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13. ABSTRACT (*Maximum 200 words*)
This document is an assessment of the various steps within the M&S hierarchy typically used in the system acquisition life cycle of a weapon system. This assessment addresses the different levels of M&S fidelity and scope within a hierarchy and how the IPPD management technique utilizes the M&S results to support the Milestone Decision Authority (MDA) associated with system acquisition. Also, this document addresses interoperability between the different levels of within the hierarchy and provides a recommended effort between two popular M&S currently being used by a variety of DoD agencies. These are the FireSimXXI force level and GENEric Smart Indirect fire (GENESIS) many-on-many engagement level M&S.

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1. INTRODUCTION

Modeling and Simulation (M&S) is an essential part of the military systems acquisition life cycle. From the simplest of structures to the most complex of systems, M&S is used to evolve and prove the concept. In order to understand how the system will behave, these models can be interfaced with other models and implemented over time with conditions, referred to as a simulation. In addition, a simulation can represent a technique for testing, analyzing or training using real systems or physical models of systems interfaced with digital models as well.

The main purpose for using M&S during the system acquisition life cycle is to reduce programmatic and operational risk as well as life cycle cost. The risks associated with the acquisition process of today's highly technical and costly systems can be significantly minimized with the proper planning, management, use and understanding of models and simulations. The use of modeling and simulation offers a cheaper and quicker way to understand performance trends and determine failure modes than does field-testing. This has lead Simulation Based Acquisition (SBA) practices within DoD, the Armed Forces and industry[1]. SBA is a new way of doing business for acquiring DoD weapon systems.

Implementing accredited M&S can significantly improve the effectiveness of the Integrated Product and Process Development (IPPD) management technique, which is being exercised throughout DoD. This management technique integrates all acquisition activities starting with the requirements definition through production, fielding/deployment and operational support in order to optimize the design, manufacturing, business, and supportability processes. It is through the IPPD, and the Integrated Product Teams (IPT), that the full potential of M&S to support the system acquisition is realized.

This document is an assessment of the various steps within the M&S hierarchy typically used in the system acquisition life cycle of a weapon system. This assessment addresses the different levels of M&S fidelity and scope within a hierarchy and how the IPPD management technique utilizes the M&S results to support the Milestone Decision Authority (MDA) associated with system acquisition. Also, this document addresses interoperability between the different levels of M&S within the hierarchy and provides a recommended effort between two commonly used M&S. These are the FireSimXXI force level and GENEric Smart Indirect fire (GENESIS) many-on-many engagement level M&S.

2. SYSTEMS ACQUISITION PROCESS

2.1 Program Structure

Each Program Manager (PM) has the responsibility of developing a program structure that makes sense for the specific program. This means establishing the phases and milestone decision points for the program in order to facilitate the orderly translation of broadly stated mission needs into system-specific performance requirements and a stable design that can be produced efficiently. This is the fundamental building block of the program's acquisition strategy.

There are four program structure models often practiced that are suitable for the majority of program developments within DoD. These four structure models are as follows[2]:

- Traditional Model - This is DoDs typical approach to major acquisition development programs. It is the fundamental approach to the "Milestone and Phases" decision criteria. Statutory requirements are associated with this model's phases and milestones. For example, it requires an Independent Cost Estimate and a Manpower Estimate at Milestone II, as a prerequisite to the Milestone Decision Authority (MDA) authorizing commencement of Phase II, "Engineering and Manufacturing Development (EMD)."

- Grand Design Model - This model is characterized by acquisition, development, and deployment of the total operational capability in a single increment. This model is most appropriate when the user requirements are well understood, supported by precedent, easily defined, and assessment of other consideration, such as risk, funding, schedule, etc., indicates that a phased approach is not required, and enhancement is not foreseen to be necessary.

- Incremental Model - This model is characterized by acquisition, development, and deployment of capability through a number of clearly defined system "increments" that stand on their own. An incremental model is most appropriate when the user requirements are well understood and easily defined, but assessment of other considerations, such as risk, funding, schedule, etc., indicates a phased approach is more prudent or beneficial. An example of this model is Pre-Planned Product Improvement (P3I).

- Evolutionary Model - This model is characterized by the design, development, and deployment of a preliminary capability using current technology that includes provisions for the evolutionary addition of future capabilities as requirements are further defined and technologies mature. Evolutionary Defense Acquisition (EDA) combines and collapses the EMD and Production phases through maximizing the use of proven state-of-the-art

technology and concentrating on manufacturing concurrent with design development. Advanced Concept Technology Demonstrations (ACTD) and evolutionary models share some similarities in that both involve short cycle times and address a requirement for state-of-the-art technology. ACTDs, however, are oriented to the development of an operational concept and do not necessarily result in a production program. Evolutionary models are oriented towards production from the beginning.

- Other Models - Other models are intended to encompass variations and/or combinations of the program. Models not listed above include commercial-off-the-shelf (COTS), non-developmental item (NDI), and commercial item acquisitions.

2.2 Phase and Milestone Decision Points

As mentioned above, the traditional program structure model utilizes the phases and milestone decision criteria in the system acquisition process. There are four major milestone decision points and four phases, which provide the basis for comprehensive management and progressive decision making associated with program maturity. As shown in figure 2-1, this traditional model can facilitate the orderly translation of broadly stated mission needs into system-specific performance requirements and a stable design produced in an efficient manner[3].

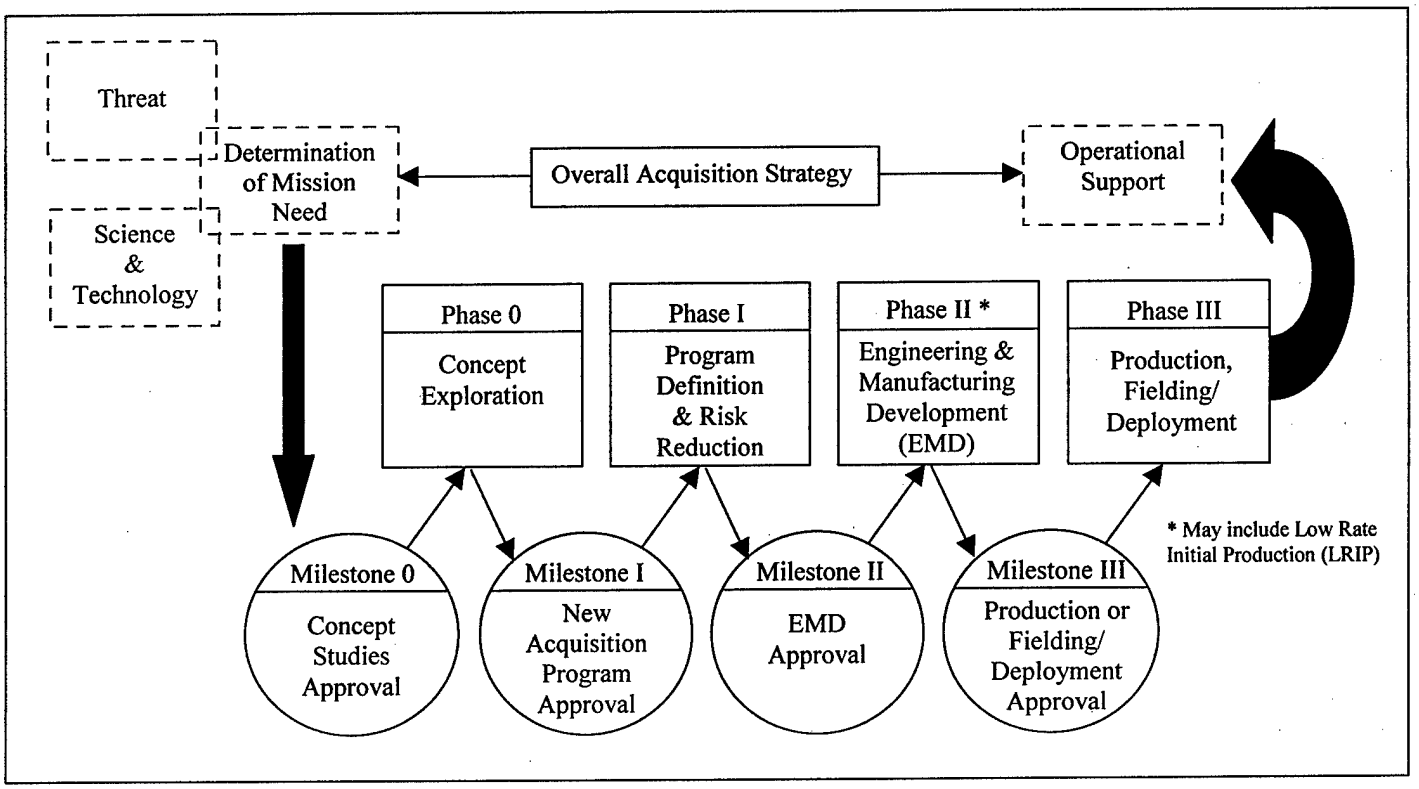

Figure 2-1 Traditional Model - Acquisition Phases and Milestone Decision Points

2.3 Decision Making Support Systems

There are three decision-making support systems linked through the SBA process, supporting an effective and efficient acquisition process. The Venn diagram shown below illustrates the interaction between the three systems[4].

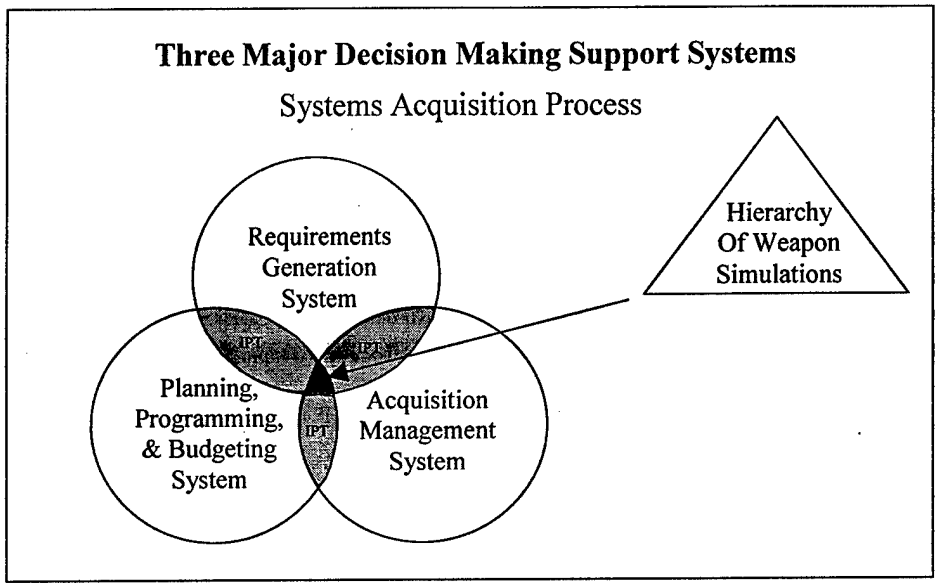

Figure 2-2 Three Major Decision Making Support Systems

The requirements generation system produces information for the decision-makers on projected mission needs. Requirements generation is based on a *continuing process* of assessing the capabilities of the current force structure to meet the projected threat, while taking into account technology, cost, and change in policy or doctrine.

The acquisition management system provides for a streamlined management structure and event-driven management process that emphasizes *risk management* and *affordability* and that explicitly links milestone decisions to demonstrated accomplishments. The first formal interface between the requirements system and the acquisition management system occurs at milestone 0, supported by the Joint Requirements Oversight Council (JROC)[5].

The planning, programming, and budgeting system (PPBS) provides the basis for making informed *affordability assessments* and *resource allocation* decisions on defense acquisition programs. The PPBS is responsible for producing a plan, a program, and a budget for DoD. The first formal interface between the acquisition management system and the PPBS occurs at milestone I. Typically, this initiates the beginning of a program.

Interaction and interfacing of these support systems is performed by the IPTs, which are key in facilitating the decision-making processes. The IPT approach takes advantage of all members' expertise and produces an acceptable product in a timely manner. Each of

the three major decision making support systems are composed of IPTs, consisting of both government and industry personnel, disciplined toward specific areas associated with that support system.

At the center of these three decision making support systems is a hierarchy of M&S tools used to support the acquisition process. These M&S tools are used to generate the requirements, manage the risks, plan and budget the program throughout the acquisition process.

2.4 Hierarchy of Weapon M&S

The hierarchy used to support the acquisition process is a suite of M&S tools with differing levels of detail suited for specific applications. There are many DoD publications describing the hierarchy of M&S and the concept varies in detail from publication to publication. However in this document we use the depiction, figure 2-3, most familiar to the indirect fire smart weapon systems community.

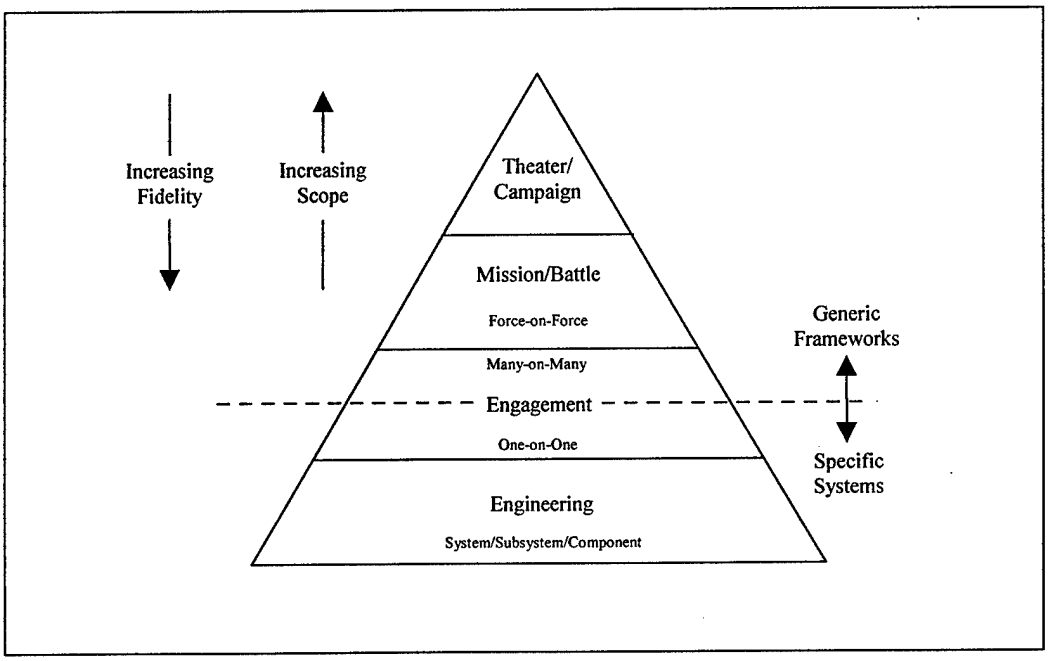

Figure 2-3 Hierarchy of Weapon Simulations

The unique feature of the hierarchy of M&S is the fact that the higher levels require input from the lower levels. By the same token, the requirements flow is from top to bottom. In other words, requirements are usually generated from the top and flown down in order to define the specs of a particular design. In many cases once hardware is built, then actual test data is used in a model-test-model loop in order to verify, validate & accredit the M&S.

There are two ways this hierarchy of M&S can be implemented to support the acquisition system lifecycle; highly aggregated or modular.

Highly aggregated is done by interfacing all levels of the M&S hierarchy and creating one big M&S. This is the popular method when performing the advanced distributed simulation techniques often-used in wargaming and training. Not a very practical way to use the M&S hierarchy for defining requirements or specifications on design through studies.

Individually the M&S levels are modular. The operational requirements generated as a result of modeling from a top level, flow down as spec for input to the lower level in order to design the system that produces the requirement.

Theater/Campaign

At the top of the hierarchy is the Theater/Campaign level M&S, which represents combined force combat operations. These M&S are used to determine the long term outcome of a major theater or campaign level of conflict. For example, regional conflicts in South West Asia (SWA) or in European theaters requiring Joint/Combined military support. This level of M&S can take weeks or days to execute. The acquisition life-cycle should begin at this level of M&S with the development of a MNS.

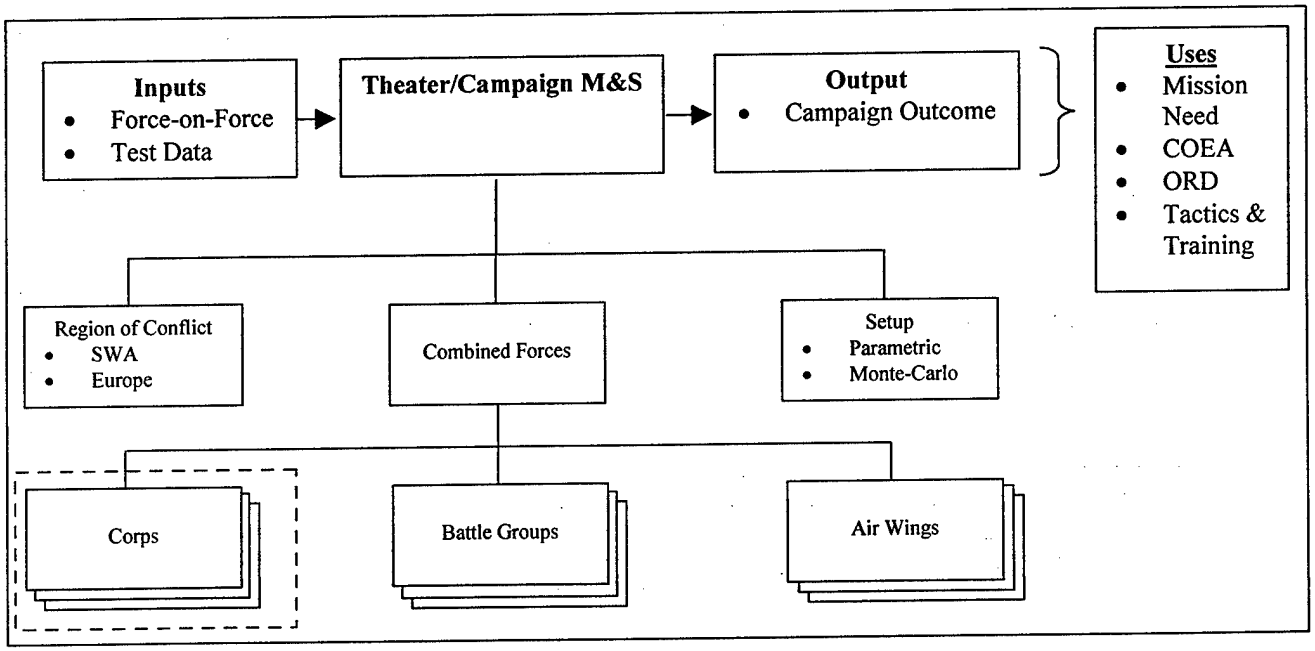

Figure 2-4 Theater/Campaign M&S Attributes and Uses

The outcome of the Theater/Campaign level M&S identifies superiority or deficiencies in force structure. Therefore, in the case of deficiencies, identifying a particular mission need. These type M&S can also be used to identify cost effectiveness, operational requirements, tactics and doctrine, as well as training.

Figure 2-4 represents a generic structure of what is modeled in a Theater/Campaign level M&S. Mission effectiveness are the inputs into the Theater/Campaign M&S. These are generated from the lower level M&S, such as the force-on-force. Mission effectiveness inputs, such as loss exchange ratios and probabilities of engagement are simulated in the Theater/Campaign model to produce a campaign outcome result.

The campaign outcome result is used to support the decision making IPTs (see figure 2-2) in formulating a Mission Need Statement (MNS), Cost Effective Analysis (COEA, also referred to as Area of Alternatives (AoA)), Operational Requirements Document (ORD), Tactics and Training.

Mission/Battle (Force-on-Force)

The Mission/Battle level of M&S represents individual force elements capability to perform it's mission objective. Individual force elements, at the corps or division level such as ground combat, battle groups, and air wings are simulated under the force-on-force M&S to determine Measures of Effectiveness (MOE) at the mission level. At this level, execution time can take several hours.

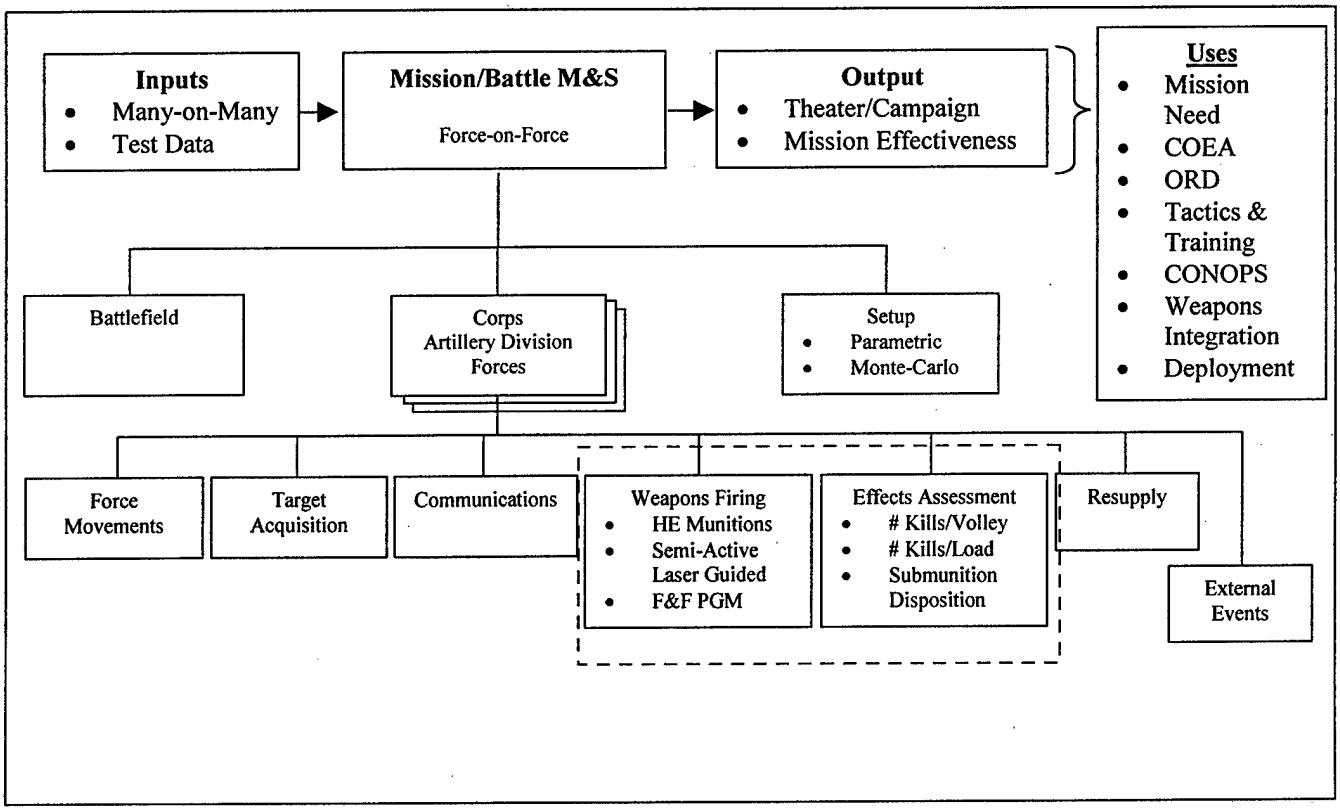

Figure 2-5 Mission/Battle M&S Attributes and Uses

The MOEs associated with the output of this level modeling may include loss exchange ratios, engageability, or level of success in achieving mission objectives. These type MOE are used to support IPT decisions on MNS, COEA, ORD, tactics & training, Concept of Operations (CONOPS), weapons integration, and force deployment. Many of these MOEs are repeated from the higher level Theater/Campaign level, but usually reflect a refinement or additions to the requirements. This is the example of how the M&S hierarchy is used in a model-assess-model loop and requirements flowdown are used to define and support exit criteria associated a different decision points of the program.

Figure 2-5 represents a generic model structure for an artillery division force, typically used at this level of M&S. The inputs are usually generated as a result of running the many-on-many effectiveness M&S defined under the engagement level. For example, within the artillery division may include a platform delivering Fire and Forget Precision Guided Munitions (F&F PGM). The input data required by the force model would include system effectiveness parameters, such as the number of kills per volley, number of kills per load, or submunition disposition (in the case of dispensing smart submunitions).

Engagement (Many-on-Many System)

The engagement level M&S is basically divided into two sublevels, where the division represents a transition from generic lower fidelity into specific system high fidelity (refer to figure 2-3). The upper level of engagement M&S represents many-on-many or few-on-few system effectiveness. As shown in figure 2-6, this example represents a fire & forget indirect fire PGM platform.

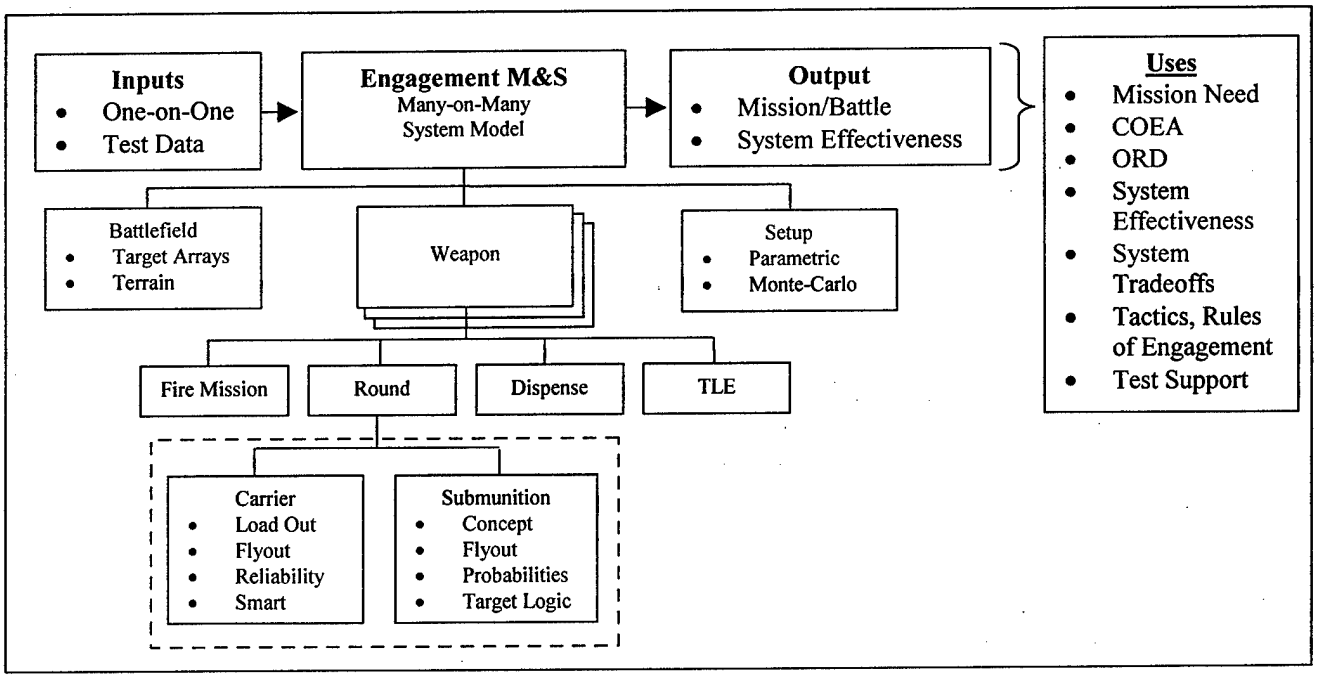

Figure 2-6 Many-on-Many Engagement M&S Attributes and Uses

Weapon platforms consisting of many systems are simulated against target arrays on the battlefield producing results used for input into the force level M&S. At this level of M&S it becomes more efficient to generate the necessary trends in performance by conducting *what if* and parametric sensitivity analyses. An example of the typical output results are shown below in figure 2-7, which include the number of kills per volley, number of kills per launcher load, sensitivity of kill performance as a function of various parameters (probability of detection, false target density, target location error (TLE), system errors, engagement logic, dispense, flyout, etc.).

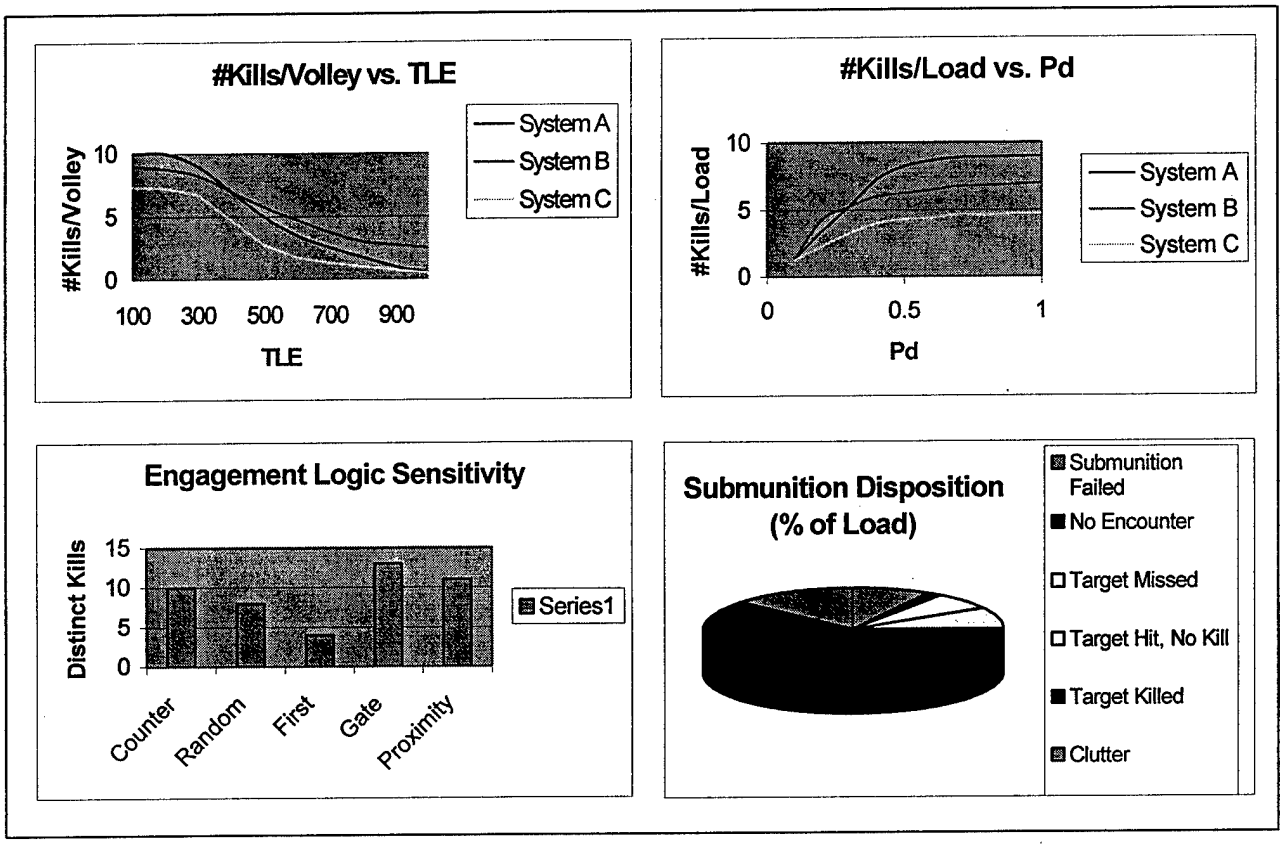

Figure 2-7 Typical Output Results Obtained From Many-on-Many Engagement M&S

It is at this level of M&S during the acquisition life-cycle that the specific system component design requirements become apparent. For example, given the flow down requirement from the campaign or force level M&S, X% of red force destruction which is reflected in a requirement of # Kills/Load or Volley, the specs such as Pd, TLE, engagement logic, load-out, etc., can then be determined by the many-on-many engagement M&S. As a result these requirements are then flowed down to the one-on-one higher fidelity level engagement M&S for the development of system component spec requirements.

The IPT decision makers use these results to evaluate alternative systems (COEA, AoA), refine/define requirements (MNS, ORD), establish system effectiveness, perform tradeoffs, explore rules of engagement, and support testing (operational, drop, or CFT).

Engagement (One-on-One System)

Typically, the one-on-one system M&S is a high fidelity architecture of specific subsystems. This level of M&S is used to evaluate the effectiveness of a particular system within the overall platform against one particular target type. Figure 2-8 represents a one-on-one submunition model typical of a fire & forget indirect fire PGM platform.

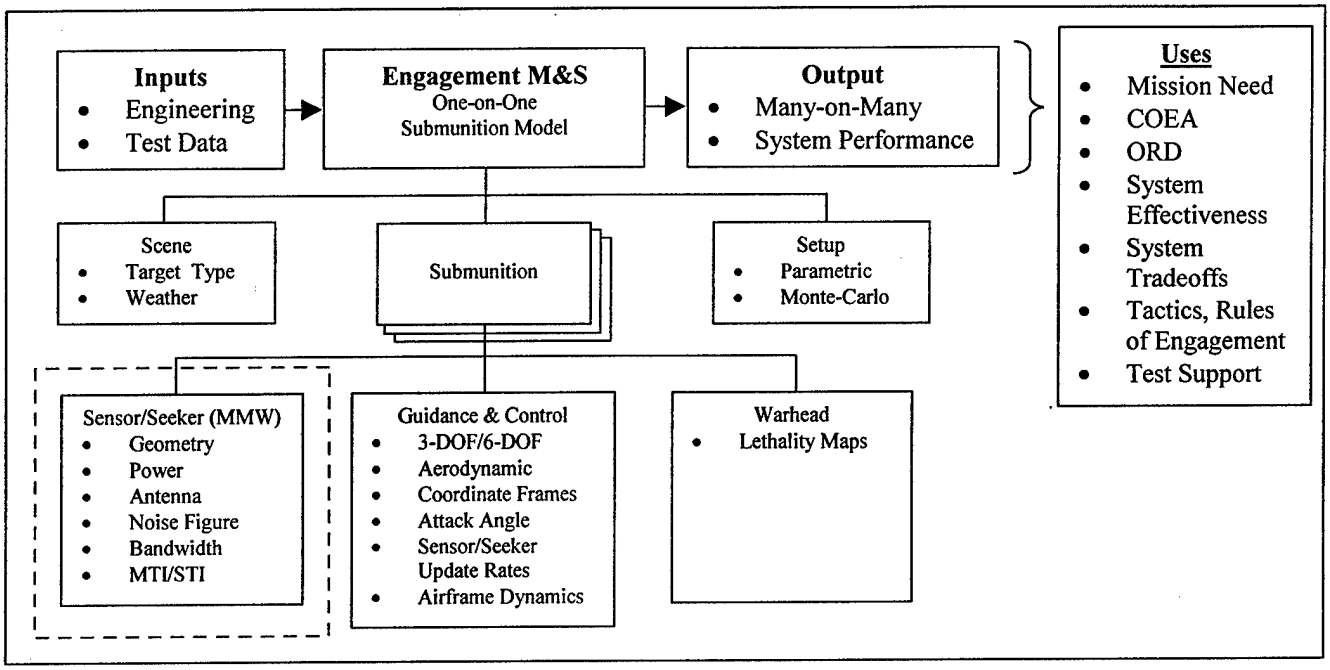

Figure 2-8 One-on-One Engagement M&S Attributes and Uses

This M&S takes the results of the engineering level M&S as input and produces conditional MOEs associated with the subsystems performance (i.e. sensor/seeker, guidance and control, and warhead). Figure 2-9 is an example of the type MOE showing a conditional probability of detection as a function of signal-to-interference ratio (SIR) for three levels of false alarm probability. The guidance and control performance is reflected in the conditional probability of hit as a function of SIR for a family of G&C parameters. The warhead effect is reflected as a conditional probability of kill as a function of 1-dimensional target surface coordinate. Because these M&Ss are high fidelity, Monte-Carlo run times can take several hours and even days.

At this point of system acquisition, the decision making support systems are utilizing their IPT groups and using this level of M&S to develop the system specific requirements and defining the Phase I (Demonstration/Validation) exit criteria. It is also necessary at this point of the program to begin the process of M&S verification, validation & accreditation (VV&A) using a model-test-model approach supported by both a simulation IPT and technical IPT.

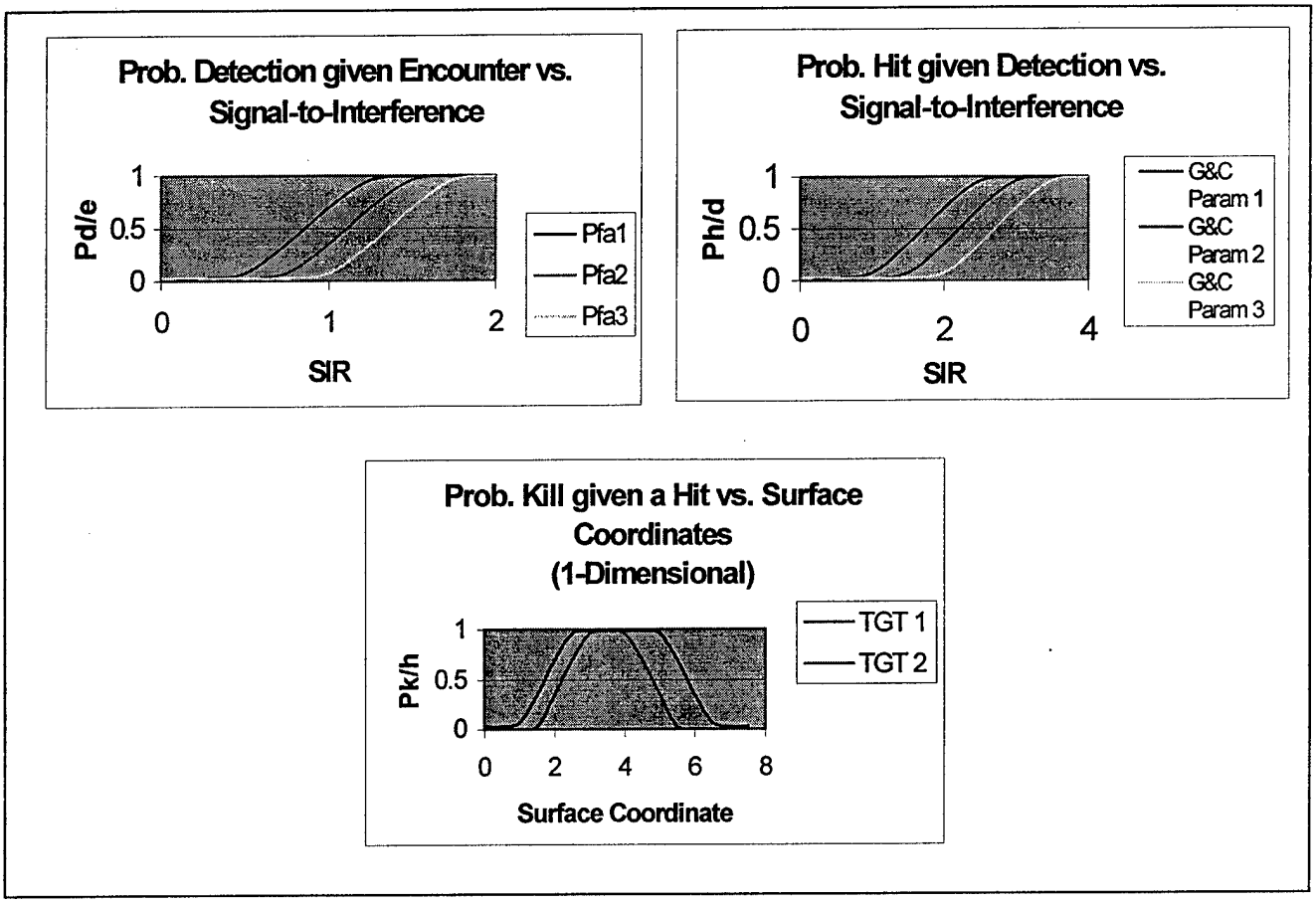

Figure 2-9 Typical Output Results Obtained From One-on-One Engagement M&S

Engineering (System/Subsystem/Component)

The engineering M&S provides the basis for the design at the subsystem and component level. Through out the acquisition life cycle, this high fidelity M&S supports the development of technical design specs and testing. Typically, engineering models begin as digital simulations and as hardware is developed it is integrated into a hardware-in-the-loop (HWIL) simulation to support VV&A of the high fidelity digital M&S.

These M&S measure performance parameters that are used in the system and development specs. For a millimeter wave (MMW) radar seeker, as shown in figure 2-10, these measures of performance (MOP) may include attributes associated with signal generation, noise and preprocessing, and autonomous target acquisition & tracking algorithms.

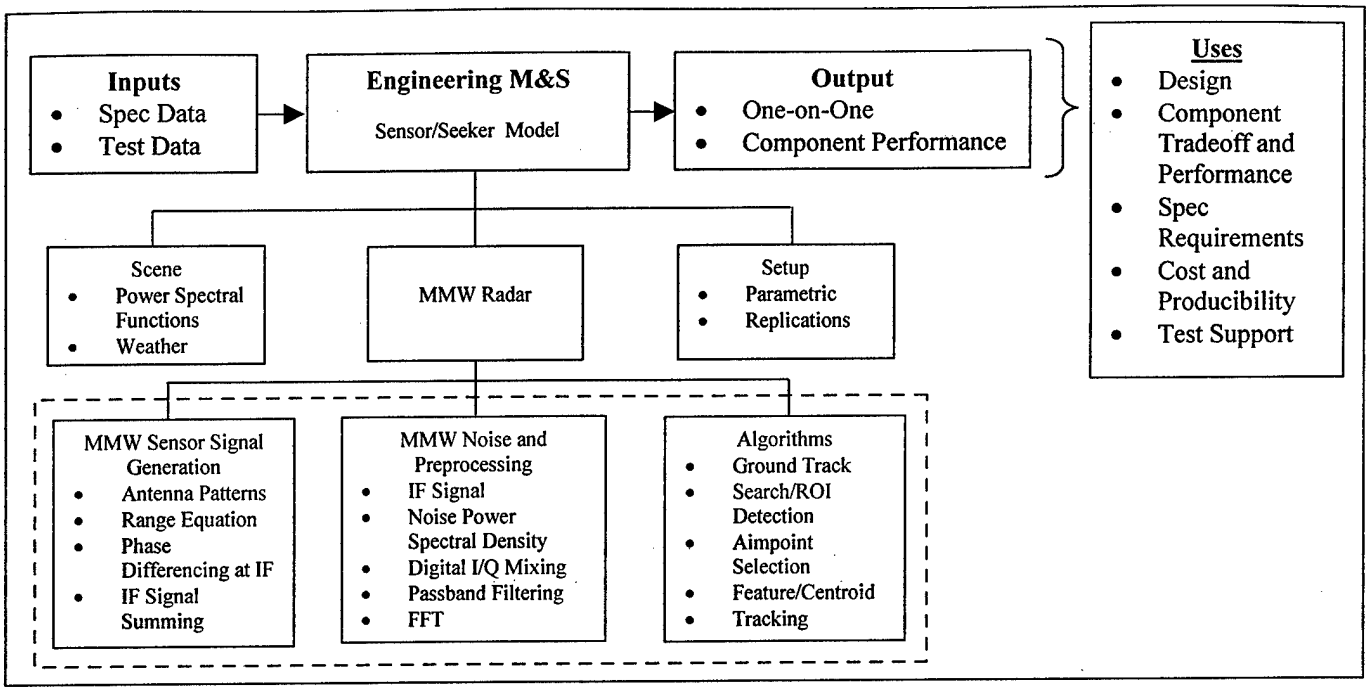

Figure 2-10 Engineering M&S Attributes and Uses

At this level, performance is based on phenomenology and physics models. In addition to the requirements support teams using this level of M&S, the acquisition and PPBS teams benefit by implementing support, cost and manufacturing models. Support models include reliability, availability and maintainability; level of repair; and provisioning analyses. Cost models provide development, production, and operations and support costs. Manufacturing M&S can provide information on producibility of a particular design, as well as simulation of work flow on the factory floor and identify facilitation requirements[6].

3. M&S INTEROPERABILITY

In many cases it is desirable to interface an M&S within the hierarchy with it's lower level, because some of the input variables are a product of the lower level outputs. A good example of this is the mission/battle level and many-on-many engagement level M&S. The results of the many-on-many engagement M&S are used as input into the force level M&S, so it seems convenient for the force modeler to have in the simulation an interface to a robust generic model of the represented weapon system(s). The use of a generic model is desirable because a high fidelity system specific engagement model may limit the utility of the force model to specific system and scenarios. It would not be very practical to perform analytical tradeoffs and *what if* analyses because the simulation is limited to one type weapon system and simulation resource allocations can be limited due to the level of fidelity.

Depending on what the M&S objectives are, whether for analyses or training, there are basically two options that take advantage of the fidelity found at these two levels. In this document, we will refer to these two options as - highly aggregated or modular.

As was previously mentioned, the highly aggregated architecture takes advantage of the advanced distributive simulation techniques often-used in wargaming and training. Referring back to figures 2-4 and 2-5, wargaming and training simulations are played out at a campaign or force level. Many M&S entities (elements making up the corps, battle groups, airwings, enemy targets, etc.) are networked together as individual simulations and information from each simulation as well as live data is available to the network for use as input to any other entity that requires the input. This is all to be performed at or near real-time using protocol data units (PDUs).

The modular mode takes advantage of the analytical fidelity associated with the simulation. Because of the stochastic nature associated with these models, it is important to run several hundred Monte-Carlo replications in order to obtain some level of confidence with the results. The results of a modular M&S would be in matrix form representing parametric outputs. This matrix would have to be generated offline and available as a lookup data base for the next level simulation.

3.1 Example of Interfacing Many-on-Many with Force-on-Force

The following is an example of interfacing a mission level M&S with a many-on-many engagement M&S. The mission level M&S is called FireSimXXI, which is a constructive simulation designed to model military operations, typically at division level, with particular emphasis on fire support. It simulates both friendly and enemy artillery forces, and includes sensors, C^3I, logistics, firing platforms and munitions. It is large scale (up to corps level) and yet high resolution (individual sensors, weapons, fire direction centers, munitions, messages, etc.). The FireSimXXI model is an event sequenced simulation of opposing artillery forces. This simulation models the target acquisition, communications, weapon/target allocation and artillery firing of the fire support units to a high level of detail in a dynamic scenario[7].

The many-on-many engagement level M&S is a **GENE**ric **S**mart **I**ndirect fire **S**imulation called GENESIS. GENESIS models a wide variety of indirect fire smart munitions in target engagements that vary in scope from many-on-many down to few-on-few. Glide, parachute, skeet, and bomlet munitions can be simulated with detailed dynamics and performance parameters. Targeting/delivery errors are stochastically represented. Detailed trajectories and scan dynamics are modeled for each munition with graphics (battlefield map display). Munition performance is stochastically modeled via conditional event probabilities (e.g., detection, hit and kill). The fundamental simulation output is weapon system effectiveness in terms of expected target kills per volley, history by target and disposition, and submunition disposition determined from Monte Carlo runs.

FireSimXXI currently interfaces with other entity-based M&S. These include, The Extended Air Defense Simulation (EADSIM) and its Army Tactical Command and Control System (ATCCS) communications counterpart, the Air Missile Defense Work

Station (AMDWS), and ground maneuver simultions (JANUS or ModSAF) to provide airborne sensors for target acquisition and a more complex and robust land warfare environment. GENESIS could augment FirSimXXI by providing a variety of indirect fire smart weapon concepts to be *played* realistically. Figure 3-1 depicts the flow of information through the FireSimXXI M&S. FireSimXXI is a set of three programs run serially in one or more job streams. Figure 3-2 dipicts the required interfacing and information flow associated with FireSimXXI/GENESIS.

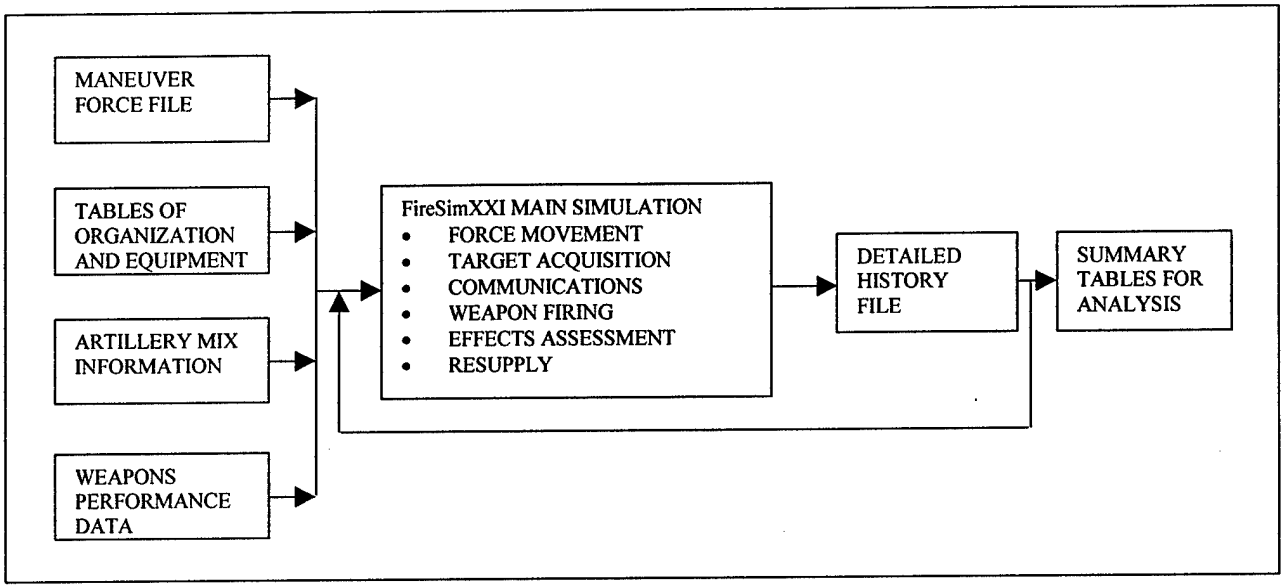

Figure 3-1 FireSimXXI Simulation Flow

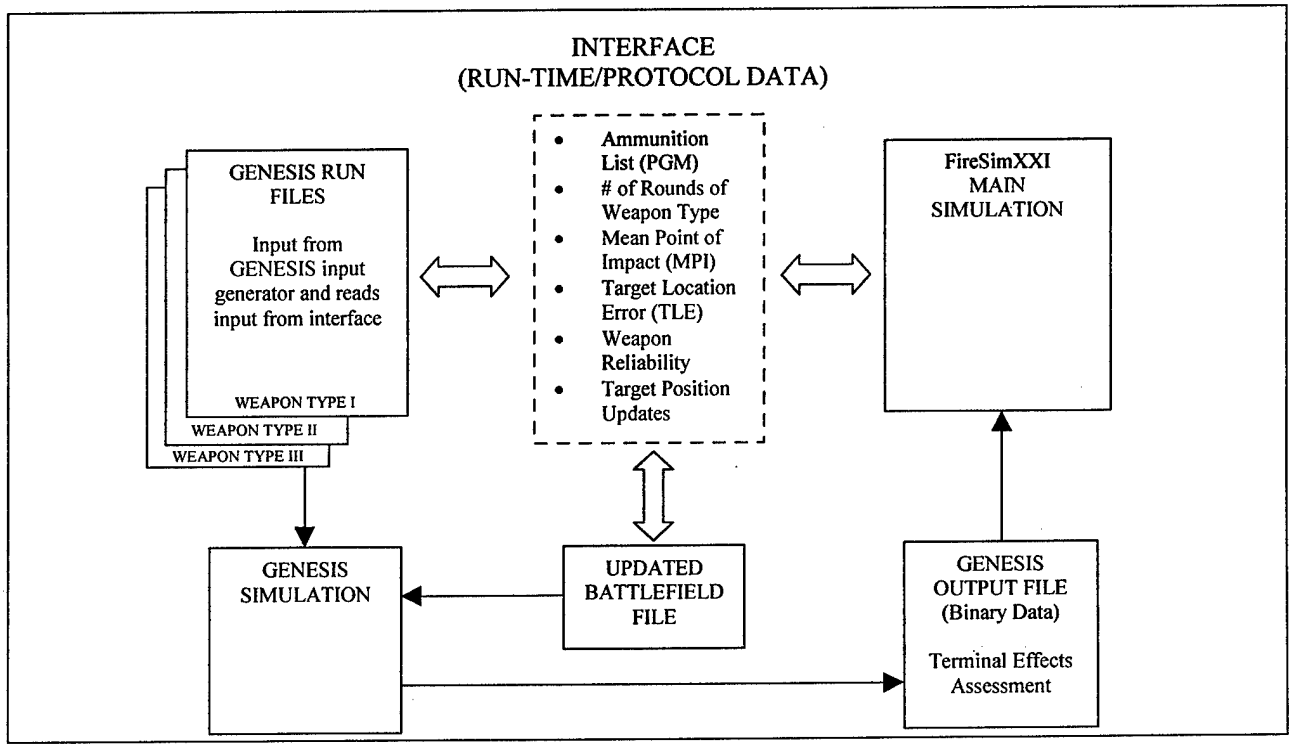

Figure 3-2 Interface Requirement

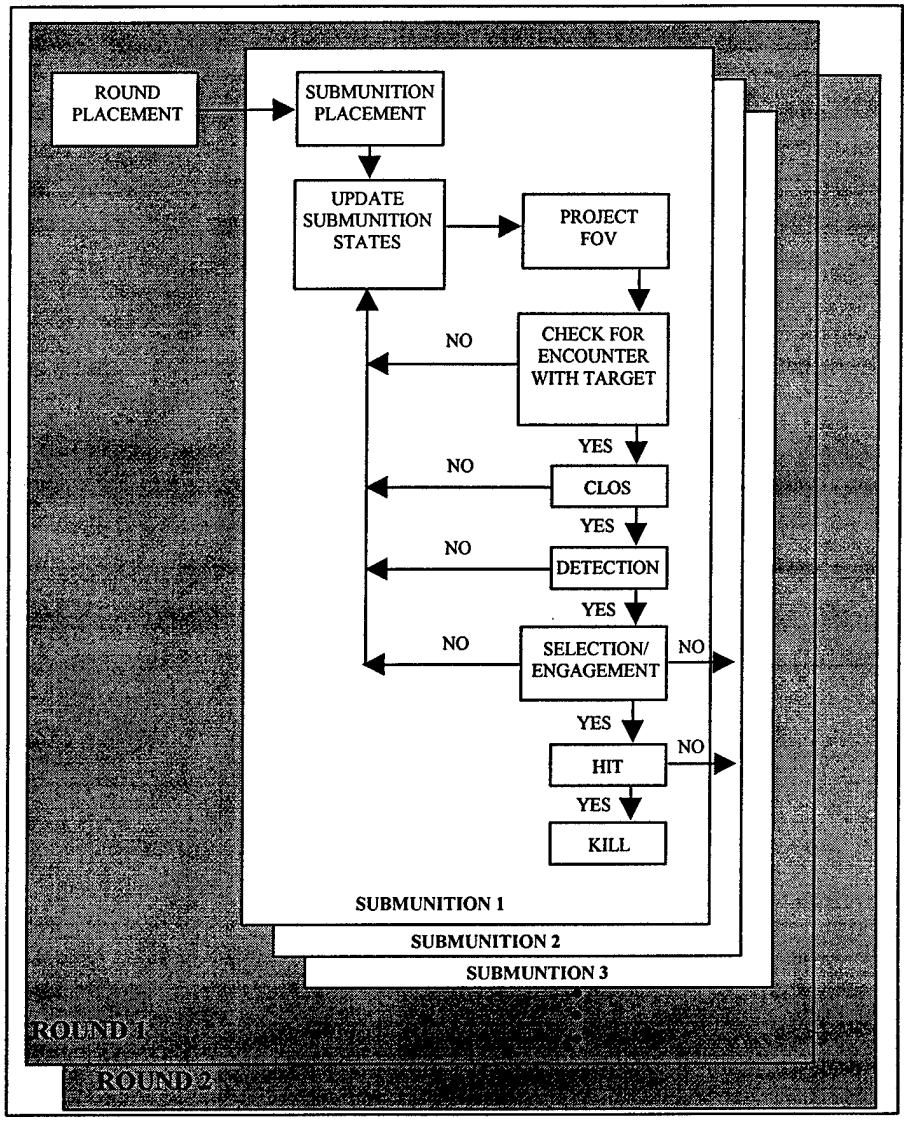

Figure 3-3 GENESIS Simulation Flow

Figure 3-3 depicts the GENESIS simulation flow. In its earlier days, prior to 1993, FireSimXXI (then called TAFSM) was primarily an analytical tool. Under new directives within DoD, it was rewritten to be DIS compliant. Therefore, GENESIS would have to undergo some structural modifications compliant with DIS standards. This would only effect the FirSimXXI simulation module and the GENESIS input generator. The GENESIS input generator is used to build the weapon run files.

The GENESIS Simulation (figure 3-3) would remain as a stand-alone outside the structure of FireSimXXI. FireSimXXI would provide required fire mission and target position data via run-time/protocol data interface. This is the DIS standard in M&S interoperability, which defines entity state information available as a Protocol Data Unit (PDU).

From figure 3-2, the variables listed in the interface are dynamically generated within FireSimXXI and would be updated to the GENESIS run files when the PGM ammunition list is invoked. GENESIS would then simulate the replication, generate a binary data output file available as input to the FireSimXXI effects assessment.

A library list of the various weapon type files can be generated offline using the GENESIS input generator, and made available to FireSimXXI through its weapon performance data input module.

4. CONCLUSION AND RECOMMENDATION

Throughout the system acquisition life cycle, M&S plays such an important role in the decision-making processes. M&S are the tools that produce the outputs, by which the decision-making support systems take as input and make judgement on needs, requirements, capabilities, alternatives, costs, and risks.

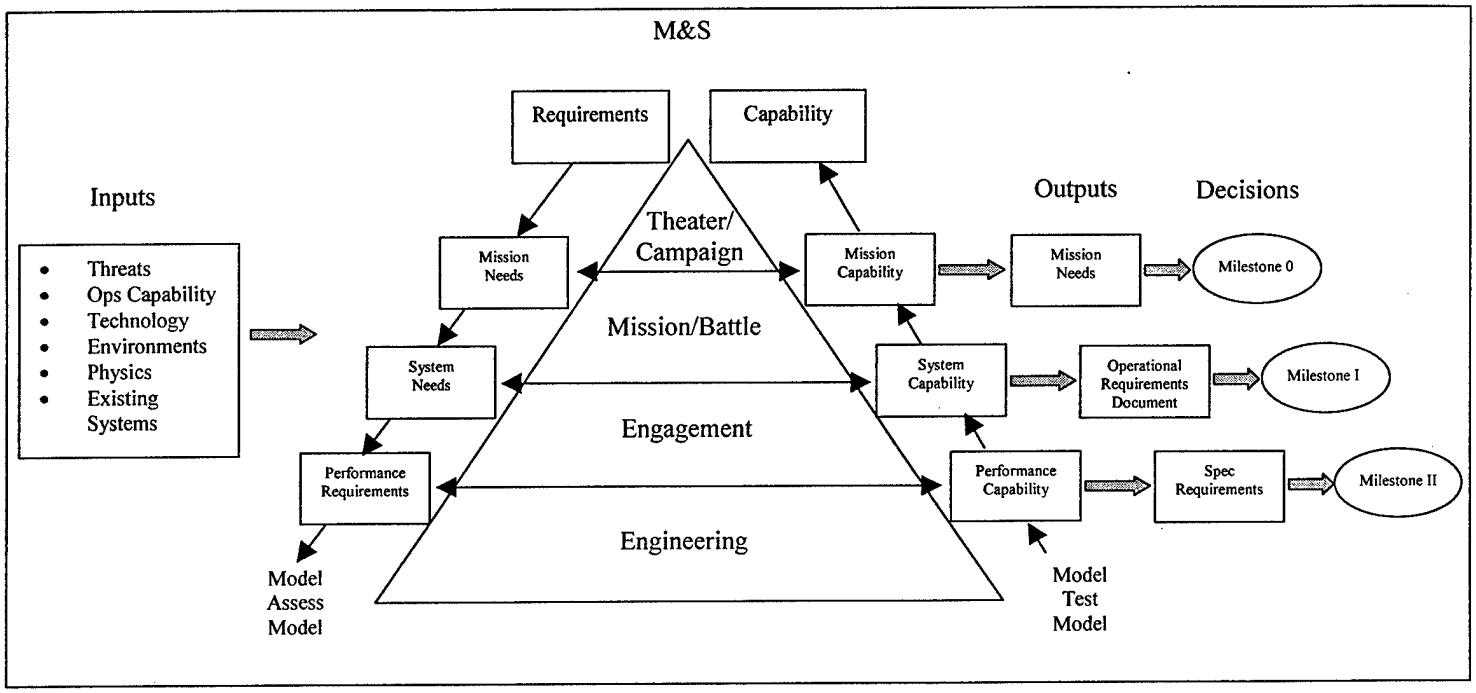

Figure 4-1 Model & Simulation Hierarchy in Support of Decision Making Process

In many cases throughout the acquisition life cycle, M&S interoperability is not required when the objectives are defined in support of analyses. However, if the upper level M&S are intended for wargaming and training then the lower level analytical M&S can be configured as a *plug in* module. The lower level analytical M&S would augment the upper level by providing some increased fidelity in modeling the particular entity it represents. Also, under the direction of DoD future M&S have to be DIS/HLA compliant. As a result it enhances M&S interoperability within the hierarchy.

As a result of this technical assessment, it is recommended to investigate the effort involved in making the FireSimXXI force level and GENESIS many-on-many engagement level M&S interoperable. FireSimXXI is being used by analyst at both the U.S. Army Field Artillery School, Fort Sill, Oklahoma and TRAC WSMR and have expressed interest in using GENESIS with that model.

References

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4. Piplani, Colonel Lalit K., USA, *et al*; **Systems Acquisition Manager's Guide for the use of MODELS AND SIMULATIONS**; Defense Systems Management College Press, Fort Belvoir, VA, September 1994, pg. 2-3.

5. *ibid.*

6. *ibid.*

7. **FireSimXXI Database Administration Manual**; Depth and Simultaneous Attack Battle Laboratory; Fort Sill, Oklahoma; April 1999.