21st CENTURY SURFACE COMBATANT

Executive Summary

Modeling and Simulation Master Plan

Version 1.0

SC-21 Program Office

Naval Sea Systems Command

Arlington, VA 22242-5160

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I. INTRODUCTION

At the Milestone 0 Defense Acquisition Board (DAB) review of SC 21 in January 1995, the Under Secretary of Defense for Acquisition and Technology, Dr. Paul Kaminski, indicated that Modeling and Simulation must lead the way in investigating cost/performance estimates of alternative joint force structure concepts. The Assistant Secretary of the Navy for Research, Development and Acquisition (ASN(RD&A)) identified the SC 21 as a potential pilot program where the benefits of extensive use of Modeling and Simulation will be demonstrated. As a result, existing Modeling and Simulation capabilities in the Department of Defense (DoD), industry and academia must be evaluated and integrated into a multi-warfare capability.

The major role of Modeling and Simulation (M&S) as envisioned for the SC 21 Program Office is to develop a capability, for designing complex platforms to meet US Navy operational needs and requirements. This capability will be used to support the crucial acquisition decisions at program milestones. The results of models and simulations will be used to predict ship characteristics in Joint Campaign and multi-mission warfare analysis, in platform and force engagements, system performance and acquisition and life cycle costs.

To effectively support the program, SC 21 has developed a vision for its modeling and simulation activities.

"To support the design, development, manufacturing, training, and operations for the 21st Century Surface Combatant by applying an integrated set of modeling and simulation covering an entire spectrum from engineering component models to campaign simulation. Appropriate elements of the model set will be fully interactive with other models across all warfare/mission areas to replicate SC-21 performance in a realistic Joint Warfare Forces environment."

The comprehensive vision addressed in this Master Plan is broad, multi-dimensional and supports the five fundamental program principles of:

- **capability**,
- **affordability**,
- **upgradability**,
- **scalability**, and
- **flexibility**.

Through this Master Plan the foundation and framework of the SC 21 vision are created and it is upon this that subsequent implementation plans will build, transforming the vision into reality for the 21st century combatant.

The Modeling and Simulation Master Plan covers and supports the full acquisition process including analysis, engineering, production, testing , training and operational support. The acquisition process requires multiple levels of models and simulations, includes various types of models and distributed architectures, involves an extensive number of organizations and reflects a desire for significant progress in capabilities and integration of modeling and simulation activities in a joint environment. Achieving this vision requires the identification of a comprehensive set of goals and objectives. To this end, the essential task will be identified that will drive the training requirements and ultimately establish simulator/training requirements. This plan identifies the full range of program goals and objectives but limits specific task planning to those tasks that are to be funded by the SC 21 Program Office.

Goals derived from the vision include:

- Improving ship, battlegroup, and joint force performance and effectiveness
- Mapping system capabilities into operational requirements
- Reducing technical, cost and schedule risks of ship acquisition
- Including warfighter-in-the-loop to test employment concepts or to develop doctrine or tactics
- Providing accurate and timely information to the decision makers
- Improving communication of ideas within Integrated Product Team (IPT)
- Facilitating Industry involvement
- Expediting the application of new technology to surface ship development
- Improving ship operations through more effective training, logistics, operations and life cycle maintenance.

Translating these goals into SC 21 program accomplishments requires transitioning from the conceptual to the real. M&S tools make this possible by supporting the required engineering, manufacturing and development processes necessary for ship development and deployment. Thus, for modeling and simulation, the objectives and tasks will result in a Simulation Based Acquisition (SBA) environment that embodies a Virtual Ship Product Model, including its corresponding Combat Systems. The SC 21 SBA will be used to improve platform operational effectiveness and reduce risk by supporting the following system engineering tasks:

- Developing alternative ship options through multiple ship iterations
- Reducing risk of insertion of applicable technology that will enhance the SC 21 performance or reduce costs
- Analyzing Total Ownership Costs (TOC)
- Enhancing total ship system engineering development for implementing the Integrated Product Team concepts.
- Integrating models and databases across levels, disciplines and life cycle phases
- Implementing the Warfighter-in-the-loop concept through the application of High Level Architecture (HLA) compliant distributed simulation
- Performing SC 21 Verification, Validation and Accreditation (VV&A) and configuration management functions including control of modeling and simulation activities
- Transitioning DoD, Defense Advanced Research Projects Agency (DARPA), Defense Modeling and Simulation Office (DMSO), Office of Naval Research (ONR), other DoD and industry developed modeling and simulation technology developments into the foundation of the SC 21 SBA

This summary of the Modeling and Simulation Plan presented herein describes the process, organization, and M&S elements, and focuses task areas needed to implement the SC 21 vision.

II. THE MODELING AND SIMULATION PROCESS

In this section, the role of Modeling and Simulation in support of the SC 21 ship acquisition and life cycle processes will be discussed. The process begins by the extraction of requirements from the Mission Needs Statement (MNS) which describes the required performance of the ship. The requirements are the "pull" and the technologies are the "push." A common frame of reference is developed which includes the threat characteristics, scenarios and environments. Model selection is based on applicability, compatibility, and the abilities to provide Measures of Outcome (MOO), Measures of Effectiveness (MOE), Measures of Performance (MOP) and Cost Assessment. The elements of the Milestone assessment process are detailed in Figure 1 and include the responsibilities of both the SC 21 Program Management Office (PMO) and the Cost and Operational Effectiveness Analysis (COEA) Team.

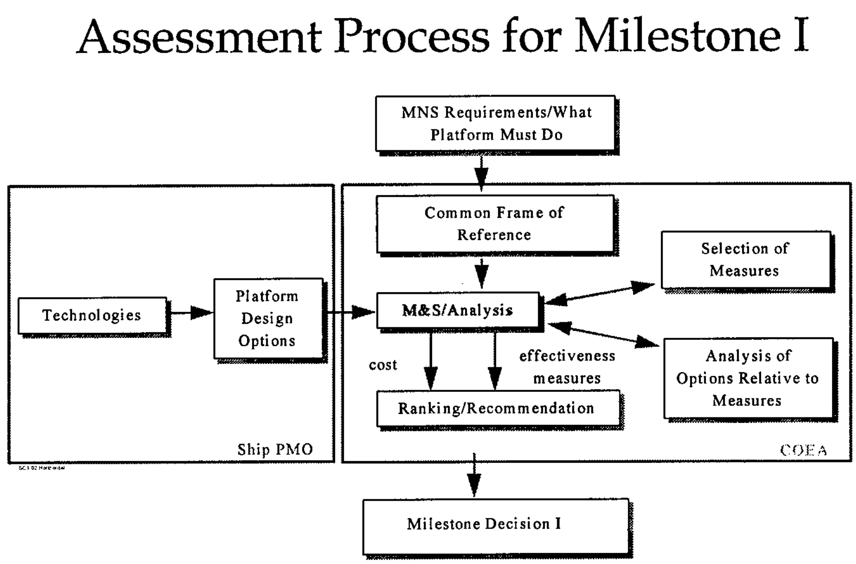

Figure 1. Elements of the Assessment Process for Milestone I

Various levels of operational simulation, as illustrated in Figure 2, are played with both campaign and missions level models. As the COEA proceeds through the milestone process, as shown in Figure 3, more detail is included in the platform and system level models. Iterative analyses of ship design options are conducted relative to the selected measures. After completion of the analysis options, ranking and recommendations are made for Milestone decisions.

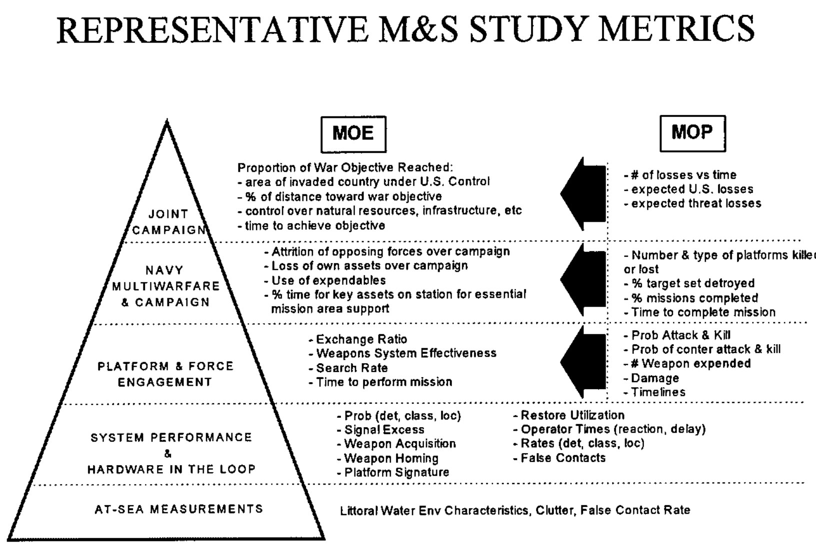

Figure 2. Modeling and Simulation Metrics

Through the SC 21 acquisition cycle, a shift will occur in the model type and usage, from heavily analysis-oriented using "constructive" simulations at the front end, through "virtual" simulations for the design and manufacturing phases and finally including "live" simulations with a focus on training and operations. A controlled validation and verification process will be implemented to support accreditation for any model or simulator intended for use during developmental or operational testing.

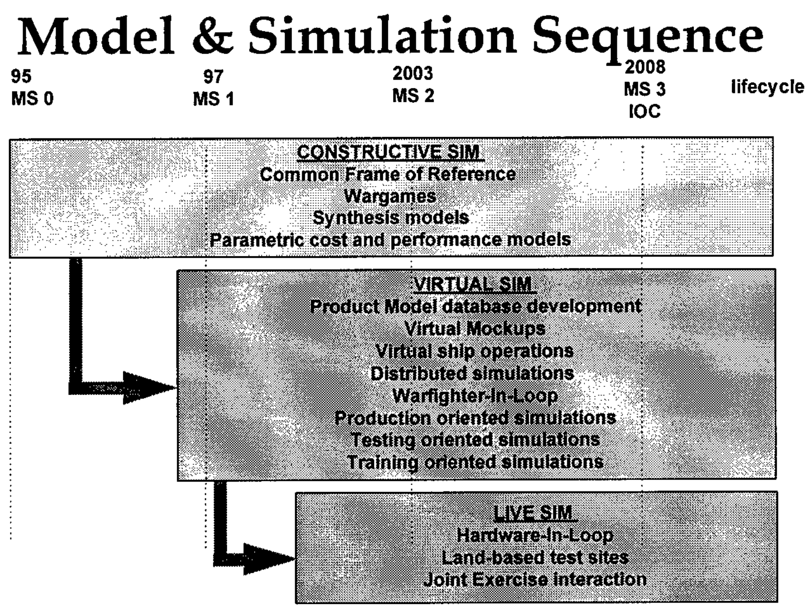

Figure 3. Sequence of Models Used in the SC-21 Acquisition Milestone Decision Process

During the post-Milestone 0 phase (Concept Evaluation), various ship options are evaluated by constructive models with respect to cost, effectiveness, and jointness. Beginning with a common frame of reference, operational wargames are played with campaign and mission level models. As the COEA proceeds through the milestone process, more detail is included in the platform and system level models. Cost models based on performance characteristics will be the primary method to obtain rough-order-of-magnitude Total Ownership Costs (TOC). The simulations will emphasize the expanded use of both visualization and virtual environments at the campaign, mission and systems levels.

As the ship concepts begin to solidify, the initial focus for virtual simulation begins by developing a systems common frame of reference, product model databases and preliminary virtual mockups. Virtual simulation of ship operations and testing allow the injection of the warfighter-in-the-loop at the earliest stages. The use of distributed interactive simulations allows the coordinated efforts of designers, manufacturers, and warfighters at remote geographical locations. Simulations developed and used for virtual training eventually become part of the embedded training within the ship.

Finally, live simulations are initiated between Milestones 1 and 2. With the use of hardware-in-the-loop, land-based test sites and fleet and joint exercises, the capabilities of ship systems are tested in realistic tactical environments and scenarios. These live simulations continue throughout the ship life-cycle.

The use of modeling and simulation allows the designers to perform multiple iterative assessments in the life cycle process before building any prototypes or initiating operations. In other words, successive virtual designs leads to an iterative cycle improvement process for the Integrated Product and Process Development (IPPD) team entirely within a virtual environment. The concept of the iterative life cycle process is shown in Figure 4. The design team will exercise the virtual processes from the requirements determination through to the embedded training onboard the ship. The iterative process is repeated for each improvement of the ship throughout its life cycle.

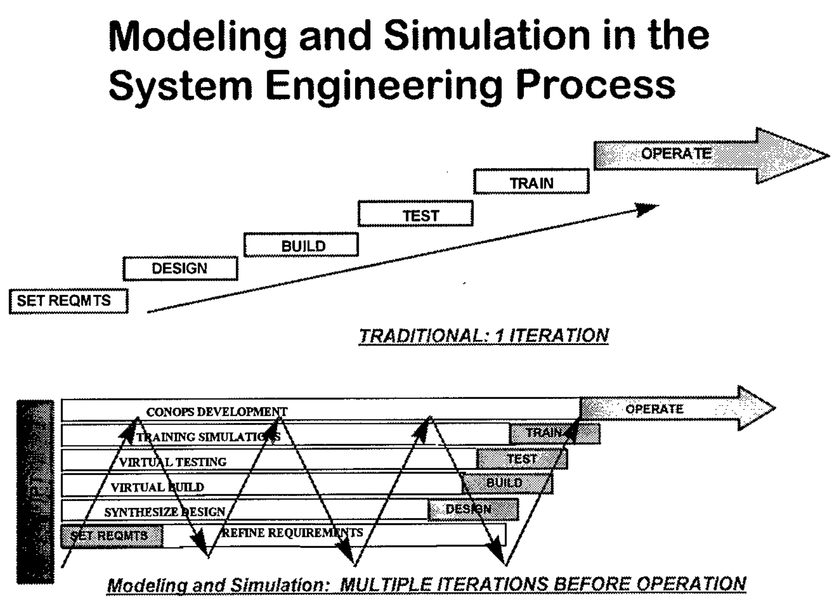

Figure 4. Modeling and Simulation enables the IPPD

The net result of the modeling and simulation efforts realizes the SC-21 Vision. Virtual prototyping encourages and requires that our customers, the designers, integrators and operators, work together closely through the formation and development of Integrated Product Teams (IPT). Integrated Product Teams will use the SC 21 SBA environment as the medium to freely exchange ship information among all activities (at all project stages) throughout the life cycle of the ship from concept definition, demonstration, design, development, testing, operation, and disposal.

III. SIMULATION BASED ACQUISITION

Simulation Based Acquisition Concept

The Simulation Based Acquisition (SBA) concept is illustrated in Figure 5. SBA will enable the Program Office to:

1. ***Conduct*** warfare and cost analysis to generate or revise ship requirements,
2. ***Design*** the virtual ship, with heavy reliance on visualization for functional analysis,
3. ***Provide*** efficiencies in the manufacturing processes,
4. ***Build*** the ship prototype without "bending metal" and only later cut the steel,
5. ***Assess*** the virtual ship to ensure that performance requirements can be met,
6. ***Operate*** the virtual ship in a realistic environment to provide training for operators;
7. ***Perform*** mission rehearsals and logistic simulations;
8. ***Build*** and maintain a validation history.

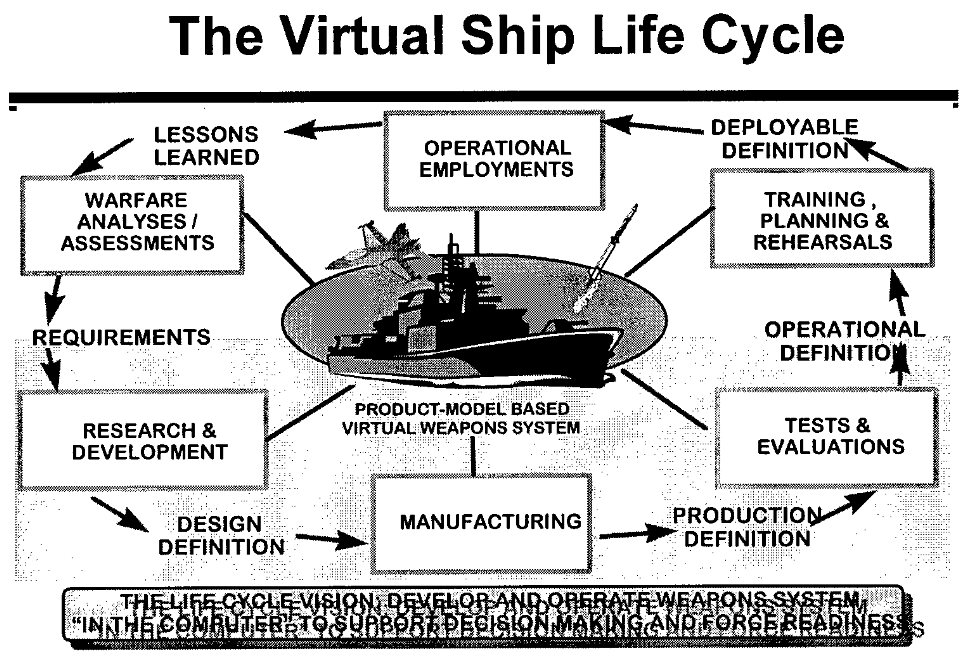

Figure 5 . Simulation Based Acquisition of a Virtual Weapons System

Through the use of virtual prototypes, virtual reality, and common electronic data bases, the use of SBA technologies not only reduces risks and minimizes life cycle costs, but also allows for a paper-less acquisition process. The SBA capabilities that are being employed by industry have resulted in cost savings through the life cycle of commercial products.

Structure Of Simulation Based Acquisition

The structure of SBA is illustrated in Figure 6. SC 21 SBA will be an evolutionary development as technology matures, standards are developed, and cooperative agreements are established with PEOs/System Commands (SYSCOMs)/ONR and their laboratories, DMSO, ONI academia, and industry.

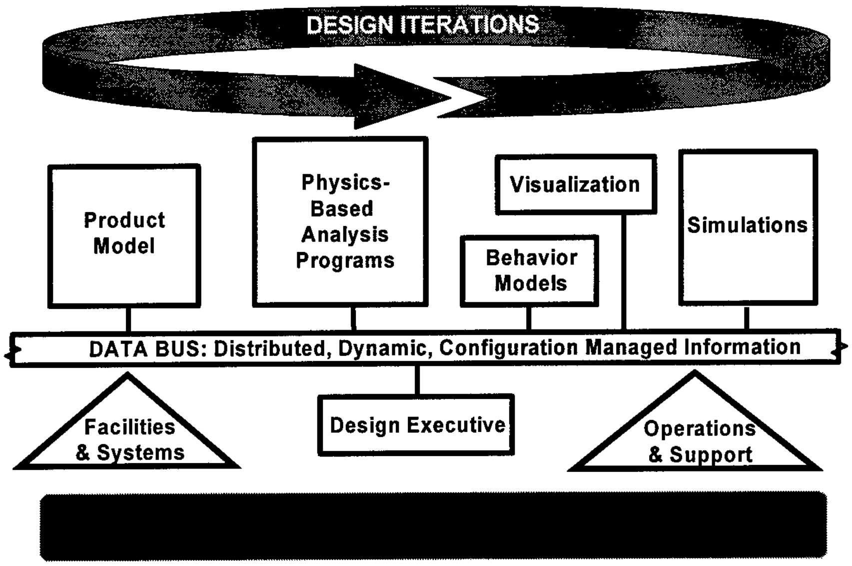

Figure 6. SC21 Simulation Based Acquisition System Technical Concept

The components of the SC 21 SBA are described below:

PRODUCT MODEL: The Product Model is a combination of geometric and non-geometric engineering data which describes the physical and logical configuration of the ship, including elements of the ship's information architecture. NAVSEA currently uses the Integrated Ship Design Program (ISDP) software for product model definition provided by the NAVSEA CAD2 contract. The long term goal for SC 21 SBA will be the inclusion of physics-based behavioral objects being developed by DARPA. The incorporation of behaviors into the product model results in a "smart" product model.

PHYSICS-BASED ANALYSIS PROGRAMS : Physics-based analysis programs predict the response of a system to its environment. Some of the SC 21 Office's analysis needs (15-20%) can be met by the adaptation of COTS analysis programs developed for general engineering use (e.g., structural finite element, pipe network, and power distribution systems analysis). The majority of needs are unique to ship design or warship design (e.g., seakeeping, survivability). For these areas the SC 21 Office will depend upon software developed by NAVSEA, Navy or other defense activities.

BEHAVIOR MODELS: Behavior models capture extensive analytical calculations as parametric equations, as in ship maneuvering coefficients and missile flight characteristics.

VISUALIZATION: This capability allows "virtual mockups" to be toured and spatial relationships to be visualized to support the functions of design review and evaluation by managers, production staff, and fleet operators.

SIMULATIONS: Simulations are the combination of visualization with realistic behaviors. The SC 21 Office will rely heavily on other Navy and defense activities, industry, and academia for identification and integration of required simulation models.

DESIGN EXECUTIVE: The Design Executive will manage a distributed computational environment, such as the one shown in Figure 7, where warfare models, databases and warfare specific synthetic environments will be initially accessible at the SC 21 Office, Navy and Defense development activities, government laboratories and contractor sites, and later at warfighter locations. SC 21 SBA will initially use object oriented DM2/PME system to manage the acquisition and systems engineering process, and streamline the analysis, visualization and simulation interfaces. Access to software and databases of all types will be provided to all sites through the Design Executive capability.

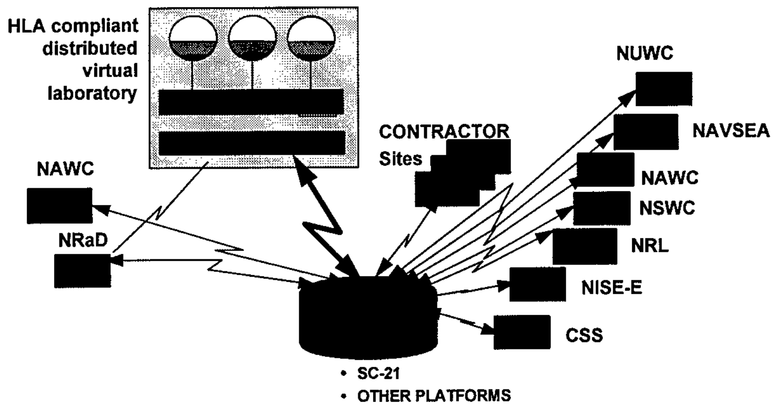

Figure 7. The Distributed Virtual Ship Sites

DATA BUS: The data bus provides communication between the Product Model, physics-based-analysis, visualization, and simulation applications. The Design Executive will control communications between SBA components for design functions. For distributed simulations, Distributed Interactive Simulation (DIS), or in the future, High Level Architecture (HLA) compliant protocols being developed by DMSO/DISA will govern the required communications. Multilevel security linkages will be necessary to maintain the appropriate levels of classified communications.

OPERATIONS AND SUPPORT : The SC 21 Office will provide personnel for the support and operation of the SC 21 SBA site. For particularly complicated simulations or distributed exercises, the Office may rely on help from participating Navy activities.

FACILITIES AND SYSTEMS : The SC 21 SBA Site is described later.

Simulation Based Acquisition Roles and Responsibilities

The roles and responsibilities for program and model selection are illustrated in Figure 8. Memorandum of Agreements will be generated between the SC 21 Office and the PEOs/ ONR/ SYSCOMs and members of the testing community to define responsibilities for the identification, validation, measures (MOPs and MOEs) and usage of the appropriate models. Industry, the Naval Research Laboratory (NRL), the Naval Warfare Centers (NWCs), and academia will provide the PEOs, ONR and the System Commands with the candidate models for use in SBA. The SC 21 Program Office is responsible for providing the common frame of reference which will include ship and threat characteristics, computational architectures and protocols, environments, databases, scenarios, visualizations and analysis tools. **The SC 21 Program Office is responsible for the validation and verification of the aggregate virtual ship models** . Integration of the resulting analysis with the IPT processes will occur within the SC 21 Office.

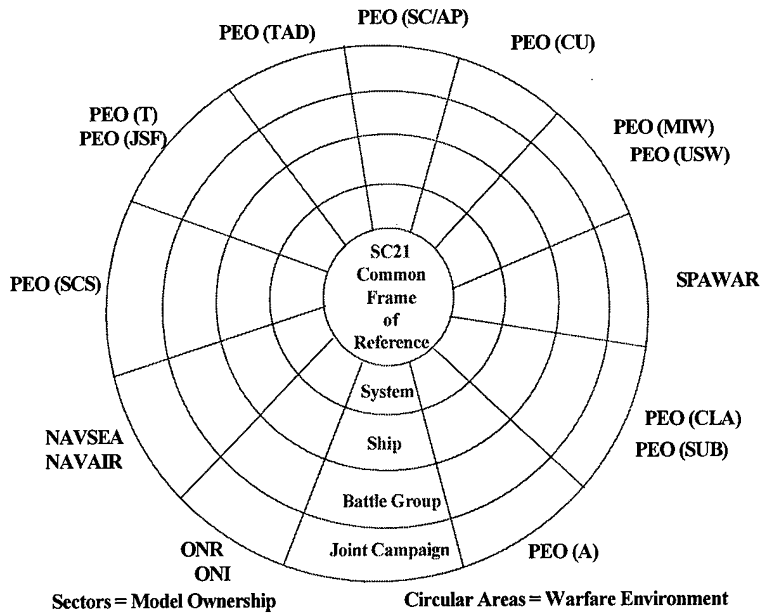

Figure 8. SC 21 Simulation Based Acquisition Roles and Responsibilities

The designated program offices are responsible for the development and validation of models that can be used for joint warfare analysis and training and the development of Measures of Outcome (MOO) for campaign analysis. Both DMSO and DONMSMO provide guidance on implementation of M&S acquisition policy as issued by DoD(OA&T) and ASN(RD&A). External links with Modeling and Simulation efforts within DoD and ASN(RD&A) such the DARPA Simulation Based Design (SBD) program, the Synthetic Theater of War (STOW) projects, the Joint Strike Fighter (JSF) and the Advanced Amphibious Assault Vehicle (AAAV) program will insure Jointness and access to the latest technological developments.

The System Commands (NAVSEA, NAVAIR, and SPAWAR) and Joint Community provide the models for ship, aircraft, ground forces, communication, intelligence, surveillance systems designs and human decision processes necessary to meet warfare requirements. NAVSEA also provides the financial support for the personnel and facilities to support and house the SC 21 SBA Site. The Office of Naval Research (ONR) in conjunction with the PEOs will provide the necessary environmental models and databases, models for advanced technological systems and the financial resources for advanced distributed simulation networks.

Location Of The SC 21 Simulation Based Acquisition Site

Although SBA will support a distributed computational environment, configuration control and management will be conducted within the SC 21 Program Office. The SC 21 SBA Site is shown in Figure 9. Site capabilities include Computer Aided Design (CAD) modeling, visualization, and physics based modeling capabilities of systems and synthetic environments. The SBA Site will also provide for interactive system engineering, via teleconferencing. This capability will enable users located at remote locations to interact with and participate in SC 21 demonstrations and assessments. The SBA Site is also envisioned to be the test site for integrated processing schema of the multi-functional and adaptable ship's information system.

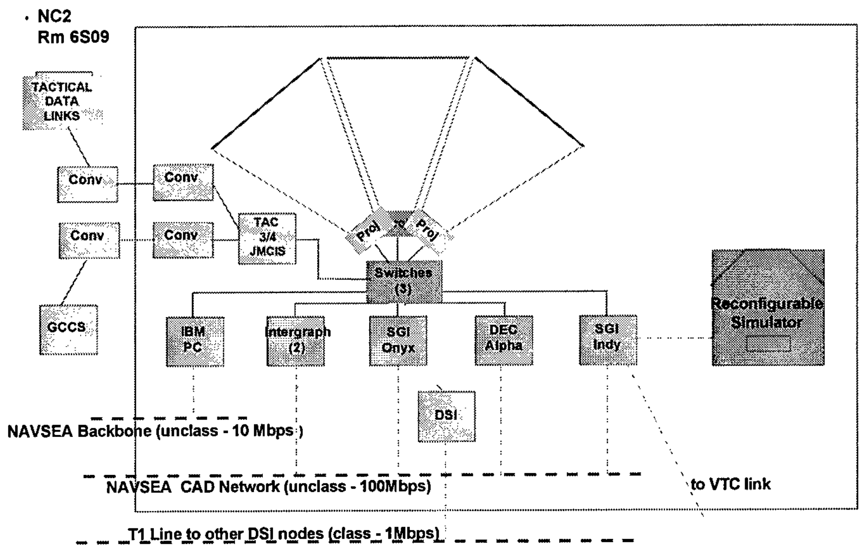

Figure 9. The SC 21 Simulation Based Acquisition Site

IV. PLANS AND MILESTONES:

In FY97, Memoranda of Agreement (MOA) will be implemented between the SC 21 Office and the organizations shown in figure 8. It is expected that model claimants will POM their own modeling needs. It is planned that in FY00 SC 21 modeling and simulation will be transitioned to industry. Detailed execution plans will be developed and added to this master plan.

V. CONCLUSION

The SC 21 Modeling and Simulation Master Plan provides a firm foundation for turning the vision of M&S driven acquisition into a reality and presents a means for achieving the maximum return on every manufacturing dollar. Manufacturing efficiencies result from modeling and simulation through a cost effective iterative design process impossible with the traditional build first then test methods of the past. Through the use of Integrated Product Teams leading to the SC 21 SBA environment, information is freely exchanged and virtual prototyping used to enhance every phase of the project. Finally, elements of the SC 21 Virtual Ship can be used to support other ship acquisitions including CVX, LHX, Arsenal Ship, and NSSN while total ship prototype elements developed for these ships can be leveraged into SC 21. Thus the SC 21 Virtual Ship will facilitate platform interoperability as well as the re-use of M&S among major shipbuilding programs.

Glossary

Abbreviations/Acronyms

AAAV	Advanced Amphibious Assault Vehicle
ASN	Assistant Secretary of the Navy
CAD	Computer Assisted Design
CAE	Computer Assisted Engineering
CINC	Commander-in-Chief
COEA	Cost, Operational, and Effectiveness Analysis
DARPA	Defense Advanced Research Projects Agency
DIS	Distributed Interactive Simulation
DISA	Defense Information Systems Agency
DMSO	Defense Modeling and Simulation Office
DoD	Department of Defense
DoN	Department of the Navy
DONMSMO	Department of the Navy Modeling and Simulation Management Office
DSI	Defense Simulation Internet
HLA	High Level Architecture
IPPD	Integrated Product and Process Development
IPT	Integrated Product Teams
JSF	Joint Strike Fighter
M&S	Modeling and Simulation
MCMSMO	Marine Corp Modeling and Simulation Management Office
MNS	Mission Needs Statement
MOO	Measures of Outcomes
MOE	Measures of Effectiveness
MOP	Measures of Performance
NAVSEA	Naval Sea Systems Command
NAVAIR	Naval Air Systems Command
NAVMSMO	Navy Modeling and Simulation Management Office
NAWC	Naval Air Warfare Center
NPS	Naval Post-graduate School
NRL	Naval Research Laboratory
NSWC	Naval Surface Warfare Center
NWC	Naval Warfare Center
ONI	Office of Naval Intelligence

ONR	Office of Naval Research
PDU	
PEO	Program Executive Office?
PM	Product Model
PMO	Program Management Office
RD&A	Research, Development, and Acquisition
SBA	Simulation Based Acquisition
SBD	Simulation Based Design
SPAWAR	Space and Naval Warfare Systems Command
SPM	Smart Product Model
STOW	Synthetic Theater of War
SYSCOM	System Command
TOC	Total Ownership Costs (related to Life Cycle Costs)
VV&A	Verification, Validation, and Accreditation
VV&C	Verification, Validation, and Certification
WAN	Wide Area Network

Definitions:

Accreditation. The official certification that a model or simulation is acceptable for use for a specific purpose.

Common Frame of Reference . A protocol to be developed by the SC 21 Program Office that will serve as a standard for simulation interoperability and compatability .

Cost and Operational Effectiveness Analysis (COEA). An analysis of the estimated costs and operational effectiveness of alternative materiel systems to meet a mission need and the associated program for acquiring each alternative.

Defense Simulation Internet (DSI). A wide-band telecommunications network operated over commercial lines with connectivity to both military and civilian satellites, allowing users to be linked on a world- wide wide-area network (WAN).

Distributed Interactive Simulation (DIS). (1) Program to electronically link organizations operating in the four domains: advanced concepts and requirements; military operations; research, development, and acquisition; and training. (2) A synthetic environment within which humans may interact through simulation(s) at multiple sites networked using compliant architecture, modeling, protocols, standards, and data bases.

Distributed Interactive Simulation (DIS) Compatible . Two or more simulations/simulators are DIS compatible if (1) they are DIS compliant and (2) their models and data that send and interpret PDUs support the realization of a common operational environment among the systems (coherent in time and space).

Distributed Interactive Simulation (DIS) Compliant . A simulation/ simulator is DIS compliant if it can send and receive PDUs in accordance with IEEE Standard 1278 and 1278 (Working Drafts). A specific statement must be made regarding the qualifications of each PDU.

Fast Time. (l) Simulated time with the property that a given period of actual time represents more than that period of time in the system being modeled; for example, in a simulation of plant growth, running the simulation for one second may result in the model advancing time by one full day; that is, simulated time advances faster than actual time. (2) The duration of activities within a simulation in which simulated time advances faster than actual time. Contrast with: real time; slow time.

Fidelity. (1) The similarity, both physical and functional, between the simulation and that which it simulates. (2) A measure of the realism of a simulation. (3) The degree to which the representation within a simulation is similar to a real world object, feature, or condition in a measurable or perceivable manner. See also: model/ simulation validation.

High Level Architecture (HLA). Major functional elements, interfaces, and design rules, pertaining as feasible to all DoD simulation applications, and providing a common framework within which specific system architectures can be defined.

Integrated Product and Process Development (IPPD). IPPD is an approach to systems acquisition which brings together all of the functional disciplines required to develop, design, test, produce and field a system. This is essentially the same as Concurrent Engineering.

Integrated Product Team (IPT). Integrated Product Teams are a means to achieve concurrent engineering or IPPD. They are multidisciplinary teams consisting of representatives from all disciplines involved in the system acquisition process, from requirements development through disposal. Having the participation of all the appropriate disciplines, IPTs are often empowered to make decisions to achieve successful development of their particular product.

Live, Virtual, and Constructive Simulation . The categorization of simulation into live, virtual, and constructive is problematic, because there is no clear division between these categories. The degree of human participation in the simulation is infinitely variable, as is the degree of equipment realism. This categorization of simulations also suffers by excluding a category for simulated people working real equipment (e.g., smart vehicles).

a. **Live Simulation**. A simulation involving real people operating real systems.

b. **Virtual Simulation**. A simulation involving real people operating simulated systems. Virtual simulations inject human-in-the-loop (HITL) in a central role by exercising motor control skills (e.g., flying an airplane), decision skills (e.g., committing fire control resources to action), or communication skills (e.g., as members of a C4I team).

c. **Constructive Model or Simulation** . Models and simulations that involve real people making inputs into a simulation that carries out those inputs by simulated people operating simulated systems.

Measures of Outcome (MOO). Metrics that define how operational requirements contribute to end results at higher levels, such as campaign or national strategic outcomes.

Measure of Performance (MOP). Measure of how the system/individual performs its functions in a given environment (e.g., number of targets detected, reaction time, number of targets nominated, susceptibility of deception, task completion time.) It is closely related to inherent parameters (physical and structural) but measures attributes of system behavior. See also: measure of effectiveness.

Modeling and Simulation (M&S). Use of models, including emulators, prototypes, simulators, and stimulators, either statically or over time, to develop data as a basis for making managerial or technical decisions. The terms "modeling" and "simulation" are often used inter-changeably.

Modeling and Simulation (M&S) Accreditation . The official certification that a model or simulation is acceptable for use for a specific purpose.

Modeling and Simulation (M&S) Application Sponsor . The organization that utilizes the results/product(s) from a specific application of an M&S.

M&S Interoperability. Ability of a model or simulation to provide services to and accept services from other models and simulations, and to use the services so exchanged to enable them to operate effectively together.

Object-Oriented. A software design methodology that when applied to DIS results in the battlefield being represented by objects, where objects encapsulate the methods or procedures associated with the object and where objects communicate with other objects by message passing. Examples of battlefield objects are platoons (unit level), tanks (platform level), main guns (component or module level), and gun barrels (part level). One of the main benefits of an object oriented approach is the inherent modularity; e.g., to change a tank model only the tank object must be changed. See also: object based.

Real-Time. In modeling and simulation, simulated time advances at the same rate as actual time; for example, running the simulation for one second results in the model advancing time by one second. Contrast with: fast time; slow time.

Simulation Fidelity. Refers to the degree of similarity between the training situation and the operational situation that is being simulated.

Slow Time. The duration of activities within a simulation in which simulated time advances slower than actual time.

Synthetic Environments (SE). Internetted simulations that represent activities at a high level of realism from simulations of theaters of war to factories and manufacturing processes. These environments may be created within a single computer or a vast distributed network connected by cal and wide area networks and augmented by super-realistic special effects and accurate behavioral models. They allow complete visualization of and total immersion into the environment being simulated.

Validation. The process of determining the degree to which a model or simulation is an accurate representation of the real-world from the perspective of the intended uses of the model or simulation.

Validity. The quality of maintained data that is found on an adequate system of classification (e.g., data model) that is rigorous enough to compel acceptance.

Virtual Modeling and Simulation . A synthetic representation of warfighting environments patterned after the simulated organization and operations of actual military units. Differences in the representation of the simulated battlefield (i.e., whether real world, computer generated, or interactive players in simulators) are transparent to the participants who interact with their particular representation of the warfighting environment.