88	0.31

Figure 80. Hand Simulation Design Point 3.

SimTime	Event	State (S)	Cargo (S)	Damage (D)	Mission Flag (M)	Shore Cargo (SC)	[Next Event]
0.00	Run	SBO	0.00	0.00	0	0.00	[0, Load]
0.00	Load	SBO	300.00	0.00	0	0.00	[0, Transit]
0.00	Transit	SBO	300.00	0.00	0	0.00	[0, SBO to SHO]
0.00	SBO to SHO	SBO	300.00	0.00	0	0.00	[0, Start Move]
0.00	Start Move	SBO	300.00	0.00	0	0.00	[5, End Move; 5, Exit Range; 1, Enter Range]
1.00	Enter Range	SBO	300.00	0.00	0	0.00	[5, End Move; 5, Exit Range; 2, Detect]
2.00	Detect	SBO	300.00	0.00	0	0.00	[5, End Move; 5, Exit Range; 2, Attack]
2.00	Attack	SBO	300.00	0.00	0	0.00	[5, End Move; 5, Exit Range; 2, BDA]
2.00	BDA	SBO	300.00	0.50	0	0.00	[5, End Move; 5, Exit Range]
5.00	Exit Range	SBO	300.00	0.50	0	0.00	[5, End Move; 5, Un-Detect]
5.00	Un-Detect	SBO	300.00	0.50	0	0.00	[5, End Move]
5.00	End Move	SBO	300.00	0.50	0	0.00	[5, State]
5.00	State Δ	SHO	300.00	0.50	0	0.00	[5, Unload]
5.00	Unload	SHO	0.00	0.50	0	300.00	[15, Transit]
15.00	Transit	SHO	0.00	0.50	0	300.00	[15, SHO to SBO]
15.00	SHO to SBO	SHO	0.00	0.50	0	300.00	[15, Start Move]
15.00	Start Move	SHO	0.00	0.50	0	300.00	[20, End Move; 20, Exit Range; 16, Enter Range]
16.00	Enter Range	SHO	0.00	0.50	0	300.00	[20, End Move; 20, Exit Range; 17, Detect]
17.00	Detect	SHO	0.00	0.50	0	300.00	[20, End Move; 20, Exit Range; 17, Attack]
17.00	Attack	SHO	0.00	0.50	0	300.00	[20, End Move; 20, Exit Range; 17, BDA]
17.00	BDA	SHO	0.00	0.55	0	300.00	[20, End Move; 20, Exit Range]
20.00	Exit Range	SHO	0.00	0.55	0	300.00	[20, End Move; 20, Un-Detect]
20.00	End Move	SHO	0.00	0.55	0	300.00	[20, State; ~~20, Un-Detect~~]
20.00	State Δ	SBO	0.00	0.55	0	300.00	[20, Repair]
20.00	Repair	SBO	0.00	0.00	0	300.00	[40, Load]
40.00	Load	SBO	550.00	0.00	0	300.00	[40, Transit]
40.00	Transit	SBO	550.00	0.00	0	300.00	[40, SBO to SHO]
40.00	SBO to SHO	SBO	550.00	0.00	0	300.00	[0, Start Move]
40.00	Start Move	SBO	550.00	0.00	0	300.00	[45, End Move; 45, Exit Range; 41, Enter Range]
41.00	Enter Range	SBO	550.00	0.00	0	300.00	[45, End Move; 45, Exit Range; 42, Detect]
42.00	Detect	SBO	550.00	0.00	0	300.00	[45, End Move; 45, Exit Range; 42, Attack]
42.00	Attack	SBO	550.00	0.00	0	300.00	[45, End Move; 45, Exit Range; 42, BDA]
42.00	BDA	SBO	550.00	0.07	0	300.00	[45, End Move; 45, Exit Range]
45.00	Exit Range	SBO	550.00	0.07	0	300.00	[45, End Move; 45, Un-Detect]
45.00	Un-Detect	SBO	550.00	0.07	0	300.00	[45, End Move]
45.00	End Move	SBO	550.00	0.07	0	300.00	[45, State]
45.00	State Δ	SHO	550.00	0.07	0	300.00	[45, Unload]
45.00	Unload	SHO	0.00	0.07	0	850.00	[45, Transit]
45.00	Transit	SHO	0.00	0.07	0	850.00	[45, SHO to SBO]
45.00	SHO to SBO	SHO	0.00	0.07	0	850.00	[45, Start Move]
45.00	Start Move	SHO	0.00	0.07	0	850.00	[50, End Move; 50, Exit Range; 46, Enter Range]
46.00	Enter Range	SHO	0.00	0.07	0	850.00	[50, End Move; 50, Exit Range; 47, Detect]
47.00	Detect	SHO	0.00	0.07	0	850.00	[50, End Move; 50, Exit Range; 47, Attack]
47.00	Attack	SHO	0.00	0.07	0	850.00	[50, End Move; 50, Exit Range; 47, BDA]
47.00	BDA	SHO	0.00	0.12	0	850.00	[50, End Move; 50, Exit Range]
50.00	Exit Range	SHO	0.00	0.12	0	850.00	[50, End Move; 50, Un-Detect]
50.00	Un-Detect	SHO	0.00	0.12	0	850.00	[50, End Move]
50.00	End Move	SHO	0.00	0.12	0	850.00	[50, State]
50.00	State Δ	SBO	0.00	0.12	0	850.00	[50, Load]
50.00	Load	SBO	680.00	0.12	0	850.00	[50, Transit]
50.00	Transit	SBO	680.00	0.12	0	850.00	[50, SBO to SHO]
50.00	SBO to SHO	SBO	680.00	0.12	0	850.00	[50, Start Move]
50.00	Start Move	SBO	680.00	0.12	0	850.00	[55, End Move; 55, Exit Range; 51, Enter Range]
51.00	Enter Range	SBO	680.00	0.12	0	850.00	[55, End Move; 55, Exit Range; 52, Detect]
52.00	Detect	SBO	680.00	0.12	0	850.00	[55, End Move; 55, Exit Range; 52, Attack]
52.00	Attack	SBO	680.00	0.12	0	850.00	[55, End Move; 55, Exit Range; 52, BDA]
52.00	BDA	SBO	680.00	0.37	0	850.00	[55, End Move; 55, Exit Range]
55.00	Exit Range	SBO	680.00	0.37	0	850.00	[55, End Move; 55, Un-Detect]
55.00	Un-Detect	SBO	680.00	0.37	0	850.00	[55, End Move]
55.00	End Move	SBO	680.00	0.37	0	850.00	[55, State]
55.00	State Δ	SHO	680.00	0.37	0	850.00	[55, Unload]
55.00	Unload	SHO	0.00	0.37	0	1530.00	[65, Transit]
65.00	Transit	SHO	0.00	0.37	0	1530.00	[65, SHO to SBO]
65.00	SHO to SBO	SHO	0.00	0.37	0	1530.00	[65, Start Move]
65.00	Start Move	SHO	0.00	0.37	0	1530.00	[70, End Move; 70, Exit Range; 66, Enter Range]
66.00	Enter Range	SHO	0.00	0.37	0	1530.00	[70, End Move; 70, Exit Range; 67, Detect]
67.00	Detect	SHO	0.00	0.37	0	1530.00	[70, End Move; 70, Exit Range; 67, Attack]
67.00	Attack	SHO	0.00	0.37	0	1530.00	[70, End Move; 70, Exit Range; 67, BDA]
67.00	BDA	SHO	0.00	0.77	0	1530.00	[70, End Move; 70, Exit Range]
70.00	Exit Range	SHO	0.00	0.77	0	1530.00	[70, End Move; 70, Un-Detect]
70.00	Un-Detect	SHO	0.00	0.77	0	1530.00	[70, End Move]
70.00	End Move	SHO	0.00	0.77	0	1530.00	[70, State]
70.00	State Δ	SBO	0.00	0.77	0	1530.00	[70, Repair]

MinLD	300.00	
MaxLD	750.00	
DT	0.80	
RT	0.30	
CT	750.00	
SL	1.00	
R	1.00	
L	1.00	
UL	1.00	
ST	2000.00	
G	20.00	20.00
H	0.00	0.00
I	-30.00	-30.00
SPt	20.00	20.00
EPt	597.73	132.39

t_E	1										
t_X	5										
t_L	10										
t_R	20										
t_U	10										
t_D	1										
u_c	200	160	400	500	350	700	120	330	750	0	0
u_c	300	550	680	500	750	700	350	450	488	344	300
d	0.5	0.05	0.07	0.05	0.25	0.4	0	0.4	0.9	0.95	0.55

Figure 81. Hand Simulation Design Point 5.

SimTime	Event	State (S)	Cargo (S)	Damage (D)	Mission Flag (M)	Shore Cargo (SC)	[Next Event]
0.00	Run	SBO	0.00	0.00	0	0.00	[0, Load]
0.00	Load	SBO	750.00	0.00	0	0.00	[0, Transit]
0.00	Transit	SBO	750.00	0.00	0	0.00	[0, SBO to SHO]
0.00	SBO to SHO	SBO	750.00	0.00	0	0.00	[0, Start Move]
0.00	Start Move	SBO	750.00	0.00	0	0.00	[5, End Move; 5, Exit Range; 1, Enter Range]
1.00	Enter Range	SBO	750.00	0.00	0	0.00	[5, End Move; 5, Exit Range; 2, Detect]
2.00	Detect	SBO	750.00	0.00	0	0.00	[5, End Move; 5, Exit Range; 2, Attack]
2.00	Attack	SBO	750.00	0.00	0	0.00	[5, End Move; 5, Exit Range; 2, BDA]
2.00	BDA	SBO	750.00	0.50	0	0.00	[5, End Move; 5, Exit Range]
5.00	Exit Range	SBO	750.00	0.50	0	0.00	[5, End Move; 5, Un-Detect]
5.00	Un-Detect	SBO	750.00	0.50	0	0.00	[5, End Move]
5.00	End Move	SBO	750.00	0.50	0	0.00	[5, State]
5.00	State Δ	SHO	750.00	0.50	0	0.00	[5, Unload]
5.00	Unload	SHO	0.00	0.50	0	750.00	[15, Transit]
15.00	Transit	SHO	0.00	0.50	0	750.00	[15, SHO to SBO]
15.00	SHO to SBO	SHO	0.00	0.50	0	750.00	[15, Start Move]
15.00	Start Move	SHO	0.00	0.50	0	750.00	[20, End Move; 20, Exit Range; 16, Enter Range]
16.00	Enter Range	SHO	0.00	0.50	0	750.00	[20, End Move; 20, Exit Range; 17, Detect]
17.00	Detect	SHO	0.00	0.50	0	750.00	[20, End Move; 20, Exit Range; 17, Attack]
17.00	Attack	SHO	0.00	0.50	0	750.00	[20, End Move; 20, Exit Range; 17, BDA]
17.00	BDA	SHO	0.00	0.55	0	750.00	[20, End Move; 20, Exit Range]
20.00	Exit Range	SHO	0.00	0.55	0	750.00	[20, End Move; 20, Un-Detect]
20.00	End Move	SHO	0.00	0.55	0	750.00	[20, State; ~~20, Un-Detect~~]
20.00	State Δ	SBO	0.00	0.55	0	750.00	[20, Repair]
20.00	Repair	SBO	0.00	0.00	0	750.00	[40, Load]
40.00	Load	SBO	550.00	0.00	0	750.00	[40, Transit]
40.00	Transit	SBO	550.00	0.00	0	750.00	[40, SBO to SHO]
40.00	SBO to SHO	SBO	550.00	0.00	0	750.00	[0, Start Move]
40.00	Start Move	SBO	550.00	0.00	0	750.00	[45, End Move; 45, Exit Range; 41, Enter Range]
41.00	Enter Range	SBO	550.00	0.00	0	750.00	[45, End Move; 45, Exit Range; 42, Detect]
42.00	Detect	SBO	550.00	0.00	0	750.00	[45, End Move; 45, Exit Range; 42, Attack]
42.00	Attack	SBO	550.00	0.00	0	750.00	[45, End Move; 45, Exit Range; 42, BDA]
42.00	BDA	SBO	550.00	0.07	0	750.00	[45, End Move; 45, Exit Range]
45.00	Exit Range	SBO	550.00	0.07	0	750.00	[45, End Move; 45, Un-Detect]
45.00	Un-Detect	SBO	550.00	0.07	0	750.00	[45, End Move]
45.00	End Move	SBO	550.00	0.07	0	750.00	[45, State]
45.00	State Δ	SHO	550.00	0.07	0	750.00	[45, Unload]
45.00	Unload	SHO	0.00	0.07	0	1300.00	[45, Transit]
45.00	Transit	SHO	0.00	0.07	0	1300.00	[45, SHO to SBO]
45.00	SHO to SBO	SHO	0.00	0.07	0	1300.00	[45, Start Move]
45.00	Start Move	SHO	0.00	0.07	0	1300.00	[50, End Move; 50, Exit Range; 46, Enter Range]
46.00	Enter Range	SHO	0.00	0.07	0	1300.00	[50, End Move; 50, Exit Range; 47, Detect]
47.00	Detect	SHO	0.00	0.07	0	1300.00	[50, End Move; 50, Exit Range; 47, Attack]
47.00	Attack	SHO	0.00	0.07	0	1300.00	[50, End Move; 50, Exit Range; 47, BDA]
47.00	BDA	SHO	0.00	0.12	0	1300.00	[50, End Move; 50, Exit Range]
50.00	Exit Range	SHO	0.00	0.12	0	1300.00	[50, End Move; 50, Un-Detect]
50.00	Un-Detect	SHO	0.00	0.12	0	1300.00	[50, End Move]
50.00	End Move	SHO	0.00	0.12	0	1300.00	[50, State]
50.00	State Δ	SBO	0.00	0.12	0	1300.00	[50, Load]
50.00	Load	SBO	680.00	0.12	0	1300.00	[50, Transit]
50.00	Transit	SBO	680.00	0.12	0	1300.00	[50, SBO to SHO]
50.00	SBO to SHO	SBO	680.00	0.12	0	1300.00	[50, Start Move]
50.00	Start Move	SBO	680.00	0.12	0	1300.00	[55, End Move; 55, Exit Range; 51, Enter Range]
51.00	Enter Range	SBO	680.00	0.12	0	1300.00	[55, End Move; 55, Exit Range; 52, Detect]
52.00	Detect	SBO	680.00	0.12	0	1300.00	[55, End Move; 55, Exit Range; 52, Attack]
52.00	Attack	SBO	680.00	0.12	0	1300.00	[55, End Move; 55, Exit Range; 52, BDA]
52.00	BDA	SBO	680.00	0.37	0	1300.00	[55, End Move; 55, Exit Range]
55.00	Exit Range	SBO	680.00	0.37	0	1300.00	[55, End Move; 55, Un-Detect]
55.00	Un-Detect	SBO	680.00	0.37	0	1300.00	[55, End Move]
55.00	End Move	SBO	680.00	0.37	0	1300.00	[55, State]
55.00	State Δ	SHO	680.00	0.37	0	1300.00	[55, Unload]
55.00	Unload	SHO	0.00	0.37	0	1980.00	[65, Transit]
65.00	Transit	SHO	0.00	0.37	0	1980.00	[65, SHO to SBO]
65.00	SHO to SBO	SHO	0.00	0.37	0	1980.00	[65, Start Move]
65.00	Start Move	SHO	0.00	0.37	0	1980.00	[70, End Move; 70, Exit Range; 66, Enter Range]
66.00	Enter Range	SHO	0.00	0.37	0	1980.00	[70, End Move; 70, Exit Range; 67, Detect]
67.00	Detect	SHO	0.00	0.37	0	1980.00	[70, End Move; 70, Exit Range; 67, Attack]
67.00	Attack	SHO	0.00	0.37	0	1980.00	[70, End Move; 70, Exit Range; 67, BDA]
67.00	BDA	SHO	0.00	0.77	0	1980.00	[70, End Move; 70, Exit Range]
70.00	Exit Range	SHO	0.00	0.77	0	1980.00	[70, End Move; 70, Un-Detect]
70.00	Un-Detect	SHO	0.00	0.77	0	1980.00	[70, End Move]
70.00	End Move	SHO	0.00	0.77	0	1980.00	[70, State]
70.00	State Δ	SHO	0.00	0.77	0	1980.00	[70, Repair]

MinLD	300.00	
MaxLD	750.00	
DT	0.80	
RT	0.30	
CT	750.00	
SL	1.00	
R	1.00	
L	1.00	
UL	1.00	
ST	2000.00	
G	20.00	20.00
H	0.00	0.00
I	-30.00	-30.00
SPt	20.00	20.00
EPt	840.22	64.60

t_E	1										
t_X	5										
t_L	10										
t_R	20										
t_U	10										
t_D	1										
u_c	200	160	400	500	350	700	120	330	750	0	0
u_c	750	550	680	500	750	700	350	450	488	344	300
d	0.5	0.05	0.07	0.05	0.25	0.4	0	0.4	0.01	0.95	0.55

Figure 82. Hand Simulation Design Point 6.

SimTime	Event	State (S)	Cargo (S)	Damage (D)	Mission Flag (M)	Shore Cargo (SC)	[Next Event]
0.00	Run	SHO	0.00	0.00	0	0.00	[0, Unload]
0.00	Unload	SHO	0.00	0.00	0	0.00	[10, Transit]
10.00	Transit	SHO	0.00	0.00	0	0.00	[10, SHO to SBO]
10.00	SHO to SBO	SHO	0.00	0.00	0	0.00	[10, Start Move]
10.00	Start Move	SHO	0.00	0.00	0	0.00	[15, End Move; 15 Exit Range; 11 Enter Range]
11.00	Enter Range	SHO	0.00	0.00	0	0.00	[15, End Move; 15, Exit Range; 12, Detect]
12.00	Detect	SHO	0.00	0.00	0	0.00	[15, End Move; 15, Exit Range; 12, Attack]
12.00	Attack	SHO	0.00	0.00	0	0.00	[15, End Move; 15, Exit Range; 12, BDA]
12.00	BDA	SHO	0.00	0.00	0	0.00	[15, End Move; 15, Exit Range]
15.00	End Move	SHO	0.00	0.00	0	0.00	[15, State; 15, Exit Range]
15.00	Exit Range	SBO	0.00	0.00	0	0.00	[15, State; 15, Un-Detect]
15.00	Un-Detect	SBO	0.00	0.00	0	0.00	[15, State]
15.00	State Δ	SBO	0.00	0.00	0	0.00	[15, Load]
15.00	Load	SBO	360.00	0.00	0	0.00	[25, Transit]
25.00	Transit	SBO	360.00	0.00	0	0.00	[25, SBO to SHO]
25.00	SBO to SHO	SBO	360.00	0.00	0	0.00	[25, Start Move]
25.00	Start Move	SBO	360.00	0.00	0	0.00	[30, End Move; 30 ,Exit Range; 26, Enter Range]
26.00	Enter Range	SBO	360.00	0.00	0	0.00	[30, End Move; 30, Exit Range; 27, Detect]
27.00	Detect	SBO	360.00	0.00	0	0.00	[30, End Move; 30, Exit Range; 27, Attack]
27.00	Attack	SBO	360.00	0.00	0	0.00	[30, End Move; 30, Exit Range; 27, BDA]
27.00	BDA	SBO	360.00	0.30	0	0.00	[30, End Move; 30, Exit Range]
30.00	End Move	SBO	360.00	0.30	0	0.00	[30, State; 30, Exit Range]
30.00	Exit Range	SBO	360.00	0.30	0	0.00	[30, State; 30, Un-Detect]
30.00	Un-Detect	SBO	360.00	0.30	0	0.00	[30, State]
30.00	State Δ	SHO	360.00	0.30	0	0.00	[30, Unload]
30.00	Unload	SHO	0.00	0.30	0	360.00	[40, Transit]
40.00	Transit	SHO	0.00	0.30	0	360.00	[40, SHO to SBO]
40.00	SHO to SBO	SHO	0.00	0.30	0	360.00	[40, Start Move]
40.00	Start Move	SHO	0.00	0.30	0	360.00	[45, End Move; 45, Exit Range; 41, Enter Range]
41.00	Enter Range	SHO	0.00	0.30	0	360.00	[45, End Move; 45, Exit Range; 42, Detect]
42.00	Detect	SHO	0.00	0.30	0	360.00	[45, End Move; 45, Exit Range; 42, Attack]
42.00	Attack	SHO	0.00	0.30	0	360.00	[45, End Move; 45, Exit Range; 42, BDA]
42.00	BDA	SHO	0.00	0.42	0	360.00	[45, End Move; 45, Exit Range]
45.00	End Move	SHO	0.00	0.42	0	360.00	[45, State; 45, Exit Range]
45.00	State Δ	SBO	0.00	0.42	0	360.00	[45, Exit Range; 45, Repair]
45.00	Exit Range	SBO	0.00	0.42	0	360.00	[45, Un-Detect; 45, Repair]
45.00	Un-Detect	SBO	0.00	0.42	0	360.00	[45, Repair]
45.00	Repair	SBO	0.00	0.00	0	360.00	[65, Load]
65.00	Load	SBO	700.00	0.00	0	360.00	[75, Transit]
75.00	Transit	SBO	700.00	0.00	0	360.00	[75, SBO to SHO]
75.00	SBO to SHO	SBO	700.00	0.00	0	360.00	[75, Start Move]
75.00	Start Move	SBO	700.00	0.00	0	360.00	[80, End Move; 80, Exit Move; 76, Enter Range]
76.00	Enter Range	SBO	700.00	0.00	0	360.00	[80, End Move; 80, Exit Range; 77, Detect]
77.00	Detect	SBO	700.00	0.00	0	360.00	[80, End Move; 80, Exit Range; 77, Attack]
77.00	Attack	SBO	700.00	0.00	0	360.00	[80, End Move; 80, Exit Range; 77, BDA]
77.00	BDA	SBO	700.00	0.56	0	360.00	[80, End Move; 80, Exit Range]
80.00	End Move	SBO	700.00	0.56	0	360.00	[80, State; 80, Exit Range; 80, Un-Detect]
80.00	Exit Range	SBO	700.00	0.56	0	360.00	[80, State; 80, Un-Detect]
80.00	Un-Detect	SBO	700.00	0.56	0	360.00	[80, State]
80.00	State Δ	SHO	700.00	0.56	0	360.00	[80, Unload]
80.00	Unload	SHO	0.00	0.56	0	1060.00	[90, Transit]
90.00	Transit	SHO	0.00	0.56	0	1060.00	[90, SHO to SBO]
90.00	SHO to SBO	SHO	0.00	0.56	0	1060.00	[90, Start Move]
90.00	Start Move	SHO	0.00	0.56	0	1060.00	[95, End Move; 95, Exit Range; 91, Enter Range]
91.00	Enter Range	SHO	0.00	0.56	0	1060.00	[95, End Move; 95, Exit Range; 92, Detect]
92.00	Detect	SHO	0.00	0.56	0	1060.00	[95, End Move; 95, Exit Range; 92, Attack]
92.00	Attack	SHO	0.00	0.56	0	1060.00	[95, End Move; 95, Exit Range; 92, BDA]
92.00	BDA	SHO	0.00	0.90	0	1060.00	[95, End Move; 95, Exit Range; 92, Killed]
92.00	Killed	SHO	0.00	0.90	0	1060.00	[~~95, End Move~~; 95, Exit Range; 92, STOP]
92.00	STOP	SHO	0.00	0.90	0	1060.00	[~~95, Exit Range~~] (X = 0)

MinLD	300.00	
MaxLD	750.00	
DT	0.80	
RT	0.30	
CT	750.00	
SL	1.00	
R	1.00	
L	1.00	
UL	1.00	
ST	2000.00	
G	20.00	20.00
H	0.00	0.00
I	-30.00	-30.00
SPt	20.00	20.00
EPt	534.66	563.90

t_E	1										
t_X	5										
t_L	10										
t_R	20										
t_U	10										
t_D	1										
u_C	0	160	400	500	350	700	120	330	750	0	0
u_C	360	700	400	500	350	700	550	330	750	300	300
d	0	0.3	0.12	0.56	0.34	0.49	0.12	0.21	0.4	0.88	0.31

Figure 83. Hand Simulation Design Point 7.

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VII. CAPABILITY EVALUATION

A detailed capabilities hierarchy, described in Chapter IV, was developed to explore the abilities of selected M&S tools used at the NPS and in the DoD to model the potential SBE Scenario. Evaluation of those M&S tools, listed in Chapter VI, were the focus of the created functionality framework that was used for M&S modeling and implementation. The purpose of this chapter is to present results of the evaluation conducted on six M&S tools: JCATS, MANA, Pythagoras, NSS, Simkit, and Arena. The specific usability, flexibility, and scalability of the models were examined separately and then combined for a full comparison of the models across capabilities. Figures 84 through 101 show the complete evaluation of all M&S tools.

Interpretation of the normalized factor in the evaluation of models was subjective based on the structure of the capabilities framework. A quartile approach was applied to associate a quick reference term with the determined value. Possible values for normalized factors range from zero to one, where threshold points for the quartiles were designated into four regions. Table 21 indicates the threshold points and associated labels, where Very High represented a perfect contribution factor.

Quartile Approach		
Value Range	Associate Terms	Definition
0 to 0.25	Low	Contributes less than a quarter of the functionalities.
0.26 to 0.50	Medium	Contributes less than half of the functionalities.
0.51 to 0.75	High	Contributes greater than half of the functionalities.
0.76 to 1.00	Very High	Contributes greater than three quarters of the functionalities.

Table 21. Quartile Approach Listings.

A. JCATS EVALUATION

JCATS was evaluated with the use of the Jimenez model where Usability and Flexibility were High and Scalability was Medium. Table 22 shows the calculated values for JCATS capabilities.

Joint Conflict and Tactical Simulation (JCATS)				
Capability	Total Functionalities	Σ(f)	Roll up Probability	Normalized (c)
Usability	53	38	0.72	0.64
Flexibility	49	34	0.69	0.62
Scalability	42	22	0.52	0.46

Table 22. JCATS Capabilities Evaluation.

1. Advantages

The first advantage of JCATS lied within the Dynamic situations that the M&S tool created with real-world values and physic representation. This functionality enabled direct translation of results; however, it also increased run times. Secondly, JCATS was one of two simulations evaluated that utilized securities by handling classified databases. Handling classified data was a key functionality DoD M&S tools possess. Lastly, JCATS was one of two simulations that were developed to be used in combination with other M&S tools for reusability, which allowed for the added benefit of architectural design to be observed.

2. Disadvantages

The first disadvantage of JCATS was implementation of real-world physics in the T-craft model during cargo transfer. T-craft's waypoints were modeled to allow for movement near the shore without landing, while remaining in sea mode. JCATS imposed shore landing conditions into the model and did not allow for T-craft to transit to the shore when the waypoints were placed on the shore line. Switching of modes from sea to hover consumed time during simulation and was not implemented in the Jimenez model. The second disadvantage was the lack of supportabilities provided to users. LT Jimenez had the benefit of hands on training with JCATS supported by the System Engineering program leadership. JCATS complexity did not lend itself to novice computer users like typical decision makers.

B. MANA EVALUATION

MANA was evaluated with the implementation of the Basic and Advanced Scenarios in which all capabilities were rated as High. Table 23 shows the calculated values for MANA capabilities.

Map Aware Non-Uniform Automata (MANA)				
Capability	Total Functionalities	Σ(f)	Roll up Probability	Normalized (c)
Usability	53	41	0.77	0.57
Flexibility	49	37	0.76	0.55
Scalability	42	35	0.83	0.61

Table 23. MANA Capabilities Evaluation.

1. Advantages

The first advantage of MANA was the ease of implementation with MANA interface capabilities. The GUI applications in MANA enabled a working model to be ready for simulation runs without the need to debug code. The user was completely separated from the programming level. The second advantage was the numerous parameter settings available for manipulation of the model environment that include terrain map editor, agent attributes, and selectable complex behavioral actions. The overall capability of MANA was considered High. The third advantage was the AABM that facilitated the adjustability of agents with attributes and triggers. This enabled the user to define complex actions and decision processes that were not commonly found in M&S tools like DES.

2. Disadvantages

There were major disadvantages in MANA that would prevent its widespread use in DoD. The first was the lack of architectural design. MANA was not HLA compliant nor open sourced. The second disadvantage accompanied the first, where MANA did not conform to protocol standards or DoD standards in terminology and representation on the battle space. MANA’s disadvantages were noticeable in its evaluations, nevertheless, most decision makers could work past these issues to use MANA and produce quality results.

C. PYTHAGORAS EVALUATION

Pythagoras evaluation yielded all capabilities as High. Table 24 shows the calculated values for Pythagoras capabilities.

Pythagorus				
Capability	Total Functionalities	Σ(f)	Roll up Probability	Normalized (c)
Usability	53	37	0.70	0.56
Flexibility	49	34	0.69	0.56
Scalability	42	32	0.76	0.61

Table 24. Pythagoras Capabilities Evaluation.

1. Advantages

The first advantage of Pythagoras was the robust selection of attributes and MOEs that greatly surpassed that of MANA. The MOEs were not available to be defined by the user but were more capable in measuring parameters in the simulation than MANA recorded figures. The second advantage was the GUI that was implemented gave the user greater range of controls on agent actions. Weapons, sensors, and communication controls enabled the user to build elements of a model that accounted for significant amounts of probability. Pythagoras also introduced a "sideness" functionality that allowed for other entities to be created that were neutral, which added to dynamic situations.

2. Disadvantages

The first disadvantage of Pythagoras was that the large number of controls available to be adjusted by the user. The increased number of attributes, attitude changers, and movement desires often made the dynamics of the situation difficult to control without rigorous implementation plans. The second disadvantage was the lack of physics on entities. The bottom up approach of AABM did not seem to focus on real physics based models, but merely the behavior that modeled the individual entity actions. Pythagoras had the same disadvantages of MANA with reference to System architecture and interface functionalities, in which the observed capabilities contributions were High.

D. NSS EVALUATION

NSS was evaluated with the implementation of the Basic and Advanced Scenarios where all capabilities were High. Table 25 shows the calculated values for NSS capabilities.

Naval Simulation System (NSS)				
Capability	Total Functionalities	Σ(f)	Roll up Probability	Normalized (c)
Usability	53	34	0.64	0.55
Flexibility	49	33	0.67	0.57
Scalability	42	30	0.71	0.61

Table 25. NSS Capabilities Evaluation.

1. Advantages

The first advantage of NSS was the use of real physics and environmental effects on entities during simulation like sea state and wind. NSS took input factors and applied physics forces during run time similar to JCATS. The second advantage was that the discrete-based processes allowed for more accurate results than time-step models. This was observed through the ability to select confidence interval values. The third advantage was NSS simulation run time durations were faster than those of JCATS in conducting multiple replication of the scenario. NSS simulation runs were conducted over hours, where JCATS were days in duration. The last advantage was that NSS allowed for near real time inputs to be fed into the model for course of action analysis.

2. Disadvantages

The first disadvantage of NSS was the inability of a DES to not model waiting queues to analysis processes in a model. The major advantage of the two following M&S tools was waiting queues for recorded MOPs. The second disadvantage was resource capabilities that did not allow for cargo transfer to be measured. NSS was a federation program, but was not open source or HLA compliant in accordance with DoD mandates. The last disadvantage was the non access to probability tables of entities imported or copied from database instances. The ability to create a user defined entity was also not available.

E. SIMKIT EVALUATION

Simkit was evaluated with the implementation of the Basic and Advanced Scenarios where all capabilities were High. Table 26 shows the calculated values for Simkit capabilities.

Simkit DES				
Capability	Total Functionalities	$\Sigma(f)$	Roll up Probability	Normalized (c)
Usability	53	25	0.47	0.64
Flexibility	49	19	0.39	0.53
Scalability	42	17	0.40	0.55

Table 26. Simkit Capabilities Evaluation.

1. Advantages

The first advantage of Simkit was the discrete event processes that inherently provided highly accurate simulation results. The ability of the user to define virtually every aspect of the model interactions increased the Usability of Simkit with a 0.64 factor. The second was the technical support provided by the NPS in an academic setting that could be made available to decision makers.

The third was the freedom of programming to define parameters and output results that was not available in the other M&S tools.

2. Disadvantages

The first disadvantage of Simkit was the result data were highly dependent on the distributions used during simulations. The distributions were not limited by the Simkit API, only the ability of the user to create randomness for realistic interactions. The second disadvantage of Simkit was the lack of a GUI to implement models. This swing in capabilities between user interfaces made differences in the implementation of the SBE Scenarios but were leveled out in the evaluation processes. Simkit still offered High capabilities contributions.

F. ARENA EVALUATION

Arena was evaluated with the implementation of the Basic and Advanced Scenarios where the Usability capability was Very High and Flexibility and Scalability capabilities were Low. Table 27 shows the calculated values for Arena capabilities.

Arena				
Capability	Total Functionalities	Σ(f)	Roll up Probability	Normalized (c)
Usability	53	40	0.75	0.92
Flexibility	49	10	0.20	0.25
Scalability	42	10	0.24	0.29

Table 27. Arena Capabilities Evaluation.

1. Advantages

The first advantage of Arena was the GUI of a DES that provided Strong Usability of the M&S tool. This enabled MOPs to represent specific processes and obtain accurate results with confidence intervals. The second advantage was the ability of Arena to import and export databases for complex simulations. The McDonald model allowed for an implementation of a full factorial analysis to be conducted with varying parameters needed to determine relationships. The third advantage was the functionality of selectable units in the model that allowed for rapid MOP translations.

2. Disadvantages

The GUI of Arena was a highlight in its abilities due to the limitations of the M&S tool to model Military operations key to the Advanced Scenario. The first disadvantage was the lack of visual representation of a battle space in which the T-craft operated. The Arena processes were independent of location and based on a flowchart method. The second was the inability for entity interactions. Entity creation was limited to T-craft instances where escort and hostile forces could not be modeled. Similar to other M&S tool evaluated, Arena also was poorly designed for use in DoD with no HLA compliance or reusability.

G. EVALUATION SUMMARY

The evaluation of a capability hierarchy framework was an extensive compilation of six models created in six different M&S tools used in DoD and academia. The evaluation summary is shown in Table 28 and compared M&S tools across capabilities. It was important to remember that all models were designed for a specific application of real situations and required validation in those areas.

Capability Hierarchy Comparison						
Capability	JCATS	MANA	Pythagorus	NSS	Simkit	Arena
Usability	0.64	0.57	0.56	0.55	0.64	0.92
Flexibility	0.62	0.55	0.56	0.57	0.53	0.25
Scalability	0.46	0.61	0.61	0.61	0.55	0.29
Roll-up	0.57	0.58	0.58	0.58	0.58	0.49

Table 28. Capabilities Evaluation Summary.

The evaluation of the M&S tools showed similarities and differences in their capabilities. Comparison of the evaluations revealed that initial assessments of similarities between MANA and Pythagoras held true with High values in all capabilities. NSS was similar to MANA and Pythagoras despite being in different category types of M&S. The next major difference was found in the Arena evaluation where its Usability showed Very High values but Flexibility and Scalability had Low values. This was no surprise based on the limitations of the GUI based DES. Simkit and JCATS held similarities in Usability but differed in Scalability. JCATS and Arena Low values for Scalability both stemmed from the inability to allow for user access to attain abilities. Arena is the odd model with Low values for Flexibility and Scalability. Thus, the M&S user had multiple options that yielded high results. In the next chapter, a “suite of simulations” is suggested as a viable option.

Joint Conflict and Tactical Simulation (JCATS)

Capability Evaluation

Cap	Charact	Ility	Trait	Funct	Functionality Element	Pts	Eval	Total	Remarks
USABILITY						SUM		0.72	
	VALIDATION					SUM		0.49	
		CONSTRUCTABILITIES				SUM		0.38	
			DYNAMIC SITUATIONS			SUM		0.25	
				SENSOR PROB. TABLES		1	1	0.02	Actual Values
				WEAPON PROB. TABLES		1	1	0.02	Actual Values
				INDIVIDUAL UNIT ACTIONS		1	1	0.02	Limited
				AGENT INFORMATION (AI)		1	1	0.02	Limited
				AI -	COURSE	1	1	0.02	
				AI -	SPEED	1	1	0.02	
				AI -	POSITIONAL DATA	1	1	0.02	
				AI -	REFUELING RATES	1	1	0.02	
				AI -	CARGO CAPACITIES	1	1	0.02	
				COMMUNICATION (CM)		1	1	0.02	Information Exchange
				CM -	COMMAND AND CONTROL ENTITY	1	0	0.00	Live SIM only
				CM -	MILITARY OPERATIONS other than WARFARE	1	1	0.02	Ground Operations only
				CM -	LOGISTIC CAPABILITIES	1	1	0.02	
				WAITING QUEUES		1	1	0.02	Supported DES
				PERSONAL SETTINGS		1	0	0.00	
				SEMI-AUTOMATED FORCES		1	0	0.00	
			REPLICABLE			SUM		0.13	
				SIMULATE a user DEFINED MODEL		1	1	0.02	
				MULTIPLE RUNS DEFINED by user		1	1	0.02	
				MEASURES OF PERFORMANCE		1	1	0.02	Not User Defined
				PARAMETERS		1	1	0.02	Selectable
				RESET SIMULATION PARAMETERS		1	0	0.00	
				User DEFINED OUTPUT VARIABLES		1	1	0.02	Selectable
				START/STOP CRITERIA		1	1	0.02	Only Time
				ACCURACY		1	0	0.00	
				SPOT SAMPLING		1	1	0.02	Playback only
		SUPPORTABILITIES				SUM		0.11	
			CONTRACTOR SUPPORT			SUM		0.09	
				BASIC INFORMAITON (BI)		1	1	0.02	
				BI -	VERSION NUMBER	1	1	0.02	
				Bi -	UPGRADE INFORMATION	1	1	0.02	
				REACH-BACK AVAILABILITY		1	0	0.00	
				POINTS OF CONTACTS (PC)		1	0	0.00	
				PC -	WEBSITE AVAILABILITY	1	0	0.00	No Active URL
				TRAINING and EDUCATION		1	1	0.02	Limited
				FEEDBACK LOOP		1	1	0.02	
				AUTHORITATIVE SOURCES		1	0	0.00	
			DOCUMENTATION			SUM		0.02	
				FUNCTIONALITY TUTORIALS		1	0	0.00	
				HELP WINDOWS		1	0	0.00	
				User MANUAL		1	1	0.02	Fair
				PUBLICATIONS		1	0	0.00	
				ONLINE SUPPORT		1	0	0.00	
	User INTERFACE					SUM		0.23	
		Representabilities				SUM		0.23	
			Graphical User Interface (GUI)			SUM		0.09	
				User input windows (UI)		1	1	0.02	
				UI -	Pull Down Menus	1	1	0.02	
				UI -	Check Boxes	1	1	0.02	
				UI -	Typed in Values	1	1	0.02	
				UI -	Adjustment sliders	1	1	0.02	
				Set-up Wizards		1	0	0.00	
			Comprehensive able			SUM		0.13	
				Pop-up Information		1	0	0.00	
				Common Terminology		1	1	0.02	Based on DoD Instructions
				User Feedback		1	1	0.02	Limited
				Help Menus		1	1	0.02	
				Standard Symbology (SM)		1	1	0.02	Based on DoD Instructions
				SM -	Friendly, Hostile, & Neutral	1	1	0.02	Based on DoD Instructions
				Forces		1	1	0.02	
				Object Templates		1	1	0.02	

Figure 84. JCATS Usability Evaluation Sheet.

Joint Conflict and Tactical Simulation (JCATS)

Capability Evaluation

Cap	Charact	Ility	Trait	Funct	Functionality Element	Pts	Eval	Total	Remarks
Flexibility						SUM		0.69	
	Modelable					SUM		0.53	
		Securities				SUM		0.04	
			Classification			SUM		0.04	
				Safeguard & Handle Classified Information		1	1	0.02	Government Certified
				Encryption / Decryption Devices		1	1	0.02	
		Export / Import abilities				SUM		0.06	
			Databases			SUM		0.06	
				Systems (Created Models)		1	1	0.02	
				Environment (Terrian / Weather / etc.)		1	1	0.02	
				Imagary Data		1	0	0.00	
				Scenario Files		1	1	0.02	
		Adjust abilities				SUM		0.43	
			Systems			SUM		0.22	
				Multiple Attributes		1	1	0.02	Poor
				Model Basic Physics		1	1	0.02	Excellent
				Refueling Capabilities		1	1	0.02	
				Movement Parameters		1	1	0.02	Indirect Application
				Mode Selection		1	0	0.00	
				Clone / Copy Functions		1	1	0.02	Standard Copy
				Military Operations (MO)		1	0	0.00	
				MO -	Guard	1	0	0.00	
				MO -	Patrol	1	0	0.00	
				MO -	Orbit	1	0	0.00	
				MO -	Attack	1	1	0.02	Standard
				MO -	Flee / Run	1	1	0.02	
				MO -	Grouping Functions	1	1	0.02	C2 Hierarchy
				MO -	Inter Communications	1	0	0.00	
				MO -	Remain in place	1	1	0.02	
				MO -	Waypoint selection	1	1	0.02	Mandatory
				MO -	Unit operations	1	1	0.02	C2 Hierarchy
			Environment			SUM		0.14	
				2D Terrain Modeling (2D)		1	1	0.02	Limited
				2D -	Surface Configuration	1	1	0.02	
				2D -	Natural Features	1	0	0.00	
				2D -	Man-made Features	1	0	0.00	
				Oceanographic Modeling (OM)		1	1	0.02	Limited
				OM -	Contours with depth data	1	1	0.02	
				External Forces (EF)		1	1	0.02	
				EF -	Wind	1	1	0.02	
				EF -	Sea State	1	1	0.02	
			Measures of Performance			SUM		0.04	
				Survivability		1	1	0.02	
				Transit Times		1	1	0.02	
				Cargo Transfer		1	0	0.00	
			Resolution			SUM		0.02	
				T-craft Levels (Single vs. Multiple)		1	1	0.02	
	Architectural Design					SUM		0.12	
		Interoperability Standards & Protocol				1	1	0.02	
		Federate Capable				SUM		0.06	
			High Level Architecture (HLA) Capable			1	1	0.02	
			Reusable Program			1	1	0.02	
			Program History			1	1	0.02	
		Program Considerations				SUM		0.04	
			Open Source Code			1	0	0.00	
				Input Operational Data (IO)		1	1	0.02	Operational User
				IO -	Object Library	1	1	0.02	Main Database
				Auto Save / Auto Recover		1	0	0.00	
	Stochastic Process					SUM		0.04	
		Scriptable				1	1	0.02	
			Discrete-Event			1	0	0.00	
				Random Variables/Markov Principles		1	0	0.00	
			Time_Step			1	1	0.02	
				Random Variables/Markov Principles		1	0	0.00	

Figure 85. JCATS Flexibility Evaluation Sheet.

Joint Conflict and Tactical Simulation (JCATS)

Capability Evaluation

Cap	Charact	Ility	Trait	Funct	Functionality Element	Pts	Eval	Total	Remarks
Scalability						SUM		0.52	
	Variation					SUM		0.52	
		Adjust abilities				SUM		0.45	
			Systems			SUM		0.26	
				Multiple Attributes		1	1	0.02	Poor
				Model Basic Physics		1	1	0.02	Excellent
				Refueling Capabilities		1	1	0.02	
				Movement Parameters		1	1	0.02	Indirect Application
				Mode Selection		1	0	0.00	
				Clone / Copy Functions		1	1	0.02	Standard Copy
				Military Operations (MO)		1	0	0.00	
				MO -	Guard	1	0	0.00	
				MO -	Patrol	1	0	0.00	
				MO -	Orbit	1	0	0.00	
				MO -	Attack	1	1	0.02	Standard
				MO -	Flee / Run	1	1	0.02	
				MO -	Grouping Functions	1	1	0.02	C2 Hierarchy
				MO -	Inter Communications	1	0	0.00	
				MO -	Remain in place	1	1	0.02	
				MO -	Waypoint selection	1	1	0.02	Mandatory
				MO -	Unit operations	1	1	0.02	C2 Hierarchy
			Environment			SUM		0.12	
				2D Terrain Modeling (2D)		1	1	0.02	Limited
				2D -	Surface Configuration	1	0	0.00	
				2D -	Natural Features	1	0	0.00	
				2D -	Man-made Features	1	0	0.00	
				Oceanographic Modeling (OM)		1	0	0.00	Limited
				OM -	Contours with depth data	1	1	0.02	
				External Forces (EF)		1	1	0.02	
				EF -	Wind	1	1	0.02	
				EF -	Sea State	1	1	0.02	
			Measures of Performance			SUM		0.05	
				Survivability		1	1	0.02	
				Transit Times		1	1	0.02	
				Cargo Transfer		1	0	0.00	
			Resolution			SUM		0.02	
				T-craft Levels (Single vs. Multiple)		1	1	0.02	
		Adjudication				SUM		0.07	
			Attain abilities			SUM		0.07	
				Results (RS)		1	1	0.02	Limited
				RS -	Units of Measure	1	0	0.00	
				RS -	MOP's Translations	1	1	0.02	Indirect Application
				RS -	User Defined Data Output	1	1	0.02	
				RS -	Battle Damage Assessments	1	0	0.00	
				Engagement (EG)		1	0	0.00	
				EG -	Probability Tables Ph/Pk	1	0	0.00	
				EG -	Sensor Algorithms Integration	1	0	0.00	
				EG -	Weapons Algorithms Integration	1	0	0.00	
				EG -	Indirect Fire Capabilities	1	0	0.00	
				EG -	Sensor Detections	1	0	0.00	
				EG -	Battle Damage	1	0	0.00	

Figure 86. JCATS Scalability Evaluation Sheet.

Map Aware Non-Uniform Automata (MANA)					
Capability Evaluation					
Cap / Charact / Ility / Trait / Funct / Functionality Element		Pts	Eval	Total	Remarks
USABILITY		SUM		0.77	
VALIDATION		SUM		0.58	
CONSTRUCTABILITIES		SUM		0.42	
DYNAMIC SITUATIONS		SUM		0.26	
SENSOR PROB. TABLES		1	1	0.02	
WEAPON PROB. TABLES		1	1	0.02	
INDIVIDUAL UNIT ACTIONS		1	1	0.02	
AGENT INFORMATION (AI)		1	1	0.02	
AI -	COURSE	1	1	0.02	
AI -	SPEED	1	1	0.02	
AI -	POSITIONAL DATA	1	1	0.02	
AI -	REFUELING RATES	1	1	0.02	
AI -	CARGO CAPACITIES	1	0	0.00	
COMMUNICATION (CM)		1	1	0.02	Inter / Intra
CM -	COMMAND AND CONTROL ENTITY	1	1	0.02	C2 Hierarchy
CM -	MILITARY OPERATIONS other than WARFARE	1	1	0.02	Indirect Applications
CM -	LOGISTIC CAPABILITIES	1	1	0.02	
WAITING QUEUES		1	0	0.00	
PERSONAL SETTINGS		1	1	0.02	Excellent
SEMI-AUTOMATED FORCES		1	1	0.02	Common Attributes
REPLICABLE		SUM		0.15	
SIMULATE a user DEFINED MODEL		1	1	0.02	
MULTIPLE RUNS DEFINED by user		1	1	0.02	
MEASURES OF PERFORMANCE		1	1	0.02	
PARAMETERS		1	1	0.02	
RESET SIMULATION PARAMETERS		1	1	0.02	
User DEFINED OUTPUT VARIABLES		1	0	0.00	
START/STOP CRITERIA		1	1	0.02	
ACCURACY		1	1	0.02	
SPOT SAMPLING		1	1	0.02	
SUPPORTABILITIES		SUM		0.17	
CONTRACTOR SUPPORT		SUM		0.13	
BASIC INFORMAITON (BI)		1	1	0.02	
BI -	VERSION NUMBER	1	1	0.02	Versio 4.04.1
Bi -	UPGRADE INFORMATION	1	1	0.02	
REACH-BACK AVAILABILITY		1	1	0.02	Limited
POINTS OF CONTACTS (PC)		1	1	0.02	Email only
PC -	WEBSITE AVAILABILITY	1	0	0.00	
TRAINING and EDUCATION		1	1	0.02	Limited
FEEDBACK LOOP		1	0	0.00	
AUTHORITATIVE SOURCES		1	1	0.02	Project Albert
DOCUMENTATION		SUM		0.04	
FUNCTIONALITY TUTORIALS		1	1	0.02	User Manual
HELP WINDOWS		1	0	0.00	
User MANUAL		1	1	0.02	Outdated
PUBLICATIONS		1	0	0.00	
ONLINE SUPPORT		1	0	0.00	
User INTERFACE		SUM		0.19	
Representabilities		SUM		0.19	
Graphical User Interface (GUI)		SUM		0.09	
User input windows (UI)		1	1	0.02	
UI -	Pull Down Menus	1	1	0.02	
UI -	Check Boxes	1	1	0.02	
UI -	Typed in Values	1	1	0.02	
UI -	Adjustment sliders	1	1	0.02	
Set-up Wizards		1	0	0.00	
Comprehensive able		SUM		0.09	
Pop-up Information		1	1	0.02	Show Hints
Common Terminology		1	0	0.00	
User Feedback		1	1	0.02	
Help Menus		1	0	0.00	
Standard Symbology (SM)		1	0	0.00	
SM -	Friendly, Hostile, & Neutral	1	1	0.02	Selectable Icons
Forces		1	1	0.02	Transferable Scenario Files
Object Templates		1	1	0.02	Transferable Scenario Files

Figure 87. MANA Usability Evaluation Sheet.

Map Aware Non-Uniform Automata (MANA)

Capability Evaluation

Cap	Charact	Ility	Trait	Funct	Functionality Element	Pts	Eval	Total	Remarks
Flexibility						SUM		0.76	
	Modelable					SUM		0.63	
		Securities				SUM		0.00	
			Classification			SUM		0.00	
				Safeguard & Handle Classified Information		1	0	0.00	
				Encryption / Decryption Devices		1	0	0.00	
		Export / Import abilities				SUM		0.08	
			Databases			SUM		0.08	
				Systems (Created Models)		1	1	0.02	Import Functions
				Environment (Terrian / Weather / etc.)		1	1	0.02	Limited
				Imagary Data		1	1	0.02	Bitmap Format
				Scenario Files		1	1	0.02	XML Format
		Adjust abilities				SUM		0.55	
			Systems			SUM		0.33	
				Multiple Attributes		1	1	0.02	Good
				Model Basic Physics		1	0	0.00	
				Refueling Capabilities		1	1	0.02	
				Movement Parameters		1	1	0.02	Good
				Mode Selection		1	1	0.02	Trigger Activated
				Clone / Copy Functions		1	1	0.02	
				Military Operations (MO)		1	1	0.02	
				MO -	Guard	1	1	0.02	
				MO -	Patrol	1	1	0.02	
				MO -	Orbit	1	1	0.02	
				MO -	Attack	1	1	0.02	
				MO -	Flee / Run	1	1	0.02	
				MO -	Grouping Functions	1	1	0.02	
				MO -	Inter Communications	1	1	0.02	
				MO -	Remain in place	1	1	0.02	
				MO -	Waypoint selection	1	1	0.02	
				MO -	Unit operations	1	1	0.02	
			Environment			SUM		0.14	
				2D Terrain Modeling (2D)		1	1	0.02	Terrain Map Editor
				2D -	Surface Configuration	1	1	0.02	Terrain Map Editor
				2D -	Natural Features	1	1	0.02	Terrain Map Editor
				2D -	Man-made Features	1	1	0.02	Terrain Map Editor
				Oceanographic Modeling (OM)		1	0	0.00	
				OM -	Contours with depth data	1	0	0.00	
				External Forces (EF)		1	1	0.02	Indirectly in Terrain Map
				EF -	Wind	1	1	0.02	Indirectly in Terrain Map
				EF -	Sea State	1	1	0.02	Indirectly in Terrain Map
			Measures of Performance			SUM		0.06	
				Survivability		1	1	0.02	
				Transit Times		1	1	0.02	
				Cargo Transfer		1	1	0.02	
			Resolution			SUM		0.02	
				T-craft Levels (Single vs. Multiple)		1	1	0.02	
	Architectural Design					SUM		0.06	
		Interoperability Standards & Protocol				1	0	0.00	
		Federate Capable				SUM		0.02	
			High Level Architecture (HLA) Capable			1	0	0.00	
			Reusable Program			1	0	0.00	
			Program History			1	1	0.02	Project Albert
		Program Considerations				SUM		0.04	
			Open Source Code			1	0	0.00	
				Input Operational Data (IO)		1	1	0.02	Transferable Scenario Files
				IO -	Object Library	1	1	0.02	Transferable Scenario Files
				Auto Save / Auto Recover		1	0	0.00	
	Stochastic Process					SUM		0.06	
		Scriptable				1	1	0.02	
			Discrete-Event			1	0	0.00	
				Random Variables/Markov Principles		1	0	0.00	
			Time_Step			1	1	0.02	
				Random Variables/Markov Principles		1	1	0.02	

Figure 88. MANA Flexibility Evaluation Sheet.

Map Aware Non-Uniform Automata (MANA)

Capability Evaluation

Cap	Charact	Ility	Trait	Funct	Functionality Element	Pts	Eval	Total	Remarks
Scalability						SUM		0.83	
	Variation					SUM		0.83	
		Adjust abilities				SUM		0.64	
			Systems			SUM		0.38	
				Multiple Attributes		1	1	0.02	Good
				Model Basic Physics		1	0	0.00	
				Refueling Capabilities		1	1	0.02	
				Movement Parameters		1	1	0.02	Good
				Mode Selection		1	1	0.02	Trigger Activated
				Clone / Copy Functions		1	1	0.02	
				Military Operations (MO)		1	1	0.02	
				MO -	Guard	1	1	0.02	
				MO -	Patrol	1	1	0.02	
				MO -	Orbit	1	1	0.02	
				MO -	Attack	1	1	0.02	
				MO -	Flee / Run	1	1	0.02	
				MO -	Grouping Functions	1	1	0.02	
				MO -	Inter Communications	1	1	0.02	
				MO -	Remain in place	1	1	0.02	
				MO -	Waypoint selection	1	1	0.02	
				MO -	Unit operations	1	1	0.02	
			Environment			SUM		0.17	
				2D Terrain Modeling (2D)		1	1	0.02	Terrain Map Editor
				2D -	Surface Configuration	1	1	0.02	Terrain Map Editor
				2D -	Natural Features	1	1	0.02	Terrain Map Editor
				2D -	Man-made Features	1	1	0.02	Terrain Map Editor
				Oceanographic Modeling (OM)		1	0	0.00	
				OM -	Contours with depth data	1	0	0.00	
				External Forces (EF)		1	1	0.02	Indirectly in Terrain Map
				EF -	Wind	1	1	0.02	Indirectly in Terrain Map
				EF -	Sea State	1	1	0.02	Indirectly in Terrain Map
			Measures of Performance			SUM		0.07	
				Survivability		1	1	0.02	Causuality only
				Transit Times		1	1	0.02	System time units
				Cargo Transfer		1	1	0.02	Fuel units transferred
			Resolution			SUM		0.02	
				T-craft Levels (Single vs. Multiple)		1	1	0.02	
		Adjudication				SUM		0.19	
			Attain abilities			SUM		0.19	
				Results (RS)		1	1	0.02	
				RS -	Units of Measure	1	1	0.02	Model defined units
				RS -	MOP's Translations	1	1	0.02	Cargo measured in Fuel units
				RS -	User Defined Data Output	1	0	0.00	Limited
				RS -	Battle Damage Assessments	1	0	0.00	
				Engagement (EG)		1	1	0.02	
				EG -	Probability Tables Ph/Pk	1	1	0.02	
				EG -	Sensor Algorithms Integration	1	1	0.02	Sensor Tab
				EG -	Weapons Algorithms Integration	1	1	0.02	Weapon Tab
				EG -	Indirect Fire Capabilities	1	0	0.00	
				EG -	Sensor Detections	1	1	0.02	Sensor Tab
				EG -	Battle Damage	1	0	0.00	

Figure 89. MANA Scalability Evaluation Sheet.

Pythagorus

Capability Evaluation

Cap	Charact	Ility	Trait	Funct	Functionality Element	Pts	Eval	Total	Remarks
USABILITY						SUM		0.70	
	VALIDATION					SUM		0.53	
		CONSTRUCTABILITIES				SUM		0.34	
			DYNAMIC SITUATIONS			SUM		0.19	
				SENSOR PROB. TABLES		1	0	0.00	
				WEAPON PROB. TABLES		1	0	0.00	
				INDIVIDUAL UNIT ACTIONS		1	1	0.02	
				AGENT INFORMATION (AI)		1	1	0.02	
				AI -	COURSE	1	0	0.00	
				AI -	SPEED	1	0	0.00	
				AI -	POSITIONAL DATA	1	1	0.02	
				AI -	REFUELING RATES	1	1	0.02	
				AI -	CARGO CAPACITIES	1	1	0.02	
				COMMUNICATION (CM)		1	1	0.02	
				CM -	COMMAND AND CONTROL ENTITY	1	1	0.02	Leadership Settings
				CM -	MILITARY OPERATIONS other than WARFARE	1	1	0.02	Indirect Applications
				CM -	LOGISTIC CAPABILITIES	1	1	0.02	Resource Settings
				WAITING QUEUES		1	0	0.00	
				PERSONAL SETTINGS		1	1	0.02	Attribute Settings
				SEMI-AUTOMATED FORCES		1	0	0.00	
			REPLICABLE			SUM		0.15	
				SIMULATE a user DEFINED MODEL		1	1	0.02	
				MULTIPLE RUNS DEFINED by user		1	1	0.02	Command Window Excution
				MEASURES OF PERFORMANCE		1	1	0.02	Not User Defined
				PARAMETERS		1	1	0.02	
				RESET SIMULATION PARAMETERS		1	1	0.02	
				User DEFINED OUTPUT VARIABLES		1	0	0.00	
				START/STOP CRITERIA		1	1	0.02	
				ACCURACY		1	1	0.02	Agent Attribute Settings only
				SPOT SAMPLING		1	1	0.02	Playback only
		SUPPORTABILITIES				SUM		0.19	
			CONTRACTOR SUPPORT			SUM		0.13	
				BASIC INFORMAITON (BI)		1	1	0.02	
				BI -	VERSION NUMBER	1	1	0.02	Version 2.1.0
				Bi -	UPGRADE INFORMATION	1	1	0.02	User Manual
				REACH-BACK AVAILABILITY		1	1	0.02	Limited
				POINTS OF CONTACTS (PC)		1	1	0.02	User Manual
				PC -	WEBSITE AVAILABILITY	1	0	0.00	
				TRAINING and EDUCATION		1	0	0.00	
				FEEDBACK LOOP		1	1	0.02	
				AUTHORITATIVE SOURCES		1	1	0.02	Project Albert
			DOCUMENTATION			SUM		0.06	
				FUNCTIONALITY TUTORIALS		1	1	0.02	User Manual
				HELP WINDOWS		1	0	0.00	
				User MANUAL		1	1	0.02	
				PUBLICATIONS		1	1	0.02	Good
				ONLINE SUPPORT		1	0	0.00	
	User INTERFACE					SUM		0.17	
		Representabilities				SUM		0.17	
			Graphical User Interface (GUI)			SUM		0.09	
				User input windows (UI)		1	1	0.02	
				UI -	Pull Down Menus	1	1	0.02	Main File Menu only
				UI -	Check Boxes	1	1	0.02	
				UI -	Typed in Values	1	1	0.02	
				UI -	Adjustment sliders	1	1	0.02	
				Set-up Wizards		1	0	0.00	
			Comprehensive able			SUM		0.08	
				Pop-up Information		1	0	0.00	
				Common Terminology		1	0	0.00	
				User Feedback		1	1	0.02	
				Help Menus		1	0	0.00	
				Standard Symbology (SM)		1	0	0.00	
				SM -	Friendly, Hostile, & Neutral	1	1	0.02	
				Forces		1	1	0.02	XML Format
				Object Templates		1	1	0.02	XML Format

Figure 90. Pythagoras Usability Evaluation Sheet.

Pythagorus

Capability Evaluation

Cap	Charact	Ility	Trait	Funct	Functionality Element	Pts	Eval	Total	Remarks
Flexibility						SUM		0.69	
	Modelable					SUM		0.57	
		Securities				SUM		0.00	
			Classification			SUM		0.00	
				Safeguard & Handle Classified Information		1	0	0.00	
				Encryption / Decryption Devices		1	0	0.00	
		Export / Import abilities				SUM		0.08	
			Databases			SUM		0.08	
				Systems (Created Models)		1	1	0.02	XML Format
				Environment (Terrian / Weather / etc.)		1	1	0.02	XML Format
				Imagary Data		1	1	0.02	Bitmap Format
				Scenario Files		1	1	0.02	XML Format
		Adjust abilities				SUM		0.49	
			Systems			SUM		0.33	
				Multiple Attributes		1	1	0.02	Agent Tab
				Model Basic Physics		1	0	0.00	
				Refueling Capabilities		1	1	0.02	Resouce Tab
				Movement Parameters		1	1	0.02	Agent Tab / Position Property
				Mode Selection		1	1	0.02	Triggers
				Clone / Copy Functions		1	1	0.02	
				Military Operations (MO)		1	1	0.02	Agent Tab
				MO -	Guard	1	1	0.02	Agent Tab
				MO -	Patrol	1	1	0.02	Agent Tab
				MO -	Orbit	1	1	0.02	Agent Tab
				MO -	Attack	1	1	0.02	Agent Tab
				MO -	Flee / Run	1	1	0.02	Agent Tab
				MO -	Grouping Functions	1	1	0.02	Agent Tab
				MO -	Inter Communications	1	1	0.02	Agent Tab
				MO -	Remain in place	1	1	0.02	Agent Tab
				MO -	Waypoint selection	1	1	0.02	Agent Tab
				MO -	Unit operations	1	1	0.02	Agent Tab
			Environment			SUM		0.08	
				2D Terrain Modeling (2D)		1	1	0.02	Terrain Tab
				2D -	Surface Configuration	1	1	0.02	Terrain Tab
				2D -	Natural Features	1	1	0.02	Terrain Tab
				2D -	Man-made Features	1	1	0.02	Terrain Tab
				Oceanographic Modeling (OM)		1	0	0.00	
				OM -	Contours with depth data	1	0	0.00	
				External Forces (EF)		1	0	0.00	
				EF -	Wind	1	0	0.00	
				EF -	Sea State	1	0	0.00	
			Measures of Performance			SUM		0.06	
				Survivability		1	1	0.02	MOE Tab
				Transit Times		1	1	0.02	MOE Tab
				Cargo Transfer		1	1	0.02	MOE Tab
			Resolution			SUM		0.02	
				T-craft Levels (Single vs. Multiple)		1	1	0.02	
	Architectural Design					SUM		0.06	
		Interoperability Standards & Protocol				1	0	0.00	
		Federate Capable				SUM		0.02	
			High Level Architecture (HLA) Capable			1	0	0.00	
			Reusable Program			1	0	0.00	
			Program History			1	1	0.02	Project Albert
		Program Considerations				SUM		0.04	
			Open Source Code			1	0	0.00	
				Input Operational Data (IO)		1	1	0.02	
				IO -	Object Library	1	1	0.02	XML Format
				Auto Save / Auto Recover		1	0	0.00	
	Stochastic Process					SUM		0.06	
		Scriptable				1	1	0.02	Agent Tab
			Discrete-Event			1	0	0.00	
				Random Variables/Markov Principles		1	0	0.00	
			Time_Step			1	1	0.02	
				Random Variables/Markov Principles		1	1	0.02	

Figure 91. Pythagoras Flexibility Evaluation Sheet.

Pythagorus

Capability Evaluation

Cap	Charact	Ility	Trait	Funct	Functionality Element	Pts	Eval	Total	Remarks
Scalability						SUM		0.76	
	Variation					SUM		0.76	
		Adjust abilities				SUM		0.57	
			Systems			SUM		0.38	
				Multiple Attributes		1	1	0.02	Agent Tab
				Model Basic Physics		1	0	0.00	
				Refueling Capabilities		1	1	0.02	Resouce Tab
				Movement Parameters		1	1	0.02	Agent Tab / Position Property
				Mode Selection		1	1	0.02	Triggers
				Clone / Copy Functions		1	1	0.02	
				Military Operations (MO)		1	1	0.02	Agent Tab
				MO -	Guard	1	1	0.02	Agent Tab
				MO -	Patrol	1	1	0.02	Agent Tab
				MO -	Orbit	1	1	0.02	Agent Tab
				MO -	Attack	1	1	0.02	Agent Tab
				MO -	Flee / Run	1	1	0.02	Agent Tab
				MO -	Grouping Functions	1	1	0.02	Agent Tab
				MO -	Inter Communications	1	1	0.02	Agent Tab
				MO -	Remain in place	1	1	0.02	Agent Tab
				MO -	Waypoint selection	1	1	0.02	Agent Tab
				MO -	Unit operations	1	1	0.02	Agent Tab
			Environment			SUM		0.10	
				2D Terrain Modeling (2D)		1	1	0.02	Terrain Tab
				2D -	Surface Configuration	1	1	0.02	Terrain Tab
				2D -	Natural Features	1	1	0.02	Terrain Tab
				2D -	Man-made Features	1	1	0.02	Terrain Tab
				Oceanographic Modeling (OM)		1	0	0.00	
				OM -	Contours with depth data	1	0	0.00	
				External Forces (EF)		1	0	0.00	
				EF -	Wind	1	0	0.00	
				EF -	Sea State	1	0	0.00	
			Measures of Performance			SUM		0.07	
				Survivability		1	1	0.02	MOE Tab
				Transit Times		1	1	0.02	MOE Tab
				Cargo Transfer		1	1	0.02	MOE Tab
			Resolution			SUM		0.02	
				T-craft Levels (Single vs. Multiple)		1	1	0.02	
		Adjudication				SUM		0.19	
			Attain abilities			SUM		0.19	
				Results (RS)		1	1	0.02	
				RS -	Units of Measure	1	1	0.02	
				RS -	MOP's Translations	1	1	0.02	
				RS -	User Defined Data Output	1	1	0.02	
				RS -	Battle Damage Assessments	1	0	0.00	
				Engagement (EG)		1	1	0.02	
				EG -	Probability Tables Ph/Pk	1	0	0.00	
				EG -	Sensor Algorithms Integration	1	1	0.02	
				EG -	Weapons Algorithms Integration	1	1	0.02	
				EG -	Indirect Fire Capabilities	1	0	0.00	
				EG -	Sensor Detections	1	1	0.02	
				EG -	Battle Damage	1	0	0.00	

Figure 92. Pythagoras Scalability Evaluation Sheet.

Naval Simulation System (NSS)

Capability Evaluation

Cap	Charact	Ility	Trait	Funct	Functionality Element	Pts	Eval	Total	Remarks
USABILITY						SUM		0.64	
	VALIDATION					SUM		0.51	
		CONSTRUCTABILITIES				SUM		0.34	
			DYNAMIC SITUATIONS			SUM		0.19	
				SENSOR PROB. TABLES		1	1	0.02	Inherient in Physic Model
				WEAPON PROB. TABLES		1	1	0.02	Inherient in Physic Model
				INDIVIDUAL UNIT ACTIONS		1	1	0.02	
				AGENT INFORMATION (AI)		1	1	0.02	
				AI -	COURSE	1	0	0.00	
				AI -	SPEED	1	1	0.02	
				AI -	POSITIONAL DATA	1	1	0.02	
				AI -	REFUELING RATES	1	0	0.00	
				AI -	CARGO CAPACITIES	1	0	0.00	
				COMMUNICATION (CM)		1	1	0.02	
				CM -	COMMAND AND CONTROL ENTITY	1	1	0.02	Communication Matrix
				CM -	MILITARY OPERATIONS other than WARFARE	1	0	0.00	
				CM -	LOGISTIC CAPABILITIES	1	1	0.02	No User Defined Settings
				WAITING QUEUES		1	0	0.00	
				PERSONAL SETTINGS		1	1	0.02	Display only
				SEMI-AUTOMATED FORCES		1	0	0.00	
			REPLICABLE			SUM		0.15	
				SIMULATE a user DEFINED MODEL		1	1	0.02	
				MULTIPLE RUNS DEFINED by user		1	1	0.02	
				MEASURES OF PERFORMANCE		1	1	0.02	User Defined
				PARAMETERS		1	0	0.00	
				RESET SIMULATION PARAMETERS		1	1	0.02	
				User DEFINED OUTPUT VARIABLES		1	1	0.02	
				START/STOP CRITERIA		1	1	0.02	
				ACCURACY		1	1	0.02	Confidence Interval
				SPOT SAMPLING		1	1	0.02	Playback only
		SUPPORTABILITIES				SUM		0.17	
			CONTRACTOR SUPPORT			SUM		0.13	
				BASIC INFORMAITON (BI)		1	1	0.02	
				BI -	VERSION NUMBER	1	1	0.02	Version 3.4.1 (Beta)
				Bi -	UPGRADE INFORMATION	1	1	0.02	Software User Manual
				REACH-BACK AVAILABILITY		1	1	0.02	Limited
				POINTS OF CONTACTS (PC)		1	1	0.02	Software User Manual
				PC -	WEBSITE AVAILABILITY	1	0	0.00	
				TRAINING and EDUCATION		1	1	0.02	Limited
				FEEDBACK LOOP		1	1	0.02	
				AUTHORITATIVE SOURCES		1	0	0.00	
			DOCUMENTATION			SUM		0.04	
				FUNCTIONALITY TUTORIALS		1	0	0.00	
				HELP WINDOWS		1	0	0.00	
				User MANUAL		1	1	0.02	Software User Manual
				PUBLICATIONS		1	1	0.02	Good
				ONLINE SUPPORT		1	0	0.00	
	User INTERFACE					SUM		0.13	
		Representabilities				SUM		0.13	
			Graphical User Interface (GUI)			SUM		0.02	
				User input windows (UI)		1	1	0.02	Click & Drag interface
				UI -	Pull Down Menus	1	0	0.00	
				UI -	Check Boxes	1	0	0.00	
				UI -	Typed in Values	1	0	0.00	
				UI -	Adjustment sliders	1	0	0.00	
				Set-up Wizards		1	0	0.00	
			Comprehensive able			SUM		0.11	
				Pop-up Information		1	1	0.02	
				Common Terminology		1	1	0.02	Based on DoD Guidance
				User Feedback		1	1	0.02	
				Help Menus		1	0	0.00	
				Standard Symbology (SM)		1	1	0.02	Based on DoD Guidance
				SM -	Friendly, Hostile, & Neutral	1	1	0.02	Common Tactical Symbols
				Forces		1	0	0.00	
				Object Templates		1	1	0.02	Limited

Figure 93. NSS Usability Evaluation Sheet.

Naval Simulation System (NSS)

Capability Evaluation

Cap	Charact	Ility	Trait	Funct	Functionality Element	Pts	Eval	Total	Remarks
Flexibility						SUM		0.67	
	Modelable					SUM		0.51	
		Securities				SUM		0.04	
			Classification			SUM		0.04	
				Safeguard & Handle Classified Information		1	1	0.02	Linked to Classified Network
				Encryption / Decryption Devices		1	1	0.02	Linked to Classified Network
		Export / Import abilities				SUM		0.06	
			Databases			SUM		0.06	
				Systems (Created Models)		1	1	0.02	XML Format
				Environment (Terrian / Weather / etc.)		1	1	0.02	XML Format
				Imagary Data		1	0	0.00	
				Scenario Files		1	1	0.02	XML Format
		Adjust abilities				SUM		0.41	
			Systems			SUM		0.18	
				Multiple Attributes		1	0	0.00	
				Model Basic Physics		1	1	0.02	Complex Physics
				Refueling Capabilities		1	1	0.02	Automated
				Movement Parameters		1	0	0.00	
				Mode Selection		1	0	0.00	
				Clone / Copy Functions		1	1	0.02	Database Administrator
				Military Operations (MO)		1	1	0.02	Mission Plans
				MO -	Guard	1	0	0.00	
				MO -	Patrol	1	0	0.00	
				MO -	Orbit	1	0	0.00	
				MO -	Attack	1	1	0.02	Aliance Differences only
				MO -	Flee / Run	1	0	0.00	
				MO -	Grouping Functions	1	1	0.02	C2 Plans
				MO -	Inter Communications	1	1	0.02	C2 Plans
				MO -	Remain in place	1	0	0.00	
				MO -	Waypoint selection	1	1	0.02	Track/Region Editor
				MO -	Unit operations	1	1	0.02	Ops Plans
			Environment			SUM		0.16	
				2D Terrain Modeling (2D)		1	1	0.02	Database only
				2D -	Surface Configuration	1	1	0.02	Database only
				2D -	Natural Features	1	1	0.02	Database only
				2D -	Man-made Features	1	1	0.02	Database only
				Oceanographic Modeling (OM)		1	1	0.02	Database only
				OM -	Contours with depth data	1	1	0.02	Database only
				External Forces (EF)		1	0	0.00	
				EF -	Wind	1	1	0.02	
				EF -	Sea State	1	1	0.02	
			Measures of Performance			SUM		0.04	
				Survivability		1	1	0.02	User Defined MOP
				Transit Times		1	1	0.02	User Defined MOP
				Cargo Transfer		1	0	0.00	
			Resolution			SUM		0.02	
				T-craft Levels (Single vs. Multiple)		1	1	0.02	
	Architectural Design					SUM		0.10	
		Interoperability Standards & Protocol				1	0	0.00	
		Federate Capable				SUM		0.04	
			High Level Architecture (HLA) Capable			1	0	0.00	
			Reusable Program			1	1	0.02	Federation Reuse
			Program History			1	1	0.02	Software User Manual
		Program Considerations				SUM		0.06	
			Open Source Code			1	0	0.00	
				Input Operational Data (IO)		1	1	0.02	Global C2 System (GCCS) inputs
				IO -	Object Library	1	1	0.02	NSS Databases
				Auto Save / Auto Recover		1	1	0.02	
	Stochastic Process					SUM		0.06	
		Scriptable				1	1	0.02	Track/Region Editor
			Discrete-Event			1	1	0.02	
				Random Variables/Markov Principles		1	1	0.02	
			Time_Step			1	0	0.00	
				Random Variables/Markov Principles		1	0	0.00	

Figure 94. NSS Flexibility Evaluation Sheet.

Naval Simulation System (NSS) Capability Evaluation									
Cap	Charact Ility	Trait	Funct		Functionality Element	Pts	Eval	Total	Remarks
Scalability						SUM		0.71	
	Variation					SUM		0.71	
		Adjust abilities				SUM		0.48	
			Systems			SUM		0.21	
				Multiple Attributes		1	0	0.00	
				Model Basic Physics		1	1	0.02	Comple Physics
				Refueling Capabilities		1	1	0.02	Automated
				Movement Parameters		1	0	0.00	
				Mode Selection		1	0	0.00	
				Clone / Copy Functions		1	1	0.02	Database Administrator
				Military Operations (MO)		1	1	0.02	Mission Plans
				MO -	Guard	1	0	0.00	
				MO -	Patrol	1	0	0.00	
				MO -	Orbit	1	0	0.00	
				MO -	Attack	1	1	0.02	Aliance Differences only
				MO -	Flee / Run	1	0	0.00	
				MO -	Grouping Functions	1	1	0.02	C2 Plans
				MO -	Inter Communications	1	1	0.02	C2 Plans
				MO -	Remain in place	1	0	0.00	
				MO -	Waypoint selection	1	1	0.02	Track/Region Editor
				MO -	Unit operations	1	1	0.02	Ops Plans
			Environment			SUM		0.19	
				2D Terrain Modeling (2D)		1	1	0.02	Database only
				2D -	Surface Configuration	1	1	0.02	Database only
				2D -	Natural Features	1	1	0.02	Database only
				2D -	Man-made Features	1	1	0.02	Database only
				Oceanographic Modeling (OM)		1	1	0.02	Database only
				OM -	Contours with depth data	1	1	0.02	Database only
				External Forces (EF)		1	0	0.00	
				EF -	Wind	1	1	0.02	
				EF -	Sea State	1	1	0.02	
			Measures of Performance			SUM		0.05	
				Survivability		1	1	0.02	User Defined MOP
				Transit Times		1	1	0.02	User Defined MOP
				Cargo Transfer		1	0	0.00	
			Resolution			SUM		0.02	
				T-craft Levels (Single vs. Multiple)		1	1	0.02	
		Adjudication				SUM		0.24	
			Attain abilities			SUM		0.24	
				Results (RS)		1	1	0.02	
				RS -	Units of Measure	1	1	0.02	Limited
				RS -	MOP's Translations	1	0	0.00	
				RS -	User Defined Data Output	1	1	0.02	
				RS -	Battle Damage Assessments	1	1	0.02	
				Engagement (EG)		1	1	0.02	
				EG -	Probability Tables Ph/Pk	1	1	0.02	
				EG -	Sensor Algorithms Integration	1	1	0.02	Actual System Parameter Settings
				EG -	Weapons Algorithms Integration	1	1	0.02	Actual System Parameter Settings
				EG -	Indirect Fire Capabilities	1	0	0.00	
				EG -	Sensor Detections	1	1	0.02	
				EG -	Battle Damage	1	1	0.02	

Figure 95. NSS Scalability Evaluation Sheet.

Simkit API

Capability Evaluation

Cap	Charact	Ility	Trait	Funct	Functionality Element	Pts	Eval	Total	Remarks
USABILITY						SUM		0.47	
	VALIDATION					SUM		0.45	
		CONSTRUCTABILITIES				SUM		0.25	
			DYNAMIC SITUATIONS			SUM		0.08	
				SENSOR PROB. TABLES		1	0	0.00	
				WEAPON PROB. TABLES		1	0	0.00	
				INDIVIDUAL UNIT ACTIONS		1	1	0.02	Object Orientated
				AGENT INFORMATION (AI)		1	0	0.00	
				AI -	COURSE	1	0	0.00	
				AI -	SPEED	1	0	0.00	
				AI -	POSITIONAL DATA	1	0	0.00	
				AI -	REFUELING RATES	1	1	0.02	User Defined
				AI -	CARGO CAPACITIES	1	1	0.02	User Defined
				COMMUNICATION (CM)		1	0	0.00	
				CM -	COMMAND AND CONTROL ENTITY	1	0	0.00	
				CM -	MILITARY OPERATIONS other than WARFARE	1	0	0.00	
				CM -	LOGISTIC CAPABILITIES	1	0	0.00	
				WAITING QUEUES		1	1	0.02	Simkit API
				PERSONAL SETTINGS		1	0	0.00	
				SEMI-AUTOMATED FORCES		1	0	0.00	
			REPLICABLE			SUM		0.17	
				SIMULATE a user DEFINED MODEL		1	1	0.02	Simkit API
				MULTIPLE RUNS DEFINED by user		1	1	0.02	Simkit API
				MEASURES OF PERFORMANCE		1	1	0.02	Simkit API
				PARAMETERS		1	1	0.02	User Defined
				RESET SIMULATION PARAMETERS		1	1	0.02	Simkit API
				User DEFINED OUTPUT VARIABLES		1	1	0.02	
				START/STOP CRITERIA		1	1	0.02	Simkit API
				ACCURACY		1	1	0.02	Simkit API
				SPOT SAMPLING		1	1	0.02	User Defined
		SUPPORTABILITIES				SUM		0.21	
			CONTRACTOR SUPPORT			SUM		0.15	
				BASIC INFORMAITON (BI)		1	1	0.02	Website
				BI -	VERSION NUMBER	1	1	0.02	Version 1.3.8
				Bi -	UPGRADE INFORMATION	1	1	0.02	Website
				REACH-BACK AVAILABILITY		1	1	0.02	at NPS
				POINTS OF CONTACTS (PC)		1	1	0.02	Website
				PC -	WEBSITE AVAILABILITY	1	1	0.02	tp://diana.cs.nps.navy.mil/mv43
				TRAINING and EDUCATION		1	1	0.02	NPS Course Material
				FEEDBACK LOOP		1	0	0.00	
				AUTHORITATIVE SOURCES		1	1	0.02	Open Source
			DOCUMENTATION			SUM		0.06	
				FUNCTIONALITY TUTORIALS		1	1	0.02	NPS Course Material
				HELP WINDOWS		1	0	0.00	
				User MANUAL		1	1	0.02	
				PUBLICATIONS		1	0	0.00	
				ONLINE SUPPORT		1	1	0.02	Website
	User INTERFACE					SUM		0.02	
		Representabilities				SUM		0.02	
			Graphical User Interface (GUI)			SUM		0.00	
				User input windows (UI)		1	0	0.00	
				UI -	Pull Down Menus	1	0	0.00	
				UI -	Check Boxes	1	0	0.00	
				UI -	Typed in Values	1	0	0.00	
				UI -	Adjustment sliders	1	0	0.00	
				Set-up Wizards		1	0	0.00	
			Comprehensive able			SUM		0.02	
				Pop-up Information		1	0	0.00	
				Common Terminology		1	0	0.00	
				User Feedback		1	0	0.00	
				Help Menus		1	0	0.00	
				Standard Symbology (SM)		1	0	0.00	
				SM -	Friendly, Hostile, & Neutral	1	0	0.00	
				Forces		1	0	0.00	
				Object Templates		1	1	0.02	

Figure 96. Simkit Usability Evaluation Sheet.

Simkit API

Capability Evaluation

Cap	Charact	Ility	Trait	Funct	Functionality Element	Pts	Eval	Total	Remarks
Flexibility						SUM		0.39	
	Modelable					SUM		0.24	
		Securities				SUM		0.00	
			Classification			SUM		0.00	
				Safeguard & Handle Classified Information		1	0	0.00	
				Encryption / Decryption Devices		1	0	0.00	
		Export / Import abilities				SUM		0.00	
			Databases			SUM		0.00	
				Systems (Created Models)		1	0	0.00	
				Environment (Terrian / Weather / etc.)		1	0	0.00	
				Imagary Data		1	0	0.00	
				Scenario Files		1	0	0.00	
		Adjust abilities				SUM		0.24	
			Systems			SUM		0.16	
				Multiple Attributes		1	0	0.00	
				Model Basic Physics		1	0	0.00	
				Refueling Capabilities		1	1	0.02	
				Movement Parameters		1	1	0.02	Point 2D
				Mode Selection		1	1	0.02	
				Clone / Copy Functions		1	0	0.00	
				Military Operations (MO)		1	1	0.02	Limited
				MO -	Guard	1	0	0.00	
				MO -	Patrol	1	0	0.00	
				MO -	Orbit	1	0	0.00	
				MO -	Attack	1	1	0.02	Probabilities only
				MO -	Flee / Run	1	0	0.00	
				MO -	Grouping Functions	1	0	0.00	
				MO -	Inter Communications	1	0	0.00	
				MO -	Remain in place	1	1	0.02	
				MO -	Waypoint selection	1	1	0.02	
				MO -	Unit operations	1	1	0.02	
			Environment			SUM		0.00	
				2D Terrain Modeling (2D)		1	0	0.00	
				2D -	Surface Configuration	1	0	0.00	
				2D -	Natural Features	1	0	0.00	
				2D -	Man-made Features	1	0	0.00	
				Oceanographic Modeling (OM)		1	0	0.00	
				OM -	Contours with depth data	1	0	0.00	
				External Forces (EF)		1	0	0.00	
				EF -	Wind	1	0	0.00	
				EF -	Sea State	1	0	0.00	
			Measures of Performance			SUM		0.06	
				Survivability		1	1	0.02	Excellent
				Transit Times		1	1	0.02	Good
				Cargo Transfer		1	1	0.02	Fair
			Resolution			SUM		0.02	
				T-craft Levels (Single vs. Multiple)		1	1	0.02	
	Architectural Design					SUM		0.08	
		Interoperability Standards & Protocol				1	0	0.00	
		Federate Capable				SUM		0.02	
			High Level Architecture (HLA) Capable			1	0	0.00	
			Reusable Program			1	0	0.00	
			Program History			1	1	0.02	Thesis Work
		Program Considerations				SUM		0.06	
			Open Source Code			1	1	0.02	Java Programming
				Input Operational Data (IO)		1	1	0.02	
				IO -	Object Library	1	1	0.02	Simkit API
				Auto Save / Auto Recover		1	0	0.00	
	Stochastic Process					SUM		0.06	
		Scriptable				1	1	0.02	
			Discrete-Event			1	1	0.02	
				Random Variables/Markov Principles		1	1	0.02	
			Time_Step			1	0	0.00	
				Random Variables/Markov Principles		1	0	0.00	

Figure 97. Simkit Flexibility Evaluation Sheet.

Simkit API

Capability Evaluation

Cap	Charact	Ility	Trait	Funct	Functionality Element	Pts	Eval	Total	Remarks
Scalability						SUM		0.40	
	Variation					SUM		0.40	
		Adjust abilities				SUM		0.29	
			Systems			SUM		0.19	
				Multiple Attributes		1	0	0.00	
				Model Basic Physics		1	0	0.00	
				Refueling Capabilities		1	1	0.02	
				Movement Parameters		1	1	0.02	Point 2D
				Mode Selection		1	1	0.02	
				Clone / Copy Functions		1	0	0.00	
				Military Operations (MO)		1	1	0.02	Limited
				MO -	Guard	1	0	0.00	
				MO -	Patrol	1	0	0.00	
				MO -	Orbit	1	0	0.00	
				MO -	Attack	1	1	0.02	Probabilities only
				MO -	Flee / Run	1	0	0.00	
				MO -	Grouping Functions	1	0	0.00	
				MO -	Inter Communications	1	0	0.00	
				MO -	Remain in place	1	1	0.02	
				MO -	Waypoint selection	1	1	0.02	
				MO -	Unit operations	1	1	0.02	
			Environment			SUM		0.00	
				2D Terrain Modeling (2D)		1	0	0.00	
				2D -	Surface Configuration	1	0	0.00	
				2D -	Natural Features	1	0	0.00	
				2D -	Man-made Features	1	0	0.00	
				Oceanographic Modeling (OM)		1	0	0.00	
				OM -	Contours with depth data	1	0	0.00	
				External Forces (EF)		1	0	0.00	
				EF -	Wind	1	0	0.00	
				EF -	Sea State	1	0	0.00	
			Measures of Performance			SUM		0.07	
				Survivability		1	1	0.02	Excellent
				Transit Times		1	1	0.02	Good
				Cargo Transfer		1	1	0.02	Fair
			Resolution			SUM		0.02	
				T-craft Levels (Single vs. Multiple)		1	1	0.02	
		Adjudication				SUM		0.12	
			Attain abilities			SUM		0.12	
				Results (RS)		1	1	0.02	
				RS -	Units of Measure	1	1	0.02	User Defined
				RS -	MOP's Translations	1	0	0.00	
				RS -	User Defined Data Output	1	1	0.02	Excellent
				RS -	Battle Damage Assessments	1	1	0.02	User Defined
				Engagement (EG)		1	0	0.00	
				EG -	Probability Tables Ph/Pk	1	0	0.00	
				EG -	Sensor Algorithms Integration	1	0	0.00	
				EG -	Weapons Algorithms Integration	1	0	0.00	
				EG -	Indirect Fire Capabilities	1	0	0.00	
				EG -	Sensor Detections	1	0	0.00	
				EG -	Battle Damage	1	1	0.02	User Defined

Figure 98. Simkit Scalability Evaluation Sheet.

Arena *Capability Evaluation*									
Cap	Charact	Ility	Trait	Funct	Functionality Element	Pts	Eval	Total	Remarks
USABILITY						SUM		0.75	
	VALIDATION					SUM		0.60	
		CONSTRUCTABILITIES				SUM		0.38	
			DYNAMIC SITUATIONS			SUM		0.21	
				SENSOR PROB. TABLES		1	1	0.02	
				WEAPON PROB. TABLES		1	1	0.02	
				INDIVIDUAL UNIT ACTIONS		1	1	0.02	
				AGENT INFORMATION (AI)		1	1	0.02	
				AI -	COURSE	1	0	0.00	
				AI -	SPEED	1	1	0.02	
				AI -	POSITIONAL DATA	1	0	0.00	
				AI -	REFUELING RATES	1	1	0.02	
				AI -	CARGO CAPACITIES	1	1	0.02	
				COMMUNICATION (CM)		1	0	0.00	
				CM -	COMMAND AND CONTROL ENTITY	1	0	0.00	
				CM -	MILITARY OPERATIONS other than WARFARE	1	1	0.02	
				CM -	LOGISTIC CAPABILITIES	1	0	0.00	
				WAITING QUEUES		1	1	0.02	
				PERSONAL SETTINGS		1	1	0.02	
				SEMI-AUTOMATED FORCES		1	1	0.02	Single Entity Replication
			REPLICABLE			SUM		0.17	
				SIMULATE a user DEFINED MODEL		1	1	0.02	
				MULTIPLE RUNS DEFINED by user		1	1	0.02	
				MEASURES OF PERFORMANCE		1	1	0.02	
				PARAMETERS		1	1	0.02	
				RESET SIMULATION PARAMETERS		1	1	0.02	
				User DEFINED OUTPUT VARIABLES		1	1	0.02	
				START/STOP CRITERIA		1	1	0.02	
				ACCURACY		1	1	0.02	
				SPOT SAMPLING		1	1	0.02	
		SUPPORTABILITIES				SUM		0.23	
			CONTRACTOR SUPPORT			SUM		0.13	
				BASIC INFORMAITON (BI)		1	1	0.02	
				BI -	VERSION NUMBER	1	1	0.02	Version 12.0
				Bi -	UPGRADE INFORMATION	1	1	0.02	
				REACH-BACK AVAILABILITY		1	1	0.02	
				POINTS OF CONTACTS (PC)		1	0	0.00	
				PC -	WEBSITE AVAILABILITY	1	1	0.02	www.arenasimulation.com
				TRAINING and EDUCATION		1	1	0.02	
				FEEDBACK LOOP		1	1	0.02	
				AUTHORITATIVE SOURCES		1	0	0.00	
			DOCUMENTATION			SUM		0.09	
				FUNCTIONALITY TUTORIALS		1	1	0.02	
				HELP WINDOWS		1	1	0.02	
				User MANUAL		1	1	0.02	Updated
				PUBLICATIONS		1	1	0.02	Outstanding
				ONLINE SUPPORT		1	1	0.02	
	User INTERFACE					SUM		0.15	
		Representabilities				SUM		0.15	
			Graphical User Interface (GUI)			SUM		0.09	
				User input windows (UI)		1	1	0.02	
				UI -	Pull Down Menus	1	1	0.02	
				UI -	Check Boxes	1	1	0.02	
				UI -	Typed in Values	1	1	0.02	
				UI -	Adjustment sliders	1	1	0.02	
				Set-up Wizards		1	0	0.00	Templates Available
			Comprehensive able			SUM		0.06	
				Pop-up Information		1	1	0.02	
				Common Terminology		1	0	0.00	
				User Feedback		1	0	0.00	
				Help Menus		1	1	0.02	
				Standard Symbology (SM)		1	0	0.00	
				SM -	Friendly, Hostile, & Neutral	1	0	0.00	
				Forces		1	1	0.02	User Defined
				Object Templates		1	0	0.00	

Figure 99. Arena Usability Evaluation Sheet.

Arena

Capability Evaluation

Cap	Charact	Ility	Trait	Funct	Functionality Element	Pts	Eval	Total	Remarks
Flexibility						SUM		0.20	
	Modelable					SUM		0.10	
		Securities				SUM		0.00	
			Classification			SUM		0.00	
				Safeguard & Handle Classified Information		1	0	0.00	
				Encryption / Decryption Devices		1	0	0.00	
		Export / Import abilities				SUM		0.02	
			Databases			SUM		0.02	
				Systems (Created Models)		1	1	0.02	
				Environment (Terrian / Weather / etc.)		1	0	0.00	
				Imagary Data		1	0	0.00	
				Scenario Files		1	0	0.00	
		Adjust abilities				SUM		0.08	
			Systems			SUM		0.02	
				Multiple Attributes		1	0	0.00	
				Model Basic Physics		1	0	0.00	
				Refueling Capabilities		1	1	0.02	
				Movement Parameters		1	0	0.00	
				Mode Selection		1	0	0.00	
				Clone / Copy Functions		1	0	0.00	
				Military Operations (MO)		1	0	0.00	
				MO -	Guard	1	0	0.00	
				MO -	Patrol	1	0	0.00	
				MO -	Orbit	1	0	0.00	
				MO -	Attack	1	0	0.00	
				MO -	Flee / Run	1	0	0.00	
				MO -	Grouping Functions	1	0	0.00	
				MO -	Inter Communications	1	0	0.00	
				MO -	Remain in place	1	0	0.00	
				MO -	Waypoint selection	1	0	0.00	
				MO -	Unit operations	1	0	0.00	
			Environment			SUM		0.00	
				2D Terrain Modeling (2D)		1	0	0.00	
				2D -	Surface Configuration	1	0	0.00	
				2D -	Natural Features	1	0	0.00	
				2D -	Man-made Features	1	0	0.00	
				Oceanographic Modeling (OM)		1	0	0.00	
				OM -	Contours with depth data	1	0	0.00	
				External Forces (EF)		1	0	0.00	
				EF -	Wind	1	0	0.00	
				EF -	Sea State	1	0	0.00	
			Measures of Performance			SUM		0.06	
				Survivability		1	1	0.02	Excellent Processes
				Transit Times		1	1	0.02	Excellent Processes
				Cargo Transfer		1	1	0.02	Excellent Processes
			Resolution			SUM		0.00	
				T-craft Levels (Single vs. Multiple)		1	0	0.00	Sinlge Entity Replicated
	Architectural Design					SUM		0.04	
		Interoperability Standards & Protocol				1	0	0.00	
		Federate Capable				SUM		0.00	
			High Level Architecture (HLA) Capable			1	0	0.00	
			Reusable Program			1	0	0.00	
			Program History			1	0	0.00	
		Program Considerations				SUM		0.04	
			Open Source Code			1	0	0.00	
				Input Operational Data (IO)		1	1	0.02	Databases
				IO -	Object Library	1	1	0.02	Transferable Scenario Files
				Auto Save / Auto Recover		1	0	0.00	
	Stochastic Process					SUM		0.06	
		Scriptable				1	1	0.02	
			Discrete-Event			1	1	0.02	
				Random Variables/Markov Principles		1	1	0.02	Distributions
			Time_Step			1	0	0.00	
				Random Variables/Markov Principles		1	0	0.00	

Figure 100. Arena Flexibility Evaluation Sheet.

Arena *Capability Evaluation*									
Cap	Charact	Ility	Trait	Funct	Functionality Element	Pts	Eval	Total	Remarks
Scalability						SUM		0.24	
	Variation					SUM		0.24	
		Adjust abilities				SUM		0.12	
			Systems			SUM		0.02	
				Multiple Attributes		1	0	0.00	
				Model Basic Physics		1	0	0.00	
				Refueling Capabilities		1	1	0.02	
				Movement Parameters		1	0	0.00	
				Mode Selection		1	0	0.00	
				Clone / Copy Functions		1	0	0.00	
				Military Operations (MO)		1	0	0.00	
				MO -	Guard	1	0	0.00	
				MO -	Patrol	1	0	0.00	
				MO -	Orbit	1	0	0.00	
				MO -	Attack	1	0	0.00	
				MO -	Flee / Run	1	0	0.00	
				MO -	Grouping Functions	1	0	0.00	
				MO -	Inter Communications	1	0	0.00	
				MO -	Remain in place	1	0	0.00	
				MO -	Waypoint selection	1	0	0.00	
				MO -	Unit operations	1	0	0.00	
			Environment			SUM		0.00	
				2D Terrain Modeling (2D)		1	0	0.00	
				2D -	Surface Configuration	1	0	0.00	
				2D -	Natural Features	1	0	0.00	
				2D -	Man-made Features	1	0	0.00	
				Oceanographic Modeling (OM)		1	0	0.00	
				OM -	Contours with depth data	1	0	0.00	
				External Forces (EF)		1	0	0.00	
				EF -	Wind	1	0	0.00	
				EF -	Sea State	1	0	0.00	
			Measures of Performance			SUM		0.07	
				Survivability		1	1	0.02	Excellent Processes
				Transit Times		1	1	0.02	Excellent Processes
				Cargo Transfer		1	1	0.02	Excellent Processes
			Resolution			SUM		0.02	
				T-craft Levels (Single vs. Multiple)		1	1	0.02	Sinlge Entity Replicated
		Adjudication				SUM		0.12	
			Attain abilities			SUM		0.12	
				Results (RS)		1	1	0.02	
				RS -	Units of Measure	1	1	0.02	Time units
				RS -	MOP's Translations	1	1	0.02	
				RS -	User Defined Data Output	1	1	0.02	
				RS -	Battle Damage Assessments	1	0	0.00	
				Engagement (EG)		1	0	0.00	
				EG -	Probability Tables Ph/Pk	1	1	0.02	Imported Databases
				EG -	Sensor Algorithms Integration	1	0	0.00	
				EG -	Weapons Algorithms Integration	1	0	0.00	
				EG -	Indirect Fire Capabilities	1	0	0.00	
				EG -	Sensor Detections	1	0	0.00	
				EG -	Battle Damage	1	0	0.00	

Figure 101. Arena Scalability Evaluation Sheet.

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VIII. SIMULATION COMPARISON

Evaluation across M&S categories revealed similarities and differences among the M&S tools. These comparisons are generalized in this chapter to understand capabilities that were determined to be present. Select capabilities of the M&S tools used gave way to a combination of functionalities that may be used in future M&S development. The use of an M&S tool or a suite of M&S tools is introduced in this chapter for SBE modeling that could be expanded to other areas of research and development. A "suite of simulation" concept was discussed, due to the fact that the validation of a single M&S tool was, by definition, narrowed for a specific use. For example, what if a series of M&S tools linked or integrated together to utilize their complementary functionalities? The pros and cons of this idea are discussed. The last idea presented in this chapter is the trade space of M&S tools analyzed in this study and their limitations in a "suite of simulations."

A. OBSERVED CAPABILITIES

The two main types of simulations evaluated were time-step and next-event based models. These models displayed opposite strengths in capabilities of modeling a SBE Scenario. Time-step simulations scored High Scalability for scenario representation and attainability. The general functionalities displayed were agent actions and visual representation of the SBE Scenario. In models like MANA and Pythagoras, the ability of the user to define agent actions exceeded the actions of entities in next-event models. AABM enabled controls for attained abilities that were specifically design to model the individual unit’s decision making process remain an aspect of time-step based models. Next-event simulations scored High Usability for scenario validation and user interface. The functionalities derived from next-event based models were the implementation of physics based models and user interface options across M&S tools. Next-event based models’ key capabilities modeled real systems in simulation environments to test and measure performance in dynamic situations. The validation of the M&S tools was critical to the outcomes of simulation. Interface characteristics were observed in next-event models, in which the ability to model a wide range of processes showed High Usability contributions.

There were associations within and across simulation types that were observed in the M&S tools used in this research. JCATS and NSS are both military-type simulations that modeled real physical entity interactions. Similarities of JCATS and NSS included (1) Environment representation that affected T-craft object motion and interactions, (2) Databases containing platform modeled objects that possessed real-world parameter inputs, (3) Federation of the M&S tools program to be reused and integrated with other source code, and (4) Securities to handle classified materials. Evaluation of MANA and Pythagoras capabilities revealed that there were similar GUI functionalities, which were attribute controls and replication abilities.

Unexpectedly there was not the same level of correspondence between the next-event based models. NSS differed from Simkit, which in turned differed from Arena. NSS and Arena shared similar functionalities like GUIs, yet showed differences in replication abilities and support systems. Simkit and Arena were both DES but differed in implementation of the interfaces. Simkit had High Flexibility and Scalability due to the MOP capabilities observed and optimized processes. Arena had Strong Usability with GUI, support functionalities, and replication applications. The three next-event models were as distinct as they were similar.

B. SIMULATION SUITES

The evaluation of the M&S tools in this research led to the question of which one or combination of simulations were capable of modeling a SBE Scenario. Combination of simulation was defined as a suite of integrated M&S tools. Beginning with the base model trade space, all possible “suites of simulations” would lie within the constructive model trade space as discussed in Chapter III. Based on the observed evaluation of the six models, the models with the highest Usability were Simkit and JCATS with 0.64, High contribution to the functionalities. Simkit’s overall processes in Flexibility and Scalability were observed as High, which made an ideal candidate for SBE Scenario processing M&S tool. The models with a High Flexibility and Scalability were MANA and Pythagoras. These observed capabilities used in conjunction with DES surrounding the next-event based models as depicted in Figure 102, provided a possible solution trade space for SBE modeling.

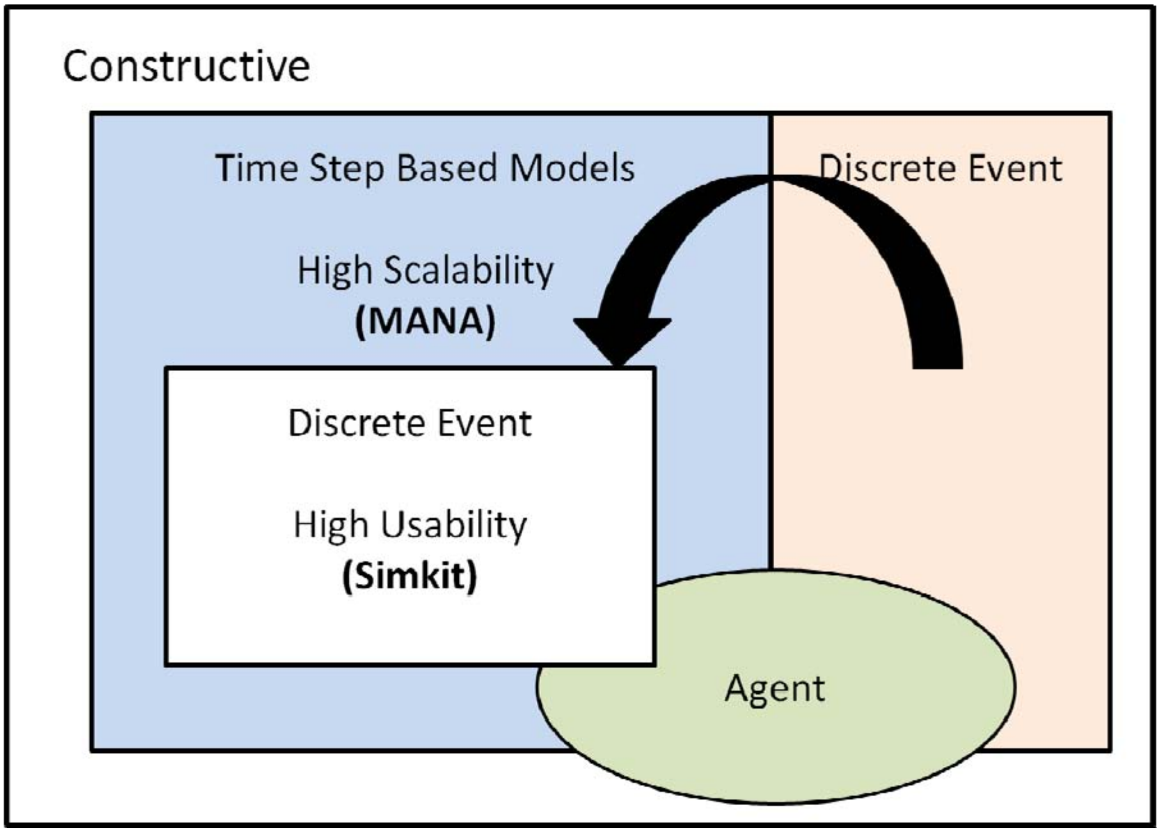

Figure 102. “Suite of Simulations” Trade Space.

Figure 102 illustrates the M&S space that a simulation or “suite of simulations” should be in for SBE Scenario modeling. The general idea behind the M&S trade space was to integrate the processing capabilities of DES with time-step based models to provide functionalities to flexible and scalable M&S tools. The limitation to this idea is the coupling of AABM with DES. Current AABM are not capable of introducing next-event based processes in the logic and/or source code. A possible “suite of simulations” is modeling cargo transfer processes in Simkit and transit interactions in MANA to solve for all MOPs. This would allow for the M&S space to encompass both types of simulations.

C. TRADE SPACE

There are options being developed at the NPS to increase the capability of Simkit and DES. The Viskit simulation is an open source simulation code that attempts to marry the processing power of a DES with the usability of a GUI program. Viskit implements Java programming for use by non programmers. Viskit is a rapid development M&S tool that is based on reusable components of the Simkit API (Buss, 2008). Viskit could be considered to provide the needed user interface that Simkit lacks. Arena can not be in the same discrete event space as Simkit because of the flowchart based model used. Arena is a next-event model but does not implement event graph properties that Simkit uses to create separate object entities.

Based on Chapter VII results, there was another option in the trade space for a “suite of simulations” for SBE modeling. Simkit and NSS displayed similar capabilities in the evaluation. The possibility of NSS replacing Simkit in the “suite of simulation” space is worth exploring. NSS is a next-event based model with equivalent contributions to their capabilities. NSS additionally offers database functionality, in conjunction with the Simkit API may prove to be a powerful M&S tool. The trade space illustrates that the possibility for using M&S tools in series or tandem may provide decision makers with a product that has Very High capabilities for analysis and use.

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IX. CONCLUSION

The goal of the hierarchy framework was to define the M&S capabilities of a SeaBase Enabler (SBE) in a set of functionalities for evaluating simulations. The framework was generated to enable the application of a systematic process to be applied to any system to determine the capabilities and put a numeric value on the abilities relative to the total number of individual functionalities of the system. The results of the evaluations were then used to determine a suitable simulation or a “suite of simulations” for SBE modeling.

There were six similar SBE models that were created in six different M&S tools. The six simple models merely provided a method for evaluating the capabilities of the simulations and to prove the framework was viable. Valuable insight was gained by scenario development of the basic models used. The intent of providing detailed modeling parameters was to enable future analysis in SBE modeling with models that are executable.

The SBE concept is unique to military operations because of the potential logistical support by a transport craft that has not been offered in the past. The use of M&S in the development of a SBE like T-craft can provide insight into the advantages of large cargo capacities and increased speed capabilities. The scenarios created in this study were designed to specifically measure T-craft performance parameters and determine what could be modeled in the two different types of simulation. The construction of a T-craft scenario in M&S tools allowed for comparison of capabilities across M&S Domains.

All simulation types seem to have components that are interchangeable with each other. This integration can blur the distinctions between the two categories depicted here. However, use of specific simulations in this study, there were comparisons within and across the categories. The goal was to define the capabilities of a simulation for a SBE and provide a baseline for simulations that decision makers would want to conduct independent analysis to awareness. The battle over money for acquisition of systems has become overwhelming. Any assistance that can be provided by the ease of M&S tools will give options to DoD employees.

The framework created has shown that an evaluation of simulations can be conducted. The bulk of the work conducted in this thesis was focused on the definition of the capability hierarchy. The initial assumption was that there would be an objective core to the framework to enable the measurement of capabilities for a given simulation. This was done by the presence or non presence of functionalities. Use of the roll-up method allowed for the contribution of any functionality to be calculated.

The capability hierarchy was initially developed from the desired capabilities of a SBE but evolved with the research to incorporate other M&S requirements. End users' (Stakeholders) needs were the driving force behind the list of capabilities for a SBE. Based on the combination of end user needs and DoD capability requirements for M&S tools, the creation of the capability hierarchy allowed for a wide range of operations to be modeled in a SBO Scenario. Model development seems to have led to additions in all areas of capabilities. The process of creating a framework for other systems may take extensive exploration in the solution trade space.

Finally, this framework demonstrated that objective comparison of simulations capabilities that could be made with what first seems to be a subjective approach. The question of how capable is a simulation at first glance, is not objective. This thesis attempted to objectively show that with the use of a roll-up method, an subjective or quantitative comparison could be made of individual M&S tools, along with comparison across multiple simulations category types. The end results of the comparison showed that a “suite of simulations” could be more capable of modeling a SBE Scenario than a single simulation, but shows that specific individual simulations have been created with a combination of the more capable elements of the M&S tools evaluated.

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APPENDIX A. CAPABILITY HIERARCHY

Usability

Validation

- *Construct abilities*
  - Dynamic Situations
    - Sensor Probability Tables
    - Weapons Probability Tables
    - Individual Unit actions
    - Agent Information
      - -Course
      - -Speed
      - -Positional Data
      - -Refueling Rates
      - -Cargo Capacities
    - Communications
      - -Command and Control Entity
      - -Operation other than Warfare
      - -Logistic Capabilities
    - Waiting Queues
    - Personal Settings
    - Semi-Automated Forces
  - Replicable
    - Simulate a user defined model
    - Multiple Runs defined by user
    - Measure of Performance Parameters
    - Reset Simulation Parameters
    - User Define output variables
    - Start/Stop Criteria
    - Accuracy
    - Spot Sampling
- *Supportabilities*
  - Contractor Support
    - Basic Information
      - -Version Number
      - -Upgrade information
    - Reach-back Availability
    - Points of Contact
      - -Web Site Availability
    - Training & Education
    - Feedback Loop
    - Authoritative Sources
  - Documentation
    - Functionality Tutorials
    - Help Windows
    - User Manual
    - Publications
    - On-line Support

User Interface

- *Represent abilities*
  - Graphical User Interface (GUI)
    - User input windows

-Pull Down Menus
-Check Boxes
-Typed in Values
-Adjustment sliders
Set-up Wizards
Comprehensive able
Pop-up Information
Common Terminology
User Feedback
Help Menus
Standard Symbology
-Friendly, Hostile, & Neutral Forces
Object Templates

Flexibility

Model able

- *Securities*
  - Classification
    - Safeguard & Handle Classified Information
    - Encryption / Decryption Devices
- *Export / Import abilities*
  - Databases
    - Systems (Created Models)
    - Environment (Terrain / Weather / etc.)
    - Imagery Data
    - Scenario Files
- *Adjust abilities*
  - Systems
    - Multiple Attributes
    - Model Basic Physics
    - Refueling Capabilities
    - Movement Parameters
    - Mode Selection
    - Clone / Copy Functions
    - Military Operations
      - -Guard
      - -Patrol
      - -Orbit
      - -Attack
      - -Flee / Run
      - -Grouping Functions
      - -Inter Communications
      - -Remain in place
      - -Waypoint selection
      - -Unit operations
  - Environment
    - 2D Terrain Model
      - -Surface Configuration
      - -Natural Features
      - -Man-made Features
    - Oceanographic Modeling
      - -Contours with depth data
    - External Forces
      - -Wind
      - -Sea State
  - Measures of Performance
    - Survivability
    - Transit Times
    - Cargo Transfer
  - Resolution
    - T-craft Levels (Single vs. Multiple)

Architectural Design

- *Interoperability Standards & Protocol*
- *Federate Capable*
  - High Level Architecture (HLA) Capable
  - Reusable Program
  - Program History

Program Considerations
Open Source Code
Input Operational Data
-Object Library
Auto Save / Auto Recover

Stochastic Process

Scriptable
Discrete-Event/Time-Step
Random Variables/Markov Principles

Scalability

Variation

Adjust abilities

- Systems
  - Multiple Attributes
  - Model Basic Physics
  - Refueling Capabilities
  - Movement Parameters
  - Mode Selection
  - Clone / Copy Functions
  - Military Operations
    - -Guard
    - -Patrol
    - -Orbit
    - -Attack
    - -Flee / Run
    - -Defend
    - -Grouping Functions
    - -Inter Communications
    - -Remain in place
    - -Waypoint selection
    - -Unit operations
- Environment
  - 2D Terrain Modeling
    - -Surface Configuration
    - -Natural Features
    - -Man-made Features
  - Oceanographic Modeling
    - -Contours with depth data
  - External Forces
    - -Wind
    - -Sea State
- Measures of Performance
  - Survivability
  - Transit Times
  - Cargo Transfer
  - Resolution
- Force Levels
  - T-craft Levels (Single vs. Multiple)

Adjudication

- Attain abilities
  - Results
    - Units of Measure
    - MOP Translations
    - User Defined Data Output
    - Battle Damage Assessments
  - Engagement
    - Probability Tables Ph/Pk
    - Sensor Algorithms Integration
    - Weapons Algorithms Integration
    - Indirect Fire Capabilities
    - Sensor Detections
    - Battle Damage

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APPENDIX B. SIMKIT SOURCE CODE FOR SBE SCENARIO

```
/**
 * SBE Scenario
 * Simkit API Source code in Java 2 Platform Standard Ed. 5.0
 * Authors:    LT Ryan Hernandez
 *             LtCOL (HEA) Sotiris Papadopoulos
 * Date:       May 2010
 * MainProgram Class
 */

package TCraftSourceCode;

import java.awt.geom.Point2D;
import java.beans.PropertyChangeListener;
import java.io.BufferedWriter;
import java.io.FileNotFoundException;
import java.io.FileWriter;
import java.io.IOException;
import java.lang.reflect.Array;
import java.util.ArrayList;
import java.util.LinkedList;
import simkit.random.RandomVariate;
import simkit.random.RandomVariateFactory;
import simkit.smd.BasicLinearMover;
import simkit.smd.BasicSensor;
import simkit.smd.CookieCutterSensor;
import simkit.smd.RandomMoverManager;
import simkit.smd.SensorMoverReferee;
import simkit.smdx.WayPoint;
import simkit.stat.SimpleStatsTimeVarying;
import simkit.Schedule;
import simkit.util.SimplePropertyDumper;

public class MainProgram {

  /**
   * @param Main program execution file
   */
  public static void main(String[] args) {

  //Friendly force setup with speed set to 40
  TCraft friend = new TCraft("TCraft,” 40.0);

  /*
   * Friendly way point inputs
   *  TCraft starts @ Debarkation point (DBK) and is loaded.
   *  TCraft transits to SeaBase Operations (SBO) area to check damage
and cargo load.
   *  TCraft then transits to Shore landing site (SHO) to unload cargo.
   *  TCraft completes Shore Cargo requirements and returns to DBK.
   *
   *   DBK => SBO => SHO ===> Complete cargo tranfer requirements => DBK
```

```
 */

LinkedList<WayPoint> wayPointList = new LinkedList<WayPoint>();

//Adds waypoints to link list for Mover Manager inputs at start time
wayPointList.add(TCraft.DBK);
wayPointList.add(TCraft.SBO);
wayPointList.add(TCraft.SHO);
wayPointList.add(TCraft.SBO);
wayPointList.add(TCraft.SHO);
wayPointList.add(TCraft.SBO);
wayPointList.add(TCraft.SHO);
wayPointList.add(TCraft.SBO);
wayPointList.add(TCraft.DBK);

TCraftMoverManager friendMM = new TCraftMoverManager(friend,
    wayPointList, true);

//Adding listeners
friend.addSimEventListener(friendMM);
friendMM.addSimEventListener(friend);

//Enemy force setup
BasicLinearMover enemy = new BasicLinearMover("Enemy,” new
    Point2D.Double(5.0, 10.0), 10.0);
RandomVariate[] rv = new RandomVariate[2];
    rv[0] = RandomVariateFactory.getInstance("Uniform,” -20.0, 20.0);
    rv[1] = RandomVariateFactory.getInstance("Normal,” 0.0, 5.0);

RandomMoverManager randomMoverManager = new RandomMoverManager(enemy,
    rv, true);
BasicSensor enemyEye = new CookieCutterSensor(enemy, 10.0);

//Sea base setup
BasicLinearMover seabase = new BasicLinearMover("Seabase,” new
    Point2D.Double(0.0, 0.0), 0.0);
BasicSensor seabaseEye = new CookieCutterSensor(seabase, 15.0);

//Print of objects in simulation to check initialization
//System.out.println(friend);
//System.out.println(friendMM);
//System.out.println(enemy);
//System.out.println(randomMoverManager);
//System.out.println(enemyEye);
//System.out.println(seabase);
//System.out.println(seabaseEye);

//Referee setup
SensorMoverReferee referee = new SensorMoverReferee();
friend.addSimEventListener(referee);
friendMM.addSimEventListener(referee);
enemy.addSimEventListener(referee);
enemyEye.addSimEventListener(referee);
seabase.addSimEventListener(referee);
seabaseEye.addSimEventListener(referee);
```

```
  //Mediator setup
  TCraftMediator tCraftMediator = new TCraftMediator();
  referee.addMediator(CookieCutterSensor.class, TCraft.class,
      tCraftMediator);

  //Sensor setup
  HostileSensor hostileSensor = new HostileSensor();
     enemyEye.addSimEventListener(hostileSensor);

  //Adjudicator setup
  Adjudicator adjudicator = new Adjudicator();
      hostileSensor.addSimEventListener(adjudicator);

  //Property dumper setup
  //SimplePropertyDumper simplePropertyDumper = new
      SimplePropertyDumper();
  //friend.addPropertyChangeListener(simplePropertyDumper);

  //Statistic listener setup
  PropertyChangeListener cargoAmount = new
      SimpleStatsTimeVarying("cargo");
  friend.addPropertyChangeListener(cargoAmount);
  PropertyChangeListener damageAmount = new
      SimpleStatsTimeVarying("damage");
  friend.addPropertyChangeListener(damageAmount);
  PropertyChangeListener shoreCargoAmount = new
      SimpleStatsTimeVarying("shoreCargo");
  friend.addPropertyChangeListener(shoreCargoAmount);
  PropertyChangeListener surv = new
      SimpleStatsTimeVarying("survivability");
  friend.addPropertyChangeListener(surv);
  PropertyChangeListener msnFlag = new
      SimpleStatsTimeVarying("missionFlag");
  friend.addPropertyChangeListener(msnFlag);

  //Simulation initial scheduling commands
  Schedule.setEventSourceVerbose(true);
  Schedule.stopAtTime(50.0);
  Schedule.setVerbose(false);

  //sets the number of iterations/replications the simulation will
conduct
  int iteration = 1;

  //Declares arraye to store data points
  double[] sc = new double [iteration];
  int[] sv = new int [iteration];
  double[] mt = new double [iteration];

  //Handles the replication of the simulation
  for (int i = 0; i < iteration; i++){

    Schedule.reset();
    Schedule.startSimulation();
```

```
    System.out.println(friend.getShoreCargo() + "     " +
      friend.getSurvivability() + " " + friend.getMissionTime());

      //Stores data values at completion of each replication
      sc[i] = friend.getShoreCargo();
      sv[i] = friend.getSurvivability();
      mt[i] = friend.getMissionTime();
  }

  //Handles writing values stored in array to designated file
  BufferedWriter bufferedWriter = null;

  try {

    //Declares BufferedWriter object
    bufferedWriter = new BufferedWriter(new FileWriter("FileName.txt"));

      for (int i = 0; i < iteration; i++){

        //Start writing to the output stream
        bufferedWriter.write(sc[i] + "    " + sv[i] + "     " + mt[i]);
        bufferedWriter.newLine();
      }
    } catch (Exception e) {
      e.printStackTrace();
    } finally {

      //Closes BufferedWriter
      try {
        if (bufferedWriter != null) {
          bufferedWriter.flush();
          bufferedWriter.close();
        }
      } catch (IOException e) {
        e.printStackTrace();
      }
    }
    System.out.println("Complete!");

  }
}
```

```
/**
 * SBE Scenario
 * Simkit API Source code in Java 2 Platform Standard Ed. 5.0
 * Authors:    LT Ryan Hernandez
 *             LtCOL (HEA) Sotiris Papadopoulos
 * Date:       May 2010
 * TCraft Class
 */

package TCraftSourceCode;

import java.awt.geom.Point2D;
import simkit.Schedule;
import simkit.random.RandomVariate;
import simkit.random.RandomVariateFactory;
import simkit.smd.BasicLinearMover;
import simkit.smdx.WayPoint;


public class TCraft extends BasicLinearMover {

  /*
   * State Variables
   */

  //monitors cargo carried on TCraft
  protected double cargo;

  //monitors damage to TCraft
  protected double damage;

  //monitors the amount of cargo received at the shore
  protected double shoreCargo;

  //monitors the survivability rate. Takes values 0 (not survive) and 1
(survive)
  protected int survivability;

  //monitors the status of the mission. Takes values 0 (not complete)
and 1 (complete)
  protected int missionFlag;

  //monitors mission time
  protected double missionTime;

  //coordinates for all possible destinations for TCraft
  protected static final WayPoint DBK = new WayPoint(new
Point2D.Double(-20.0, 20.0), 40.0);
  protected static final WayPoint SBO = new WayPoint(new
Point2D.Double(0.0, 0.0), 40.0);
  protected static final WayPoint SHO = new WayPoint(new
Point2D.Double(20.0, -20.0), 40.0);

  //cargo threshold for shore
  protected static final double SHORE_CARGO_THRESHOLD = 1000.00;
```

```
  //TCraft Mover Manager variable
  public TCraftMoverManager friendMM;

  //Declaration of TCraft Waypoint variable
  public WayPoint destination;

  //Declaration of Random Variate variable for times
  public RandomVariate repairTime =
RandomVariateFactory.getInstance("Exponential,” 15);
  public RandomVariate loadTime =
RandomVariateFactory.getInstance("Exponential,” 10);
  public RandomVariate unloadTime =
RandomVariateFactory.getInstance("Exponential,” 20);

  //Declaration of Random Variate
  public RandomVariate cargoLoadedLow;

  //Declaration of Random Variate
  public RandomVariate cargoLoadedHigh;

  //Declaration of Random Variate
  public RandomVariate number;

  /*
   * Parameters
   */

  // Threshold of damage recieved for TCraft to be killed
  public double damageThreshold = 0.8;

  // Threshold of damage recieved for TCraft to be repaired
  public double repairThreshold = 0.4;

  /**
   * Constructor
   *
   * We assume that every new TCraft is initially located at the
   * debarkation point (DBK)
   *
   * @param name, the name of the TCraft
   * speed, the speed of the TCraft
   */
  public TCraft(String name, double speed) {
    super(name, DBK.getPoint(), speed);
  }

  /**
   * Getter method for cargo
   */
  public double getCargo() {
    return cargo;
  }

  /**
```

```
 * Getter method for damage
 */
public double getDamage() {
  return damage;
}

/**
 * Getter method for shoreCargo
 */
public double getShoreCargo() {
  return shoreCargo;
}

/**
 * Getter method for survivability
 */
public int getSurvivability() {
  return survivability;
}

/**
 * Getter method for mission flag
 */
public int getMissionFlag() {
  return missionFlag;
}

/**
 * Getter method for mission time
 */
public double getMissionTime() {
  return missionTime;
}

/**
 * Repair Function
 *
 * @param mover, the TCraft to be repaired
 * All Cargo will be lost during the repair process
 * and Damage will be reset to 0.0.
 */
public void doRepair (TCraft mover) {

  //Resetting Cargo
  double oldcargo = mover.getCargo();
  cargo = 0.0;
  firePropertyChange("cargo,” oldcargo, mover.getCargo());

  //Resetting Damage
  double olddamage = mover.getDamage();
  damage = 0.0;
  firePropertyChange("damage,” olddamage, mover.getDamage());

  waitDelay("Load,” 0.0, mover);
}
```

```
  /**
   * Load Function
   *
   * @param mover, the TCraft to be loaded
   * Cargo will be loaded at DBK to initialize
   * the TCraft with a random amount of cargo.
   */
  public void doLoad (TCraft mover) {

    //Generation of random cargo amounts in one three distributions at
DBK
    //cargoLoadedLow = RandomVariateFactory.getInstance("Uniform,” 0,
750);
    //cargoLoadedLow = RandomVariateFactory.getInstance("Normal,” 525,
200);
    cargoLoadedLow = RandomVariateFactory.getInstance("Exponential,”
300);

    //Finds a random number in the distribution
    for(int i = 0; i < Math.random()*Math.random(); i++){
     cargoLoadedLow.generate();
    }

    //Generation of random cargo amounts in one three distributions at
SBO
    //cargoLoadedHigh = RandomVariateFactory.getInstance("Uniform,”
300, 750);
    //cargoLoadedHigh = RandomVariateFactory.getInstance("Normal,” 525,
200);
    cargoLoadedHigh = RandomVariateFactory.getInstance("Exponential,”
300);

    //Finds a random number in the distribution
    for(int i = 0; i < Math.random()*Math.random(); i++){
     cargoLoadedHigh.generate();
    }

    //Loading TCraft
    if (mover.getCurrentLocation().equals(DBK.getPoint())) {

     //Pulling the next random number from the generator
     double numericCargo = cargoLoadedLow.generate();

     //Updating cargo amounts
     double old = mover.getCargo();
     cargo = cargo + numericCargo;
     firePropertyChange("cargo,” old, mover.getCargo());

    } else if (mover.getCurrentLocation().equals(SBO.getPoint()) &&
(!(missionFlag == 1))) {

     //Pulling the next random number from generator
     double numericCargo = cargoLoadedHigh.generate();
```

```
      //Updating cargo amounts
      double old = getCargo();
      cargo = cargo + numericCargo;
      firePropertyChange("cargo,” old, mover.getCargo());
    }
  }

  /**
   * Unload Function
   *
   * @param mover, the TCraft to be unloaded
   */
  public void doUnload (TCraft mover) {

    //Updating cargo amounts
    double old = mover.getCargo();
    double oldSC = mover.getShoreCargo();
    shoreCargo = (shoreCargo + old);
    cargo = 0.0;
    firePropertyChange("shoreCargo,” oldSC, (mover.getShoreCargo()));
    firePropertyChange("cargo,” old, mover.getCargo());

    //Handles conditions when shore cargo requirement is complete
    if (mover.getShoreCargo() >= SHORE_CARGO_THRESHOLD) {

      //Updating mission status
      int oldm = mover.getMissionFlag();
      missionFlag = 1;
      firePropertyChange("missionFlag,” oldm, mover.getMissionFlag());
    }
    waitDelay("MoveTo,” unloadTime, mover);
  }

  /**
   * End of Service Function
   */

  public void doEndService(TCraft mover) {

    //Store time in system
    double oldTime = mover.getMissionTime();

    //Updating mission time of TCraft
    double timeInSystem = Schedule.getSimTime();
    missionTime = timeInSystem;
    firePropertyChange("missionTime,” oldTime, mover.getMissionTime());


    //Updating survivability rate of TCraft
    int oldSurv = mover.getSurvivability();
    survivability = 1;
    firePropertyChange("survivability,” oldSurv,
mover.getSurvivability());
  }
```

```
  /**
   * Reset Function
   */
  public void reset() {

    super.reset();
    cargo = 0.0;
    damage = 0.0;
    survivability = 1;
    shoreCargo = 0.0;
    missionFlag = 0;
    missionTime = 0.0;
  }

  public void doRun(TCraft mover) {

    firePropertyChange("cargo,” mover.getCargo());
    firePropertyChange("damage,” getDamage());
    firePropertyChange("survivability,” getSurvivability());
    firePropertyChange("shoreCargo,” getShoreCargo());
    firePropertyChange("missionFlag,” getMissionFlag());
  }
}
```

```java
/**
 * SBE Scenario
 * Simkit API Source code in Java 2 Platform Standard Ed. 5.0
 * Authors:    LT Ryan Hernandez
 *             LtCOL (HEA) Sotiris Papadopoulos
 * Date:       May 2010
 * TCraftMoverManager Class
 */

package TCraftSourceCode;

import java.awt.geom.Point2D;
import java.util.LinkedList;
import java.util.ListIterator;

import simkit.Schedule;
import simkit.SimEntityBase;
import simkit.random.RandomVariate;
import simkit.random.RandomVariateFactory;
import simkit.smd.Mover;
import simkit.smdx.WayPoint;


public class TCraftMoverManager extends SimEntityBase {

    /**
     * List of desired WayPoints the Mover is to traverse
     */
    private LinkedList<WayPoint> wayPoint;

    /**
     * Points to next WayPoint if hasNext() is true.
     */
    protected ListIterator<WayPoint> nextWayPointIter;

    /**
     * If true, then start Mover from Run event
     */
    private boolean startOnRun;

    /**
     * The one Mover this instance is managing
     */
    private Mover mover;

    /**
     * Instantiate a PathMoverManager with the given Mover, WayPoints,
     * and whether to start immediately or wait.
     * @param mover My Mover
     * @param waypoint List of WayPoints to traverse
     * @param startOnRun If true, start from Run event
     */
    public TCraftMoverManager(TCraft mover,
      LinkedList<WayPoint> waypoint, boolean startOnRun) {
        setMover(mover);
```

```
        setWaypoint(waypoint);
        setStartOnRun(startOnRun);
    }

    /**
     * Set nextWayPointIter to beginning of waypoint
     */
    public void reset() {
      super.reset();
      nextWayPointIter = wayPoint.listIterator();
    }

    /**
     * If startOnRun is true, schedule Start.
     */
    public void doRun() {
      if (isStartOnRun()) {
        waitDelay("Start,” 0.0);
      }
    }

    /**
     * If there is a WayPoint, schedule StartMove(d, s), where d is the
     * location and s is the speed specified by the WayPoint objst.
     */
    public void doStart() {
      nextWayPointIter = wayPoint.listIterator();
      WayPoint next = nextWayPointIter.hasNext() ?
  nextWayPointIter.next() : null;
      firePropertyChange("nextWayPoint,” next);

      if (next != null) {
        waitDelay("MoveTo,” 0.0, next.getPoint(), next.getSpeed());
      }
    }

    /**
     * Empty - to be heard.
     * @param destination desired destination
     * @param speed desired speed
     */
    public void doMoveTo(Point2D destination, double speed) {
    }

    /**
     * Heard from mover. If there is another WayPoint, schedule
     * MoveTo (d,s) for it; otherwise, schedule OrderStop(mover).
     * @param mover My mover
     */
    public void doEndMove(TCraft mover) {

      RandomVariate moveTime =
    RandomVariateFactory.getInstance("Exponential,” 1);
      WayPoint next = nextWayPointIter.hasNext() ?
    nextWayPointIter.next() : null;
```

```
  firePropertyChange("nextWayPoint,” next);

  if (next != null) {

  //Handles status of TCraft and scheduling events
  if (mover.getCurrentLocation().equals(TCraft.SBO.getPoint()) &&
    mover.getMissionFlag() == 0 &&
    mover.getDamage() >=  mover.repairThreshold) {

    waitDelay("Repair,” 0.0, mover);
  }

  if ((!mover.getCurrentLocation().equals(TCraft.SHO.getPoint())) &&
    mover.getMissionFlag() == 0 &&
    mover.getDamage() <  mover.repairThreshold &&
    mover.getCargo() <= 300) {

    waitDelay("Load,” 0.0, mover);
  }

  if (mover.getCurrentLocation().equals(TCraft.SHO.getPoint()) &&
    mover.getMissionFlag() == 0) {

    waitDelay("Unload,” 0.0, mover);
  }

  waitDelay("MoveTo,” moveTime, next.getPoint(), next.getSpeed());

  if ((!(mover.getCurrentLocation().equals(TCraft.DBK.getPoint())))
&& mover.getMissionFlag() == 1) {

    waitDelay("EndService,” 0.0, mover);
  }
}

if (next == null) {

  //Store time in system
  double oldTime = mover.getMissionTime();

  //Updating mission time of TCraft
  double timeInSystem = Schedule.getSimTime();
  mover.missionTime = timeInSystem;
  firePropertyChange("missionTime,” oldTime, mover.getMissionTime());

  waitDelay("OrderStop,” 0.0, mover);
  }
}

/**
 * Schedule OrderStop(mover).
 */
public void doStop() {

  //System.out.println("OrderStop");
```

```
  waitDelay("OrderStop,” 0.0, mover);
}

/**
 * @return the list of WayPoints (shallow copy)
 */
public LinkedList<WayPoint> getWaypoint() {
  return new LinkedList<WayPoint>(wayPoint);
}

/**
 * @param wayPoint the wayPoint to set
 */
public void setWaypoint(LinkedList<WayPoint> waypoint) {
  this.wayPoint = new LinkedList<WayPoint>(waypoint);
}

/**
 * If true, start moving at beginning of simulation
 * @return the startOnRun
 */
public boolean isStartOnRun() {
  return startOnRun;
}

/**
 * @param startOnRun the startOnRun to set
 */
public void setStartOnRun(boolean startOnRun) {
  this.startOnRun = startOnRun;
}

/**
 * @return the mover
 */
public Mover getMover() {
  return mover;
}

/**
 * @param mover the mover to set
 */
public void setMover(TCraft mover) {

  if (this.mover != null) {
    this.mover.removeSimEventListener(this);
    this.removeSimEventListener(this.mover);
  }

  this.mover = mover;
  this.mover.addSimEventListener(this);
  this.addSimEventListener(this.mover);
}
```

```
  /**
   * @return the nextWayPointIter
   */
  public ListIterator<WayPoint> getNextWayPointIter() {
    return nextWayPointIter;
  }

  /**
   * @return next WayPoint or null if none
   */
  public WayPoint getNextWayPoint() {
    int index = nextWayPointIter.nextIndex();
    if (index < wayPoint.size()) {
      return wayPoint.get(index);
    } else {
      return null;
    }
  }
}
```

```java
/**
 * SBE Scenario
 * Simkit API Source code in Java 2 Platform Standard Ed. 5.0
 * Authors:    LT Ryan Hernandez
 *             LtCOL (HEA) Sotiris Papadopoulos
 * Date:       May 2010
 * TCraftMediator Class
 */

package TCraftSourceCode;

import simkit.SimEntityBase;
import simkit.smd.CookieCutterSensor;
import simkit.smd.SensorMoverMediator;

/**
 * Simple Mediator. Schedules Detections and Undetections.
 * @version $Id: CookieCutterMediator.java
 * @author Professor Arnold Buss @ NPS
 */
public class TCraftMediator extends SimEntityBase implements
        SensorMoverMediator<TCraft, CookieCutterSensor>{

  /**
   * Schedule Detection(mover) on sensor with delay of 0.0 if the
   * sensor hasn't already detected the target.
   * @param mover The target
   * @param sensor The Sensor
   */
  public void doEnterRange(TCraft mover, CookieCutterSensor sensor) {

    if (!sensor.getContacts().contains(mover)) {
      sensor.waitDelay("Detection,” 0.0, mover);
    }
  }

  /**
   * Schedule Undetection(mover) with delay of 0.0.
   * @param mover The target
   * @param sensor The Sensor
   */
  public void doExitRange(TCraft mover, CookieCutterSensor sensor) {
    sensor.waitDelay("Undetection,” 0.0, mover);
  }
}
```

```
/**
 * SBE Scenario
 * Simkit API Source code in Java 2 Platform Standard Ed. 5.0
 * Authors:    LT Ryan Hernandez
 *             LtCOL (HEA) Sotiris Papadopoulos
 * Date:       May 2010
 * HostileSensor Class
 */

package TCraftSourceCode;

import simkit.SimEntityBase;

public class HostileSensor extends SimEntityBase {

  public void doDetection(TCraft mover) {

    //When TCraft is detected, an Attack event is scheduled
    if (mover.getName() == "TCraft") {
     waitDelay("Attack,” 0.0, mover);
    }
   }

}
```

```
/**
 * SBE Scenario
 * Simkit API Source code in Java 2 Platform Standard Ed. 5.0
 * Authors:    LT Ryan Hernandez
 *             LtCOL (HEA) Sotiris Papadopoulos
 * Date:       May 2010
 * Adjudicator Class
 */

package TCraftSourceCode;

import simkit.Schedule;


public class Adjudicator extends HostileSensor {

  public void doAttack(TCraft mover) {
    waitDelay("BDA,” 0.0, mover);
  }

  public void doBDA(TCraft mover) {

    //generates random damage amount
    double damage = Math.random();

    //Updating damage
    double old = mover.getDamage();
    mover.damage = mover.damage + damage;
    firePropertyChange("damage,” old, mover.getDamage());

    if (mover.damage > mover.damageThreshold) {

      waitDelay("Killed,” 0.0, mover);

      //Store time in system
      double oldTime = mover.getMissionTime();

      //Updating mission time of TCraft
      double timeInSystem = Schedule.getSimTime();
      mover.missionTime = timeInSystem;
      firePropertyChange("missionTime,” oldTime,
mover.getMissionTime());
    }
  }

  public void doKilled(TCraft mover) {

    //Updating survivability
    mover.survivability = 0;

    Schedule.stopSimulation();
  }
}
```

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