Chapter 7 – MODELLING AND SIMULATION FOR EW T&E

7.1 INTRODUCTION

This chapter provides an overview of M&S and emphasises its value to the EW T&E process. A rigorous yet pragmatic approach to its use is necessary to optimise benefits to platform projects. Reference is also made to the topic of threat simulation, a key capability that supports the EW T&E process.

M&S is the representation of 'reality' through the use of models and simulations, nowadays mostly hosted on non-specialised PCs. Testing of military systems can be considered to be a 'simulation' of their operational use, including combat. Figure 7-1 indicates this scope in the context of M&S – the electromagnetic battlespace, as can be generated by RF and EO/IR threat simulators for EW T&E.

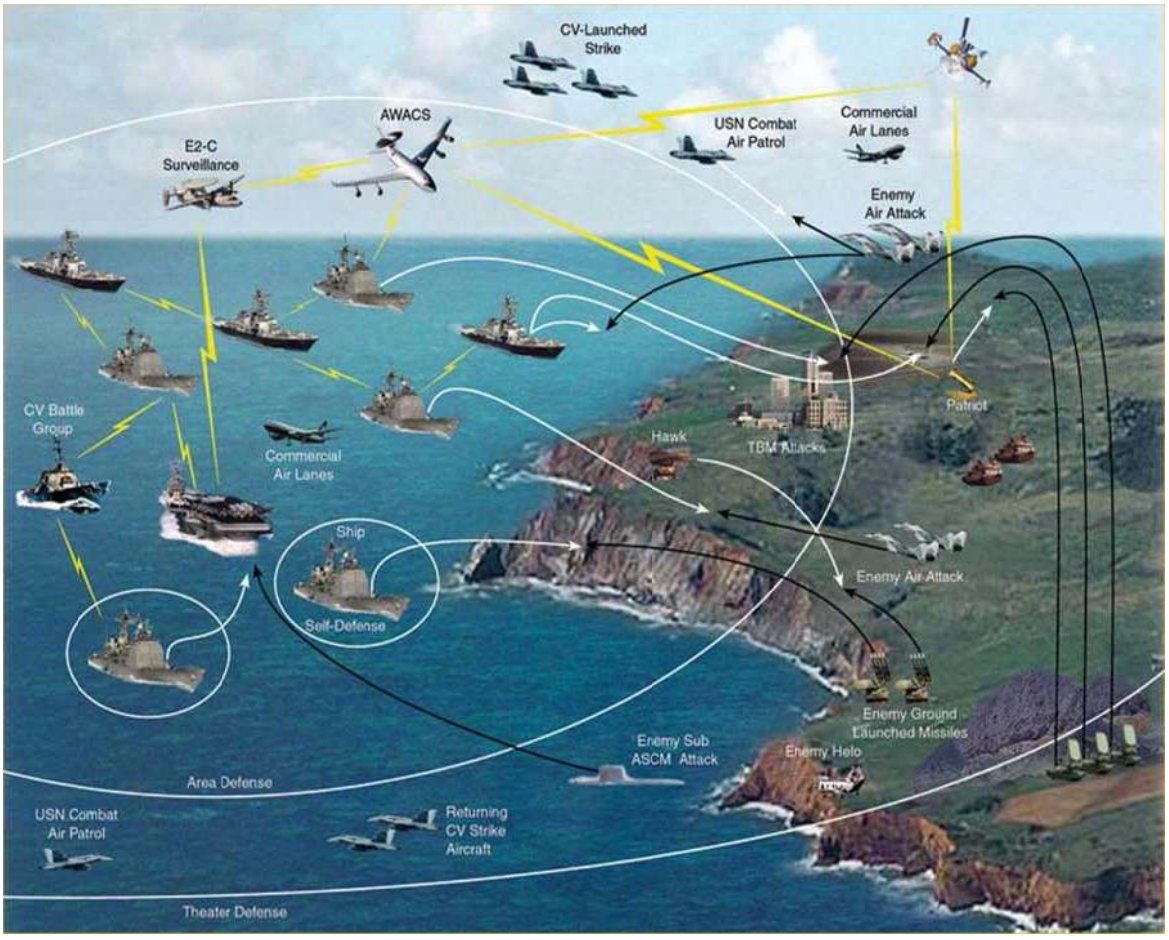

Figure 7-1: M&S Scope: The Electromagnetic Battlespace – Threat Simulation for EW T&E – (© Northrop Grumman Amherst Systems Inc. 2006).

M&S is used throughout the platform systems life cycle, from R&D to in-service support and training. Laboratory analysis, experimentation and M&S are playing an increasingly important role in T&E activities. High fidelity simulation enables mission level evaluation in a robust operational environment. Undoubtedly reducing the need to conduct physical equipment and system testing, they are not a complete solution. A shift in the balance between laboratory and physical testing is inevitable, but specialist and dedicated T&E ranges, facilities and supporting personnel will still be required. The challenge is to ensure the optimum mix is delivered and, as importantly, sustained.

The rapid rate of developments in the field of M&S and its sister domain Synthetic Environments (SE) prevents this chapter from being more than an introductory text on the topic. Whilst an overview of the through-life aspect is provided, it focuses on specific uses and benefits of M&S in the EW T&E process.

7.2 BACKGROUND, PURPOSE AND DEFINITIONS

7.2.1 Background

In the EW domain M&S was originally considered solely a tool for determining system requirements from campaign and mission requirements. Formerly also known as 'Digital M&S,' M&S now plays a crucial role in the process of acquiring and testing EW systems, and has long been recognised as a critical adjunct to ground and flight test. It is the thread that binds the various phases of the EW T&E Process together to enable a comprehensive conclusion about EW systems' fitness for purpose and effectiveness. M&S itself improves with use in the EW T&E process as test results fold back into the M&S tools to improve their fidelity and capabilities and users' confidence in them.

Historically, M&S in its wider context was problematic. The problems' primary root causes are considered to have been inadequate and/or incomplete:

- Understanding of the required fidelity of simulations/models.
- Verification of simulations/models against their designs and specifications.
- Validation and accreditation of simulations/models against the real world and relevant measured data.
- Computing power limitations (and the resultant cost required) – a significant constraint a decade ago and still a challenge.

All too often models of unverified fidelity have been used. These have led to speculation and confusion and the consequent need for further investigations – often with significant cost and time impact. Box and Draper summarised this critical fidelity factor, which remains valid today, as "*Remember that all models are wrong; the practical question is how wrong do they have to be to not be useful*." [1]

The increasing strengths and decreasing limitations of M&S are now evident, as enabled by the last decade's meteoric rise in computing power and greatly improved understanding of the simulation fidelity; VV&A and related M&S topics.

Against a back-drop of severe affordability challenges world-wide, M&S is likely a key enabler for significant improvements in EW systems' whole life affordability. As noted in Section 6.3, US and European efforts continue apace targeting realisation of the promises that M&S offers to EW T&E.

7.2.2 Purpose

This chapter describes how M&S may provide unique and practical benefits to EW testers, project managers and programme sponsors. The EW T&E Process uses M&S and analysis prior to testing to help design tests and predict test results, and, after testing, to extrapolate test results to other conditions. At each stage of the test process, models in the simulation are replaced with hardware to achieve increasing fidelity to support evaluation. In this way M&S is part of all six resource categories described earlier in this Handbook. M&S is also used to provide frequent feedback for system development and improvement.

Models and computer simulations are used to represent systems, host platforms, other friendly players, the combat environment and threat systems. They can be used to help design and define EW systems and testing with threat simulations and missile fly-out models.

Due to the relatively low cost of exercising these models, this type of activity can be run many times to conduct sensitivity and trend analyses, to check 'what ifs' and to explore the widest possible range of system parameters without flight safety concerns. These models may run interactively in real or simulated time and space domains, alongside other combat environment factors, to support the entire T&E process.

7.2.3 Definitions

TERM	MEANING AND COMMENT
M&S and SE	It is useful to clarify subtle differences between M&S and SE, which are used extensively within [2] and [3], where both are seen to be enabling capabilities that can add significantly to effectiveness and value. For this chapter the definitions in DoD 5000.59-M, 'DoD Modeling and Simulation (M&S) Glossary' are used. [4] These definitions are: • M&S is 'The 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 interchangeably.' • SE is: '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 local and wide area networks and augmented by super-realistic special effects and accurate behavioural models. They allow visualization of and immersion into the environment being simulated.' For the remainder of this chapter, the term 'M&S' is taken to include SE.
MS&SE	As often seen with terminology used across Nations and between agencies within those Nations, different views exist on precise meanings of M&S and SE. For example, in the UK's MoD Acquisition Framework: • 'Modelling, Simulation and Synthetic Environments (MS&SE)' is used. [5] • A model is defined as a static representation of an object and a simulation is a representation of how that varies through time. • A Synthetic Environment can comprise of those simulations, equipment and people require to represent the problem space defined to the appropriate level of fidelity.
VV&A	Here are the USAF VV&A definitions from AFI 99-103: [6] **VV&A** – Is a continuous process in the life cycle of a model or simulation as it gets upgraded or is used for different applications. **Verification** – Process of determining that M&S accurately represent the developer's conceptual description and specifications. **Validation** – Rigorous and structured process of determining the extent to which M&S accurately represents the intended "real world" phenomena from the perspective of the intended M&S use. **Accreditation** – The official determination that a model or simulation is acceptable for use for a specific purpose. There are some subtle but potentially significant differences in national terminology and application, examples of which are given in Section 7.8 and in UK DEF STAN 03-44 'A generic process for the Verification and Validation of Modelling and Simulation and Synthetic Environment Systems'. [7] Another critical point, again with national variations, is that the V&V part generally belongs to those developing the models and simulations whilst the Accreditation part is generally the responsibility of the model/simulation user.

Other common M&S terms can be found elsewhere, e.g., UK MoD's Acquisition Operating Framework. [8] Regardless of terminology and definitions, it should be stressed that whoever intends to use a model or simulation to satisfy some purpose, it is their responsibility to understand well enough how the model/ simulation works to be able to determine if it will adequately satisfy their requirements.

7.3 OBJECTIVES

The objectives of M&S in the EW T&E process are to:

- Prove design concepts prior to final testing.
- Demonstrate system performance:
  - For elements that are either too complex or too expensive to verify by testing.
  - To supplement testing by interpolation between sparse data points.
  - To extrapolate measured test data into un-testable or unavailable regimes.
  - Where test repeatability is difficult or where tests would yield unacceptable error bounds.
- Define safety footprints or limits.
- Increase sample size once confidence in the model is established.
- Define test facility requirements, e.g., number and types of threats, airspace required, control of background noise and emitters, and instrumentation.
- Define and optimise test scenarios.
- Select test points, i.e., successful results would not indicate the need for additional heart-of-the-envelope testing.
- Predict test results for each test objective.

Provide a complex, operationally realistic environment.

7.4 M&S CATEGORISATION AND LEVELS OF COMPLEXITY

EW models and simulations are generally categorised and constructed to the levels of technical complexity commensurate with their intended use, as shown in Table 7-1. This Table expands upon Table 6-2 in the introduction to M&S within Chapter 6.

Table 7-1: M&S Categorisation and Levels of Complexity.

LEVEL	TYPICAL APPLICATION	COMMENT	TYPICAL OUTPUTS
Campaign (Operations, Theatre)	• Optimum force allocation, force mix studies. • Balance of Investment trades, e.g., Strike vs. ISTAR assets. • Availability analysis, i.e., sortie generation rates, concept reliability and maintainability. • Logistics and spares support and footprint analysis. • Force-on-Force interactions occurring **over several days**.	This level incorporates the Command, Control, Communications, Computers and Intelligence (C4I) contributions of joint-Service (i.e., Army-Air Force-Navy) and Allied Forces operations against a combined threat force (force-on-force). It integrates the various missions into regional, day and night, and joint operations, and assesses the input of EW on force effectiveness. Campaign level is similar to mission level except that a campaign is a many-on-many simulation including the impacts of having to sustain the mission for an extended period of time. It evaluates effectiveness and force survivability of friendly, multi-platform composite forces opposing numerous threats, but also includes the issues associated with human factors, logistics (including battle damage repair), and attrition.	Answers to the questions: • Did we win the campaign/war? • How long did it take? • At what overall cost?
Mission and Multi-Mission	• Weapon system concepts and CONOPS trade-offs (e.g., survivability). • Force mix / group operations analysis (e.g., value of support jamming). • “Many on Many” interactions **over several hours**.	Multiple weapon systems level models (with varying degrees of detail) combined into a simulated mission to analyse mission effectiveness and force survivability of friendly, multi-platform composite forces opposing numerous threats (many on many). Mission level models frequently include the impact of the enemy’s command and control capability on the outcome. Sometimes contractors are tasked by defence ministries to use this level of modelling to evaluate contributions and cost of various configurations. Thus in some cases, the contractor thus defines (for example) required levels of signatures and DAS.	Answers to the questions: • How many sorties were required to achieve the given mission objective? • How many engagements did we face? • Probability of successfully completing the mission.

LEVEL	TYPICAL APPLICATION	COMMENT	TYPICAL OUTPUTS
Engagement	• Platform level, e.g., weapon system, sensor suite and DAS trades. • Tactics exploration and optimisation. • Few on Few engagements, **over many minutes**.	Weapon system level models are used to evaluate effectiveness, including associated tactics and doctrine, in the context of an integrated weapon system engaged with a single (one-on-one) or a few (one-on-few) enemy threats (e.g., SAM systems) in a simulated scenario.	• Aircraft 'state vector' at end of engagement, i.e., position, speed, fuel, weapons, expendables, etc. • Engagement outcome, e.g., in an 'm vs. n' air-to-air combat, how many emerge on each side unscathed / needing to return to base. • Length of engagement and significant events, e.g., point of detection, recognition, weapon release, threat emitter activity.
Engineering (System)	• EW sensor and ECM performance analysis. • Alleviating RF interoperability issues. • Analysis of system interaction with RF and electro-optical/IR/UV environment, e.g. natural and man-made clutter. • One vs. One system interaction **over many seconds**.	The main difference between engagement level models and system level models: the former tends to emulate the effect of EW often assuming a lot, whereas the latter simulates 'the physics' of the EW interaction and assumes very little. A key element of this level for EW, radar and radio systems is establishing ***optimal installed performance,*** as platforms – especially aircraft – invariably preclude achieving theoretical maximum performance.	• Antenna gain vs. angle tables (for on board ECM, towed decoy, threat radar). • Optimal RF/EO/IR/UV sensor and effector (ECM) positions on platforms, to maximise survivability and mission success probability. • ECM technique effectiveness vs. given threats. • Jammer power, bandwidth and other requirements. • Chaff dispersion rated and characteristics. • DIRCM cueing accuracy from MW models. • RF/IR/UV threat emitter scenarios.
Engineering (Sub-System)	• Component R&D. • Circuit analysis. • Interactions typically occurring in **fractions of a second**.	Modelling used to examine technical performance of an individual component or LRI/LRU or sub-system in accordance with their intended designs.	• Impedance requirements. • Power and cooling requirements. • Switching speeds. • Memory requirements.

Categorisation schemes vary, although there is significant commonality – the differences largely concern the resolution required of the models and simulations, i.e., how much detail is appropriate for the questions being asked? For example:

- In some schemes the 'Campaign' level is called 'Operations' and in others 'Theatre,' whilst others have Campaign and Theatre as separate levels. In this Table all three are considered to be under the 'Campaign' header.
- Likewise some schemes only have an 'Engineering' level, whereas others decompose this into 'System' and further into 'Sub-System,' 'Equipment' and 'Component (or 'Circuit'). In this Table only two levels are used: 'Engineering (System)' and Engineering (Sub-System).

7.5 APPLYING M&S IN THE EW TEST PROCESS

M&S supports EW testing throughout the EW Test Process as shown in Figure 1-6 to plan (predict), conduct (test), and analyse (compare) the test programme and evaluate SUT performance. M&S tools consist of two parts: the battle environment and the SUT. The battle environment includes software representations (models) such as the enemy's weapon system (threat) and the propagation environment. The SUT (often referred to as the Digital System Model, DSM) includes software representation of the friendly weapon system, such as the aircraft, including any electronics critical to the evaluation.

7.5.1 Defining System Requirements

M&S tools are used to examine theatre, campaign, and mission needs to determine the requirements for new or upgraded EW capabilities. Once a requirement is established, M&S tools are used to determine performance characteristics required in the EW system.

EW system performance requirements are stated as MOEs that are decomposed into MOPs from which test objectives can be derived. M&S plays a key role in the process of defining test requirements based on what information is needed about the EW system. MOEs and MOPs become the basis for planning an EW test programme, and M&S provides the tools to feed back the EW performance observed during testing into the original simulations used for determining EW performance requirements.

7.5.2 M&S in the EW Test Process

With MOEs in hand, the test team begins the test process designed to gain incremental information on the EW system's performance, increasing confidence the system will perform effectively in combat. Figure 7-2, which is similar to Figure 1-11, shows a logical flow of test activity from left to right.

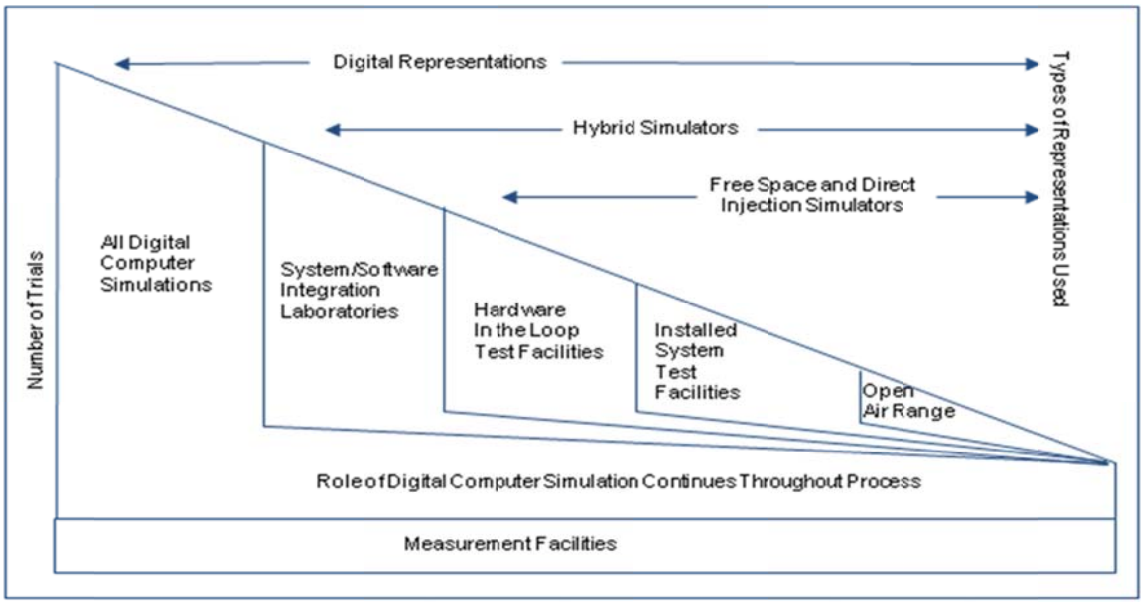

Figure 7-2: Activities Within the M&S Interface.

MFs (such as radar cross-section and antenna pattern measurement ranges) support the process continuously as needed. The majority of activity at these facilities occurs early in the process. All computer simulation also begins early in the process. It is used to assist in design, trade-off studies, system integration decisions, and test planning. As this chapter shows, M&S provides support throughout the EW test process. SILs provide the capability of testing individual EW system components (for instance, in 'brassboard' configurations) and sub-assemblies in a laboratory environment. HITL facilities allow testing the interactions of assembled EW systems with a simulated environment representing the threat situation. Frequently, the simulated environment at the HITL will include threat hardware integrated with simulation to create the battle environment. Once the EW system is integrated with other avionics on the aircraft, the integrated systems are tested in the ISTF to ensure compatibility of the various systems involved and that the EW system performs as expected when connected with other aircraft systems. The final test phase is flight testing at an OAR.

Figures 1-6 and 1-11 emphasise the continuing role of M&S throughout the EW Test Process. At each test facility, software tools play important roles in supporting test conduct and interpreting results. The roles of M&S at each test phase are very similar. Figure 7-2 graphically depicts how M&S fits in to these test phases. It is not appropriate for all M&S activities to be employed at all test phases, so the functions shown are turned on and off depending on the specific needs of the test.

A 'seamless' test process greatly benefits from continuity in the M&S functions shown in Figure 7-2. The M&S tools used for test support should be used to support simulations used at each facility. For instance, the target representation used at the HITL should be traceable to the target representation in the M&S. Models must have the appropriate fidelity to achieve the test objectives for a given phase of testing. The functions shown in Figure 7-2 apply generically to any EW test facility, but the model fidelity required can vary from facility to facility. For instance, in early phases – such as the SIL, a basic model of the SUT may be sufficient for some T&E activities. In subsequent phases, a more detailed and higher-fidelity system model is generally required, depending on the evaluation objectives.

An overview of how M&S facilitates and shapes EW testing is shown in Figure 7-3. The M&S function in each block is briefly explained later in this chapter along with a short example of each. M&S plays key

roles before, during, and following each phase of testing. M&S allows system characteristics measured and reported in engineering units to be translated into terms reflecting overall system effectiveness. Through analysis using M&S, results from one phase of testing can be used to define and optimise testing at subsequent facilities. This makes M&S an excellent risk reduction tool in the development of a friendly weapon system. This is a valuable capability since, in general, the expense of test hours increases as testing progresses from SILs, through HITL facilities and ISTFs to OARs.

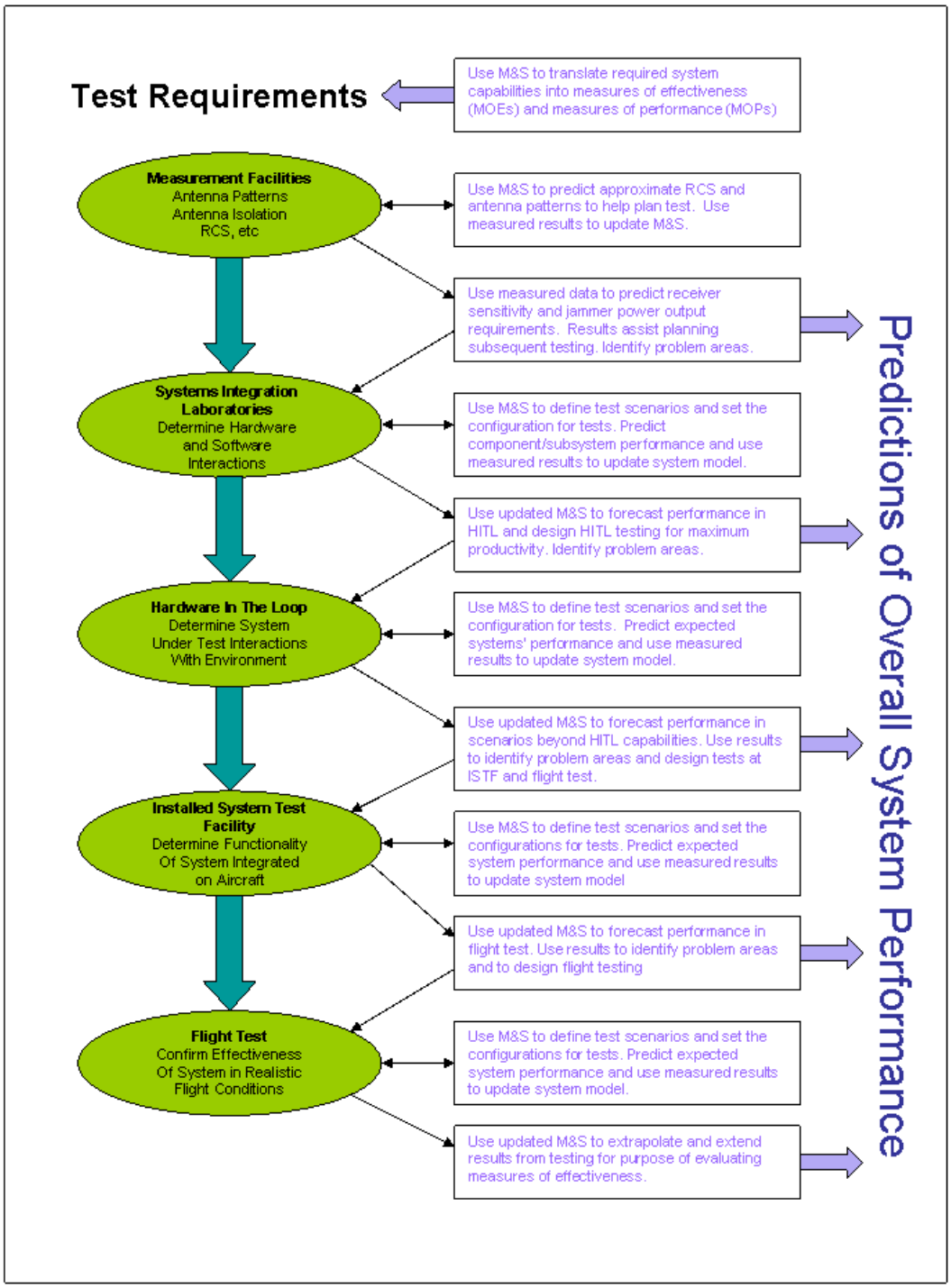

Figure 7-3: M&S Activities at Test Phases.

Figure 7-4 shows the DoD Live Virtual Constructive (LVC) continuum. Within the EW T&E activities there is likely to be mix of simulations and real equipment. The mix of this will differ through the life cycle depending on the maturity of the solution. Within this construct T&E could be performed earlier in the life cycle than it has been done traditionally, but with more simulation-based solutions. As the solution matures, real equipment will gradually replace the simulations providing a gradual de-risking process.

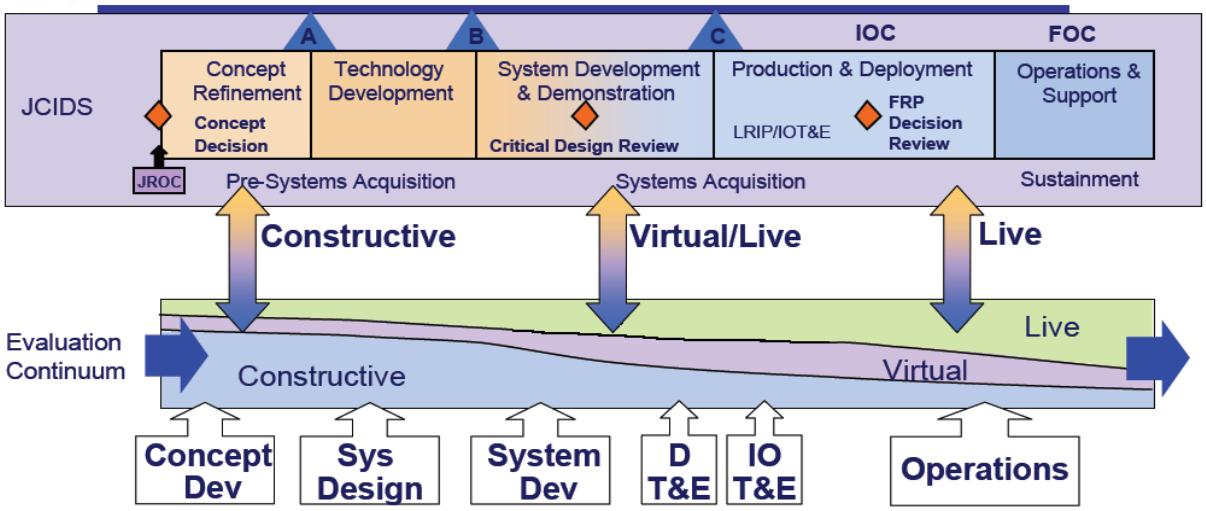

Figure 7-4: M&S Activities Supporting EW T&E: The DoD LVC Continuum.

At the conclusion of the 'test' phases, M&S plays a major role in extrapolating performance observed in test to operationally realistic scenarios as defined in the requirements document for the system. During the test process, confidence grows in the conclusions concerning the weapon system's performance. Confidence is also increased in the M&S tools since measured results provide feedback for model refinement and validation. The completed set of M&S tools can then be used to explore the EW system's performance in conditions that cannot be tested at the various facilities. At completion of testing, the validated M&S tools are available for a wide variety of analysis applications.

7.6 M&S ACTIVITIES SUPPORTING EW T&E

The following paragraphs provide generic descriptions of each of the key M&S applications.

7.6.1 Quantify Test Conditions

The use of M&S to quantify test conditions provides a firm foundation for subsequent testing using the EW T&E Process. An Analysis of Alternatives (AOA) is conducted to develop mission scenarios and evaluate effectiveness and cost trade-offs. At this stage, there are no detailed system parameters available (for example, known performance in terms of response times, jamming waveforms and the like) nor specific system performance requirements. The AOA first determines if future defence strategies require the development of a new weapon system or sub-system.

The AOA process develops operational mission scenarios including target analysis, threat system deployment, and development of realistic mission profiles. The missions are simulated and analysis of the resulting interactions between the weapon system and the threat quantifies the frequency of occurrence that specific threats engage the aircraft. The parameters of the engagement conditions such as range, offset, and the presence of other threat systems and their emissions are also predicted. The predominant

and most stressing conditions challenging system performance are identified by the M&S analysis. These provide quantified descriptions of candidate test conditions that are used to design test configurations for each of the test facility categories and specific test runs.

7.6.2 Design Tests

Based on the candidate test conditions, M&S is used to design and plan tests which obtain the most usable test points per test hour. The candidate test conditions are refined to account for limitations of the test facilities to define Reference Test Conditions (RTCs). M&S tools are then configured to simulate the RTCs for designing a set of test runs that vary key aspects of the test conditions. These are the Planned Test Conditions (PTCs) which result in the most test points for the test run matrix.

This use of M&S helps the test team to define an efficient test matrix by identifying conditions where MOP values change so no more sample test points than are needed will be planned. This improves overall test efficiency by concentrating test resources productively. Because flight test hours are usually limited based on funding constraints, using M&S for test design will not always reduce flight test hours, but it does help focus the flight test on critical data requirements.

7.6.3 Predict Test Results

The test team can use M&S to predict the expected values for each MOP in the test matrix. The predicted values support ‘Quick Look’ analysis to detect problems with the test execution if the test results differ significantly from the predictions. Test prediction is not a new concept nor is the use of M&S to help design and predict results. For years, M&S has been used in this fashion for flight performance testing and for space programmes. In their application to the EW Test Process, M&S tools become more detailed and accurate as they are validated with test data. The test team can also use the M&S tools to control the instrumentation and data reduction process by identifying essential data acquisition points. In many cases, data obtained from M&S can be used to test the analysis process to be used for actual test results. This can uncover problems in the analysis processes before actual testing begins.

7.6.4 Simulate Elements

Simulation plays a key role in many phases of testing. For instance, accurate simulations of threat radars and other emitters in the scenario are necessary to provide sources of realistic signals used to test the SUT capabilities in a dense signal environment in the SIL. This topic is discussed later in this chapter.

Another important element often available only in a simulation is the threat missile seeker hardware. For HITL testing of the SUT interaction with seeker-dependent missiles, accurate models of the missile fly-out are necessary to obtain proper seeker geometry and RF/IR/UV conditions for the test. M&S supports these and other requirements to construct meaningful test conditions by providing suitable output representations of threat activity from validated modules representing their hardware counterparts.

7.6.5 Quantify Test Results

M&S provides the link between what can be measured from testing and what must be known about the associated impact on aircraft survivability at all phases of testing. M&S can aggregate measured data from testing and project it into predicted system effectiveness terms that allow more direct evaluation of system capabilities.

7.6.6 Compare Predicted and Test Results

It is important to compare results predicted for the test using M&S with actual results. One reason for doing this is to gain confidence in or refine the M&S. Arguably, a more important reason is to ‘sanity

check' test results. In cases where measured results disagree with predictions, there is always a chance that problems with the test setup, execution, or data collection are the cause. Having confidence in the predicted results allows problems with the test to be quickly identified and corrected.

7.6.7 Extrapolate Test Results

For various reasons (cost, time, resource limitations, or safety), testing cannot collect measured data at every possible point in the region of interest. M&S can be used to increase the sample size by simulating those events that could be encountered operationally but could not be included in the test design.

M&S is also used to extrapolate results to higher level MOEs than can be directly tested. For example, tracking error, which is a MOP, is extrapolated to miss distance by simulating the missile fly-out. The miss distance for numerous test runs is then analysed to obtain the Reduction in Lethality MOE (see Annex B).

Validation of the M&S models and extrapolation of results provide the test team with tools to connect the MOPs to system effectiveness, which make test results meaningful to programme management in reaching decisions concerning the programme.

7.7 EXAMPLES OF APPLYING M&S DURING TEST PHASES

This section describes how a test team can use M&S at each test phase. It is not a comprehensive description of M&S throughout the EW T&E Process, just a sampling of how M&S can be used. One example MOP is selected for each process phase to illustrate contributions of M&S at each test phase.

As testing progresses through the process, the test team collects more measured data. As a result, there will be a reduction in remaining MOEs/MOPs to be predicted through simulation. As a specific example of this process, measured installed antenna patterns obtained at the measurement facility will replace the engineering estimated antenna patterns in the DSM. The MOEs/MOPs will be computed or re-computed using the updated model(s).

7.7.1 MF Example: Antenna Pattern Measurement for Field-of-View MOP Assessment

A platform's RWR antennas must provide visibility throughout the required range of azimuth and elevation. If the achieved field-of-view coverage is inadequate, the RWR will not provide warning for threats located outside the achieved field of view.

Design Test: The DSM will be used to specify sampling intervals and resolution required in measurements to ensure the resulting collected data are sufficient (but not wasteful 'overkill') for supporting subsequent modelling which uses the measurements as input data.

Extrapolate Test Results: The DSM will be stimulated with analytically combined measured antenna pattern data to observe predicted SUT performance in response to frequency and polarisation combinations not actually part of the measurement plan.

7.7.2 SIL Example: Detection Range MOP

The platform's RWR must warn the aircrew at a range from the threat that allows employment of suitable countermeasures. If the achieved detection range is inadequate, warning time will not be adequate to allow effective countermeasures.

Design Tests: SAMs and Airborne Interceptor systems, emitters and environment models can be used to generate expected power levels for testing jammer and RWR threat detection capabilities. The corresponding values of power will be used to design the test setup and data collection efforts. In other words, the test team will use this power as the starting point and proceed up or down in the scale as necessary to characterise detection capability.

Predict Test Results: The DSM, threat, environment, and aircraft models will be used to predict the range between the aircraft and threat at which the SUT initially detects each threat along the test scenario.

Extrapolate Test Results: Validated DSM models will be used to extend the measured results to include assessment of detection range performance against emitters not available in the SIL. This allows follow-on analysis to incorporate newly assessed threat capabilities and opens up the possibility of deployments without re-visiting the SIL facility.

7.7.3 HITL Example: Track Error MOP

Output jamming waveforms must cause sufficient degradation in threat tracking of the aircraft to prevent damage or destruction by a missile or AAA.

Design Tests: Threat models capable of predicting threat radar responses to ECM (called 'EC-capable' models) are used to evaluate the capability of the self-protection system to achieve a given degradation in threat tracking performance at various target offsets and altitudes. Resultant effectiveness estimates are used to design the HITL test setup and to specify offsets and altitudes.

Predict Test Results: DSM, threat, and environmental models are used to establish expected values of the resultant track error. Threat models used for this must be EC-capable.

Extrapolate Test Results: DSM and EC-capable threat models are used to extend results measured in the HITL to include assessment of SUT-threat interactions in conditions not actually measured at the HITL, to show SUT sensitivity to changes in environmental and/or threat factors that influence tracking error.

7.7.4 ISTF Example: Pulse Density MOP

Systems must be capable of collecting and processing all incident pulses expected in the aircraft scenario, subject to the specified tolerable pulse drop-out. If achieved pulse processing capability is inadequate, the system cannot effectively perform when conditions of pulse density are above the achieved capability.

Design Tests: Emitter, threat, and environmental models will be used to establish incident signal conditions at representative pulse densities for an operational scenario. These signal conditions will be used to design the test set-up and data collection effort at the ISTF.

Predict Test Results: The aircraft, DSM, emitter, threat, and environmental models will be used to predict SUT performance in the presence of the signal conditions derived above.

Simulate Elements: Motion of aircraft and other moving platforms of interest is simulated using M&S.

Extrapolate Test Results: Full simulation including the aircraft, DSM, emitter, threat, and environmental models can expand the scope of SUT evaluation by extending it to combinations of laydown, scan schedules, mission profiles, and other conditions not actually measured at the ISTF.

7.7.5 OAR Example: Reduction in Shots MOP

Jammers must sufficiently decrease the opportunity for missile launches with ECM versus without it. If sufficient shot opportunities cannot be denied, overall jamming effectiveness will be inadequate.

Design Tests: Aircraft, DSM, and threat models will be used to design flight tests that provide shot opportunities covering each tested threat system's engagement envelope and the mission envelope of the aircraft. Results of simulation will be used to design data collection, select threat rules of engagement (such as cueing and firing interval), and reference time TSPI coverage requirements.

Predict Test Results: Simulations used to design the flight tests will be run using derived test conditions to produce expected shot rates achievable by the threats under ECM and non-ECM conditions.

Extrapolate Test Results: M&S is used to extend results achieved at the OAR to include relevant threat density and combinations that are not available at the OAR, and, where necessary and possible, to include effects of tactics that were not employed during flight testing due to test restrictions.

7.8 SIMULATION FIDELITY, CREDIBILITY AND FITNESS FOR PURPOSE

7.8.1 M&S Fidelity and VV&A – RF Threat Simulation as an Example

This section discusses fidelity and VV&A as applicable to M&S as used in EW T&E. Sections 6.9.1 and 6.9.2 have already touched on fidelity under the topic of distinguishing factors of test facilities. This section expands on the topic with specific reference to RF threat simulators, a mainstay of many EW T&E facility categories. [9] As will be seen in this section, this can be seen as a general case for the consideration of any model or simulation to be used in the EW T&E process.

7.8.2 Definitions

There are many views of the meanings of the terms used to describe how faithful a representation of something is provided by a 'model' or a 'simulation'. Many years ago definitions were relatively straightforward: a simulation could have high or low fidelity. At its highest level of fidelity, the simulation became an emulation of the item concerned. As such it was identical to the item in all respects relevant to the emulation's use.

Nowadays terms such as 'model,' 'simulation/simulator,' 'emulation/emulator,' 'replication/replicate,' 'surrogate' and 'hybrid representation' often have multiple meanings, dependent upon Nation, agency, technical sector/domain, topic/aspect/item of concern and stage in the platform/equipment life cycle. In some countries references exist to aid clarity of this multiple usage but these are not international standards per se.

It is thus necessary to define the meaning of specific terms in the context of this section:

- **RF Emitter Simulation**: Imitation, at RF, of the real-world characteristics and behaviour of one or more RF emitters, to a given level of fidelity. Note: Simulations/simulators are usually more cost-effective than using real threat weapon system radars for most test missions.
- **Simulator Fidelity**: The measure of the quality of RF emitter simulation when compared to the real emitter, for all those spectral, spatial and temporal aspects relevant to the simulator's use in EW T&E.
- **Emulation**: Highest fidelity simulation, where a perfect EW receiver could not discriminate between the emulation and the real emitter. Note: Emulations/emulators are useful where the use of the real item is either not necessary or is undesirable.

- **Verification**: The process of determining that an EW receiver system, when tested using a threat simulator incorporating threat emitter models, meets its contractual specification.
- **Validation**: The process of determining whether the:
  - Simulator's output, when programmed with threat emitter models, is adequate for its intended use in the T&E process.
  - SUT, when programmed with theatre-specific Mission Data, correctly identifies and reacts to real/simulated threat emitters.
- **Accreditation**: The process of determining whether a simulator's rendition of threat emitters is suitably realistic, robust and credible.

7.8.3 Threat Simulation Fidelity

Threat simulation fidelity is dominated by two factors – threat emitter characteristics programmed into a simulator and the simulator's capability to translate those characteristics into a faithful representation of the RF signals that would be received by the SUT's antennas when radiated by the real threat under combat conditions. As with any simulation, a threat simulator's capabilities need to be fully understood in terms of the VV&A processes for M&S, and for SUT performance V&V. [10]

Table 7-2 depicts VV&A from a threat simulator standpoint.

Table 7-2: Threat Simulators and VV&A.

PROCESS NAME	OBJECTIVES	KEY QUESTION	PROCESS ACHIEVES	DONE BY
VERIFICATION	Uses simulator to confirm that SUT meets its specification	Was SUT built correctly?	Tests **FUNCTION and PERFORMANCE**	SUT suppliers and platform/ systems integrator
VALIDATION	Confirmation that: • Simulator produces adequate representation of emitters • SUT, when programmed with theatre-specific mission data, correctly identifies simulator-generated emitters	Do simulator-generated emitters look and behave sufficiently like the real thing?	Evaluates **FIDELITY**	Military, often with Industry support
ACCREDITATION	Certification that [simulator + threat emitter data] is adequate for proving [SUT + mission date] is fit for intended military purpose	Can simulator be used to optimise and validate mission data for EW receiver systems?	Determines **CREDIBILITY**	Military, often with Industry support

Various methods are used to confirm (or 'validate') the fidelity of a simulator's rendition of threats. National methods vary and a good example is the US CROSSBOW (Construction of a Radar to Operationally Simulate Signals Believed to Originate Worldwide) process, run by a tri-service technical agency established for the common development of EW RF simulators. It assures that simulators and models are consistent with intelligence agency threat estimates and that validation procedures are being followed. It then certifies simulator-model combinations for use for specific EW T&E cases via accreditation tests.

7.8.4 Fidelity, Affordability and the Limits of M&S Utility

Whilst it is philosophically possible to satisfy all VV&A requirements for any given system by M&S alone, there are significant obstacles that preclude its achievement. The primary reasons are affordability and computing power. Generally a better simulation needs improved fidelity and, generally, increased fidelity equals increased cost of implementation and model/simulation maintenance. It is thus considered unlikely that systems will ever be fully cleared by M&S also, i.e., without some residual element of SUT ground test and flight trials.

Again using the example of RF threat simulators, it has been long recognised that achieving emulation of combat air RF environments using simulators is utopian. The combination of affordability, highly complex electromagnetic interactions experienced in the real world and simulator technology limitations is likely to constrain simulations to limited resemblance to the high-pulse density, confusing electromagnetic 'mush' that is often the electronic battlespace in modern conflicts.

However, with reference to the definitions in Section 7.8.2, a perfect EW receiver is unlikely to ever exist. Thus the question is really whether a simulator provides sufficient fidelity for the SUT to be unable to discriminate between its outputs and emitters in the real-world RF environment. This, as for other areas of avionics T&E, is a question of adequacy – there is no need to generate significantly better fidelity than the SUT can measure.

In terms of adequacy, there are a number of rules of thumb that suggest T&E equipment should be able to simulate/generate/measure to an order better than the SUT can measure. Whilst often possible in the digital context, this is less easy in the RF world but modern simulators can, for most parameters, easily exceed the parameter range of the SUT. It is less easy, even given today's technology, to significantly improve on parameter accuracies and resolutions, though few problems have been reported in this area.

It is clear that much more can be achieved by M&S, but that the affordability boundary between M&S and testing needs to be determined carefully for each function and performance element requiring verification.

This situation has been examined for RF threat simulators, see [9], where a number of enhancements to the then existing state-of-the-art simulator were identified that appeared to promise the fidelity level where more of the T&E currently done by flight testing against real threat emitters could to be executed within the anechoic chamber and laboratory environment – offering cost saving, repeatability and investigation benefits. Once the above simulation fidelity level has been realised, the need for any further fidelity increase will need to be cost-benefit traded to determine whether the required tests might be better conducted via OAR flight trials. This situation is also in line with the US Defense Modeling and Simulation Office's view on 'State of the Art in Fidelity'. [11]

7.8.5 Fidelity Description

When determining fidelity requirements for a model or simulation it is important to provide quantitative fidelity descriptions if the model/simulation must produce critical parameters to specified levels of accuracy. [12] Qualitative (High/Medium/Low) descriptions lack the information content necessary to

support technical decisions about simulation fitness for a particular purpose. Fidelity needs to be characterised in terms of resolution, error/accuracy, sensitivity, precision and capacity.

7.8.6 M&S Credibility and Fitness for Purpose

Maximum benefit is reaped from models and simulations when their function and outputs are credible and their fidelity is sufficiently high to be affordably fit for purpose for the task at hand. Much has been written on these topics, too much to individually reference in this Handbook. The interested reader is referred the NATO Modelling and Simulation Working Group, see Section 7.9, and their National M&S agency, for guidance and other sources of information.

M&S credibility is hugely influenced by the overall experiment design process (use the right models together with the right data) and the overarching V&V process applied to that.

There are simulation processes that exist that are aimed at providing transparency and fitness for purpose. These are primarily the Federation Development and Execution Process (FEDEP) and Distributed Simulation Engineering Experimentation Process (DSEEP). [13],[14] Note that FEDEP, although known to still be in use at the time of this Handbook's issue, has been superseded by DSEEP, which was approved as a recommended IEEE standard in January 2011.

The DSEEP process builds on the FEDEP process and is a generic process which is clarified by the following steps, whose content is also outlined below:

- **Define Simulation Environment Objectives (Step 1)**
  - **Identify User and Sponsor Needs**: The requirement to produce an M&S application is started by a specific need. It is important to establish a clear understanding of the User's and Sponsor's goals.
  - **Develop Objectives**: A detailed set of specific objectives are developed and documented. The capability of M&S to be able to address these objectives is assessed in terms of cost, required timescales, risks, availability of personnel, supporting tools, security issues, network constraints, potential solution approaches, and facilities.
  - **Conduct Initial Planning**: Initial planning documentation is produced in terms of the Simulation Environment Development and Execution Plan (SEDEP), incorporating an approximate schedule with identification of major milestones, and addressing such issues as configuration management, test, security and V&V.
- **Perform Conceptual Analysis (Step 2)**
  - **Develop Scenario**: The objectives identified in Step 1 are assessed in terms of how they might be represented in the real-world domain, and from this a prototype scenario is developed. Several vignettes may be produced in order to fully satisfy the objectives. Scenario information should include the number and types of all the main entities, their positions, capabilities and behaviour, and scenario exit criteria. Geographical location and environmental conditions should also be specified. Potential reuse of previously established scenarios should be considered.
  - **Develop Conceptual Model**: From this information, the conceptual model can be established and documented. This is a real-world, implementation-independent representation which transforms the original objectives into a set of functional and behavioural descriptions designed to meet them.
  - **Develop Simulation Environment Requirements**: Detailed requirements for the simulation are established from the conceptual model and extend to consider the simulation environment

specific issues such as exercise control, monitoring, data logging and analysis, networks, test criteria, etc. Documented requirements should be traceable from the conceptual model to the original objectives.

- **Design Simulation Environment (Step 3)**
  - **Select Members**: Components of the Simulation Environment (known within DSEEP as 'members') are selected, and may vary in size from small elements to complete simulation environments in themselves. It is important to determine if pre-existing members can be reused (with the aid of a repository, if available), and to what extent they may need to be modified. Rationale for member selection should be documented.
  - **Prepare Simulation Environment Design**: The design of new members will need to be established, and the complete simulation environment design should be documented, including its overall infrastructure and selection of protocol standards.
  - **Prepare Detailed Plan**: A detailed plan for the established design is put in place. This involves updating and extending the initial SEDEP put in place in Step 1.
- **Develop Simulation Environment (Step 4)**
  - **Develop Simulation Data Exchange Model**: The information exchange data model defines how members within the simulation environment will interact with each other at runtime. This will depend, for example, upon whether an object oriented approach is being taken, or to what extent the simulation is distributed across a number of locations. The data exchange model developed should be fully documented, and must conform to the conceptual model established in Step 2.
  - **Establish Simulation Environment Agreements**: This activity is designed to ensure that all other agreements relating to interoperation are fully established before the simulation is implemented. Issues to be considered may include:
    - The need for any further software modifications to pre-existing members.
    - The need to ensure database and algorithm consistency, where appropriate.
    - Identification of definitive data sources for members and simulation environment databases.
    - Runtime management agreements, synchronisation points and initialisation procedures.
    - The definition of a save and restore strategy.
    - The definition of security procedures.
    - Data publication and subscription responsibilities.
    - Scenario instances required.
  - **Implement Member Application Designs**: During this activity, existing members are modified and member interfaces are constructed, adapted or extended as necessary. New members are implemented along with supporting databases and scenario instances.
  - **Implement Simulation Environment Infrastructure**: At this point, the required network software and hardware infrastructures are created and configured, and the facilities required to support integration and test are fully prepared. This includes availability of hardware, system administration, building air conditioning and power supply; and all other software and hardware configuration necessary. The infrastructures should be fully tested before going on to the next step.

- **Plan, Integrate and Test Simulation Environment (Step 5)**
  - **Plan Execution**: The SEDEP should be updated to take into account all the latest developments, paying particular attention to addressing V&V, test and security issues. All risks and mitigation strategies should be re-assessed, and plans for the detailed execution of the simulation fully documented.
  - **Integrate Simulation Environment**: The purpose of this task is to incorporate all members into their intended locations within the simulation environment infrastructure. Detailed progressive testing should be carried out during this process in accordance with the SEDEP, and software problems encountered should be fixed and re-tested.
  - **Test Simulation Environment**: The fully integrated simulation environment is formally tested to ensure that it can meet all its specified objectives. Test results should be reviewed with both users and sponsors, and any necessary corrective actions carried out.
- **Execute Simulation Environment and Prepare Outputs (Step 6)**
  - **Execute Simulation**: All planned simulation executions take place in accordance with the SEDEP, and all raw data outputs collected. Any problems should be documented.
  - **Prepare Simulation Environment Outputs**: Any pre-processing that is required to be carried out on the raw execution data outputs now takes place to ensure that it is in the appropriate format for subsequent analysis. This data, along with any execution problems encountered, should be reviewed to assess if there may be a need to re-run some of the simulation executions.
- **Analyse Data and Evaluate Results (Step 7)**
  - **Analyse Data**: The processed data from Step 6 is analysed using appropriate tools and methods, and results prepared for feedback to the User and Sponsor.
  - **Evaluate and Feedback Results**: The results are fed back to the User and Sponsor for evaluation, and an assessment made that the objectives of the Simulation Environment have been met. Those products developed or modified during the development process should be archived for subsequent re-use where appropriate. Lessons learned should be captured, and a final report produced.

The V&V process is an overlay over the whole of the above process, not something that is done at the end. Following the above process and learning from the experience outlined in Chapter 9 should ensure appropriate fitness for purpose and credibility, at an optimal cost and with minimum risk.

7.8.7 M&S Problems and How Best to Avoid Them

Various groups have, over the years, performed root cause analyses for problems with M&S across a wide number of domains, not just T&E. One example, given in [15] and Table 7-3, provides a typical ‘Top Ten’ list of reasons for M&S ‘unfitness’ for purpose.

Table 7-3: Top 10 Reasons for M&S 'Unfitness'.

1	People do not have enough relevant experience.
2	Evidence does not support a fitness argument.
3	Development process is wrong for the purpose.
4	Configuration management is unsuitable for the purpose.
5	Lack of recorded assumption information.
6	Data sets used in the model are inaccurate.
7	Incorrect level of modelling resolution.
8	People do not have enough training.
9	Data set is not coherent with the purpose.
10	Evidence of fitness is missing.

To elevate confidence in M&S and increase the probability of Fitness for Purpose and project success, the above can be turned into a list of recommendations. Maguire reported such a list, the QinetiQ 'Ten Commandments of M&S', see Table 7-4, and this is recommended to the reader. [15]

Table 7-4: Ten Commandments of M&S.

1	Understand the purpose of your model or simulation and re-check it often.
2	Train your people to the most appropriate level for their tasking.
3	Keep records of who did what and when.
4	Record your assumptions about reality and your model and simulation during its development.
5	Review the validity of your assumptions as development and use progresses.
6	Ensure data sets are valid, including input sets, testing sets and mathematical constants.
7	Carry out as much Validation and Verification as necessary.
8	Obtain independent checking and peer review of your work (if appropriate).
9	Collect, manage and maintain your evidence in a structured way.
10	Record system development in a Credibility Workbook.

The utility of M&S and SE to the EW T&E process can be greatly assisted by following best practice processes, such as those in the previous section, and being ever mindful of the above problem avoidance measures.

7.9 NATO MODELLING AND SIMULATION GROUP

7.9.1 Introduction

NATO RTO has a M&S Group, the NMSG, who are custodians of a wealth of information on the topic of M&S. The mission of the NMSG is to promote co-operation among Alliance bodies, NATO Member

Nations and Partners for Peace Nations to maximise the effective utilisation of M&S. They organise Symposia, Specialists Meetings, Workshops and Lecture Series on various aspects of M&S.

The interested reader is strongly recommended to visit their internet site at:

http://www.rta.nato.int/panel.asp?panel=MSG.

The remainder of this section provides top-level information on the NMSG from the above site.

7.9.2 NATO HLA Compliance Certification

The High Level Architecture (HLA) is the preferred Simulation Interoperability Standard recognised by NATO as early as 1998. HLA is an international standard as defined in IEEE and also STANAG 4603. To support proper use of HLA, the NMSG has established an HLA Compliance Certification Capability. This capability is distributed between NATO/PfP Nations and offered as a not for profit service to verify the capabilities of models and simulations relevant to being technically compliant with the HLA standard.

7.9.3 NATO Simulation Resource Library

The NATO Simulation Resource Library (NSRL) is a development tool provided by the NMSG and RTA to increase the reusability level of the simulation resources within the RTO community – registration via RTO Web Site.

7.9.4 NATO M&S Standards Sub-Group: MS3

The NMSG Sub-Group MS3 finalised the first edition of the Allied Publication entitled NATO M&S Standards Profile (NMSSP), AMSP-01. [16] This publication provides a comprehensive set of Standards that are applicable in the NATO M&S domain. The document was promulgated by the Director of NATO Standardisation Agency and is included in the NATO Standardisation Documentation Database.

The NMSSP aims to provide guidance to NATO and partner Nations, as well as national and NATO organisations who have requirements to effectively use M&S in support of NATO coalition and national requirements. It maintains information on M&S standards and recommended practices relevant to achieving M&S interoperability and re-use of M&S components, e.g., data, models. It provides a set of standards descriptions for decision making on options for the use of M&S standards for NATO activities, e.g., coalition training and experimentation.

7.10 INCREASED USE OF M&S THROUGH-LIFE

As noted in Chapter 6 and in this chapter's introduction, there is significant potential for greater use of M&S in the EW T&E process. Given the strides made to date in M&S and in the underpinning computing power increases of the last decade, this potential extends to cover the through-life case for EW and other systems. This potential for increased utility is depicted in Figure 7-5. Validated M&S, when used appropriately, can lead to reduced programme risk, schedule and cost.

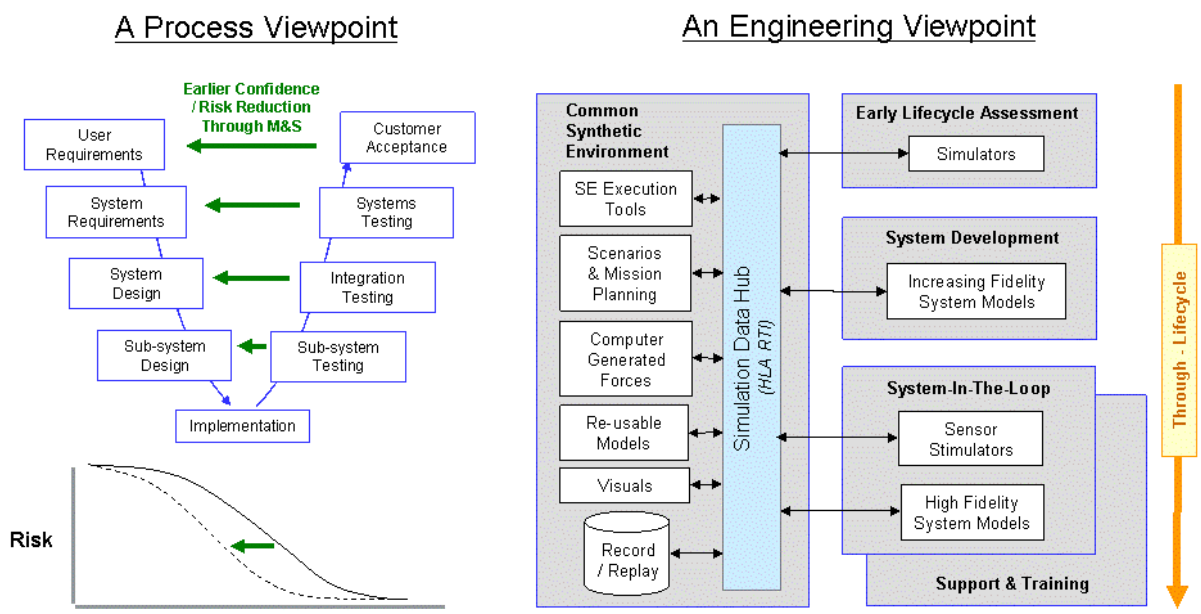

Figure 7-5: Increased Use of M&S Through-Life.

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7.12 FURTHER READING

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