NORTH ATLANTIC TREATY ORGANIZATION

SCIENCE AND TECHNOLOGY ORGANIZATION

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**STO TECHNICAL REPORT** **TR-HFM-216**

# Synthetic Environments for HSI Application, Assessment, and Improvement

## (Environnements synthétiques pour l'application, l'évaluation et l'amélioration de l'intégration homme-système)

This Report documents the findings of NATO HFM-216, and describes a modeling and simulation approach called Synthetic Environment for Assessment (SEA) that utilizes models and operators, working in a simulated environment, to measure system performance under targeted key perturbations.

Published June 2015

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# The NATO Science and Technology Organization

Science & Technology (S&T) in the NATO context is defined as the selective and rigorous generation and application of state-of-the-art, validated knowledge for defence and security purposes. S&T activities embrace scientific research, technology development, transition, application and field-testing, experimentation and a range of related scientific activities that include systems engineering, operational research and analysis, synthesis, integration and validation of knowledge derived through the scientific method.

In NATO, S&T is addressed using different business models, namely a collaborative business model where NATO provides a forum where NATO Nations and partner Nations elect to use their national resources to define, conduct and promote cooperative research and information exchange, and secondly an in-house delivery business model where S&T activities are conducted in a NATO dedicated executive body, having its own personnel, capabilities and infrastructure.

The mission of the NATO Science & Technology Organization (STO) is to help position the Nations' and NATO's S&T investments as a strategic enabler of the knowledge and technology advantage for the defence and security posture of NATO Nations and partner Nations, by conducting and promoting S&T activities that augment and leverage the capabilities and programmes of the Alliance, of the NATO Nations and the partner Nations, in support of NATO's objectives, and contributing to NATO's ability to enable and influence security and defence related capability development and threat mitigation in NATO Nations and partner Nations, in accordance with NATO policies.

The total spectrum of this collaborative effort is addressed by six Technical Panels who manage a wide range of scientific research activities, a Group specialising in modelling and simulation, plus a Committee dedicated to supporting the information management needs of the organization.

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These Panels and Group are the power-house of the collaborative model and are made up of national representatives as well as recognised world-class scientists, engineers and information specialists. In addition to providing critical technical oversight, they also provide a communication link to military users and other NATO bodies.

The scientific and technological work is carried out by Technical Teams, created under one or more of these eight bodies, for specific research activities which have a defined duration. These research activities can take a variety of forms, including Task Groups, Workshops, Symposia, Specialists' Meetings, Lecture Series and Technical Courses.



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# List of Acronyms

| | |
|---|---|
| ADIS | Armed Forces, DGA, Industry for Simulation |
| AMIE | Architecture Management Integration Environment |
| API | Application Programmer Interfaces |
| ASW | Anti-Submarine Warfare |
| C4I | Command, Control, Communications, Computers, & Intelligence |
| COMPACFLT | Commander, U.S. Pacific Fleet |
| DDG | A class of US Navy guided missile destroyer |
| DGA | Direction générale de l'armement |
| DODAF | Department Of Defense Architecture Framework |
| DOTMLPF | Doctrine Organisation Training Materiel Leadership and education Personnel Facilities |
| EADS | European Aeronautic Defence and Space |
| ERDC | (U.S. Army) Engineer Research and Development Center |
| ERS | Engineered Resilient Systems |
| FACT | Framework for Assessing Cost and Technology project |
| FISTFAC | Fleet Integrated Synthetic Training Facility |
| HBM | Human Behaviour Model |
| HPC | High Performance Computing |
| HSCB | Human, Social Cultural, Behavioral |
| HSI | Human Systems Integration |
| IBEO | Illustrateur de besoin d'exploitation opérationnelle |
| IRBA | French Armed Forces Biomedical Research Institute |
| LVC | Live, Virtual, Constructive |
| M&S | Modeling and Simulation |
| MCEL | Maritime Capability Evaluation Laboratory |
| MoD | Ministry of Defence |
| MODAF | (British) Ministry Of Defence Architecture Framework |
| MSG | Modelling and Simulation Group |
| NATO | North Atlantic Treaty Organization |
| RTG | Research Task Group |
| S&T | Science and Technology |
| SAF | Semi-Automated Forces |
| SAF | Semi-Autonomous Forces |
| SBA | Simulation-Based Acquisition |
| SEA | Synthetic Environment for Assessment |
| T&E | Test and Evaluation |
| VV&A | Verification, Validation, and Accreditation |
| vVic | Virtual Victoria |

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# Synthetic Environments for HSI Application, Assessment, and Improvement

## (STO-TR-HFM-216)

# Executive Summary

This report describes a modeling and simulation approach to experimentation that utilizes models and operators to measure system performance under targeted key perturbations. This approach, called Synthetic Environment for Assessment (SEA), is a new way to use simulation for conducting trade-off analyses and for exploring very complex design spaces. SEA has the potential to progress systems from simply sustaining incremental improvements in favor of disruptive innovation – exploring radically new ideas that change the rules of warfare and national defence. This is the goal of SEA at its highest level.

SEA provides a workable way to solve the practical problems involving the use of simulation in the capability development and procurement processes, but it also creates opportunities decision-makers have never had before. Calibrated scenarios from one lab can be used in another, resulting in data that can be fairly compared. Researchers can have realistic test environments available to test and compare theories of human performance in a variety of disciplines without having to expend precious resources learning the domain or building "throw away" simulations. Both researchers and acquisition professionals can explore a large number of potential solutions to hard problems using trade-off techniques for comparison. Most importantly, capability development and the rest of the procurement community can use SEA as a communication mechanism. For example, if capability development proposes that a new technology for the use of unmanned vehicles has a specific benefit, they could communicate this to acquisition through realistic combat scenarios within SEA.

This report presents a conceptual model of SEA that can be used to identify the key issues of concern. Use-cases were provided to show how SEA could be used with significant benefit to its user groups. Member Nation SEA activities are described, as were their usage similarities and differences. It was found that SEA, in form if not in name, is everywhere and what was missing was a unified attempt to bridge our terms and efforts in order to share experiences, technologies, and results. Thus, this report explored the descriptions of ongoing SEA activities to derive a detailed architecture for SEA that identifies resources, models and systems, input, outputs, and user communities resulting in the core technology areas within SEA and the unique technical barriers that need to be crossed to realize SEA in its fullest form.

# Environnements synthétiques pour l'application, l'évaluation et l'amélioration de l'intégration homme-système

## (STO-TR-HFM-216)

# Synthèse


Le présent rapport décrit une approche d'expérimentation qui passe par la modélisation et la simulation et utilise des modèles et des opérateurs pour mesurer le fonctionnement des systèmes dans le cadre de perturbations clés bien ciblées. Cette approche, appelée « environnement synthétique d'évaluation » (*SEA, Synthetic Environment for Assessment*), est une nouvelle manière d'utiliser la simulation pour réaliser des analyses de compromis et étudier des espaces de conception très complexes. Au lieu de soutenir les améliorations progressives des systèmes, le SEA pourrait favoriser l'innovation, en étudiant des idées totalement nouvelles qui changent les règles de la guerre et de la défense nationale. Tel est l'objectif du SEA à son niveau le plus élevé.

Le SEA est un moyen utile de résoudre les problèmes pratiques impliquant l'utilisation de la simulation dans les processus de développement et d'acquisition des capacités, mais il crée également des opportunités auxquelles les décideurs n'avaient jamais eu accès jusqu'alors. Les scénarios étalonnés dans un laboratoire peuvent être utilisés dans un autre, ce qui produit des données assez faciles à comparer. Les chercheurs peuvent disposer d'environnements d'essai réalistes pour tester et comparer les théories des performances humaines dans différentes disciplines sans avoir à utiliser de précieuses ressources pour apprendre le domaine ou construire des simulations à usage unique. Les chercheurs et les professionnels de l'acquisition peuvent étudier un grand nombre de solutions potentielles à des problèmes ardus en les comparant à l'aide de techniques de compromis. Le plus important est que la communauté de développement des capacités et le reste de la communauté d'acquisition peuvent employer le SEA comme mécanisme de communication. Par exemple, si la communauté de développement des capacités avance qu'une nouvelle technologie d'utilisation des véhicules sans pilote présente un avantage particulier, elle peut le faire savoir à la communauté d'acquisition au moyen de scénarios de combat réalistes au sein du SEA.

Le présent rapport expose un modèle conceptuel de SEA qui peut servir à identifier les questions clés. Des cas d'utilisation ont été fournis pour montrer comment utiliser le SEA pour le plus grand bénéfice de ses groupes d'utilisateurs. Les activités de SEA des pays membres sont décrites, ainsi que leurs ressemblances et leurs différences d'utilisation. Il a été conclu que dans la pratique, même s'il n'est pas désigné sous ce nom, le SEA est présent partout et qu'une tentative unifiée de rapprochement du vocabulaire et des travaux faisait défaut pour partager les expériences, les technologies et les résultats. Ce rapport a par conséquent étudié la description des activités de SEA en cours afin d'en déduire une architecture détaillée de SEA qui identifie les ressources, modèles et systèmes, entrées, sorties et communautés d'utilisateurs, ce qui indique les domaines technologiques centraux du SEA et les obstacles techniques uniques que nous devons surmonter pour réaliser pleinement le SEA.

# SYNTHETIC ENVIRONMENTS FOR HSI APPLICATION, ASSESSMENT, AND IMPROVEMENT

## 1.0 INTRODUCTION

As long as there have been models and simulations capable of reproducing complex task environments, there have been efforts to use synthetic environments for studying system performance.

The reasons for the use of synthetic environments vary across a number of critical user groups. We view SEA as the confluence of software, hardware, and context from users in a variety of roles (See Figure 1). The software component deals with models and simulations. The hardware component deals with computing, physical interfaces, and equipment. The human component deals with the different roles that people have in system design and the organisational responsibilities they represent. The NATO Modeling and Simulation (M&S) Master Plan (2012) identifies its stakeholders as:

- *Support to Operations,* which is responsible for decision-makers having access to capabilities required to decide on, initiate, sustain, and successfully conclude operations (e.g., organisations that define strategy, planning, and executing operations).
- *Capability Development,* which is responsible for the future preparation to foster continuous improvement of military capabilities in order to enhance the interoperability and effectiveness (e.g., organisations that perform doctrine validation, operational analysis in support of operational requirements definition and collection; research and technology; and concept development and experimentation).
- *Mission Rehearsal,* which is responsible for the preparation and rehearsal for a planned mission or course of action to reduce risk and surprise and to improve the knowledge and awareness of situations.
- *Training and Education,* which is responsible for collective training, individual education, exercises and training events.
- *Procurement*, which is responsible for the support of total lifecycle management of assets and systems including design risk reduction, test and evaluation.

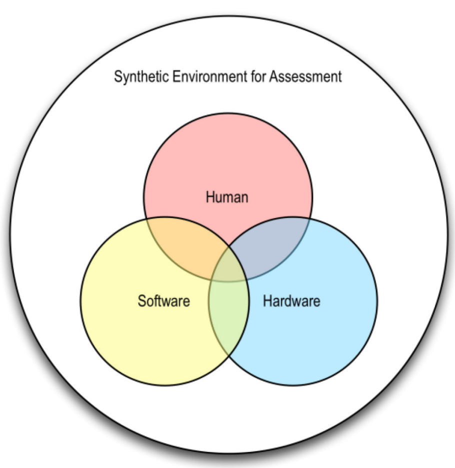


**Figure 1: SEA as the Confluence of Human, Software, and Hardware Components.**

Since every partner country has their own way of assigning roles and responsibilities, this paper will utilize the NATO Modeling and Simulation (M&S) Master Plan (2012) which identifies its stakeholders as:

- *Customers* that determine the operational needs for M&S capabilities;
- *Users* that demand M&S capabilities;
- *Suppliers* that develop M&S solutions or provide research in M&S;
- *Coordinators* that provide consistency between stakeholder groups; and
- *Advisors* that advise customers, users, and suppliers.

The NATO stakeholder groups are represented in most of the groups listed above as shown in Table 1.

**Table 1: Mapping NATO M&S Stakeholders to Organisational Responsibilities.**

| | *Support to Operations* | *Capability Development* | *Mission Rehearsal* | *Training and Education* | *Procurement* |
|---|---|---|---|---|---|
| Customers | x | x | x | x | x |
| Users | x | x | x | x | x |
| Suppliers | | x | | | x |
| Coordinators | x | x | | | x |
| Advisors | x | x | x | x | x |

Over time, the roles of the human, software, and hardware will change. Figure 1 suggests that they are equally important but this is unlikely to be the case, and it certainly will change throughout the lifecycle of any process. The role of the human is typically the most critical role (excepting perhaps a completely autonomous system) with software and hardware supporting the human in a variety of ways.

Researchers are interested in studying behavioral phenomena and testing theory. Acquisition professionals are interested in conducting cost-benefit analyses and comparing trade-offs against one another. Analysts might be interested in big-picture doctrine and policy issues. In all cases, there is a careful balance of realism against other factors in deciding what simulation to use and how to use it.

Thus far, this has been done in an ad hoc fashion with little thought to what we are balancing or how the different competing needs might be harnessed to produce *reusable* synthetic environments for assessment that fit more than one user group. Reusability is critical for two important reasons. First, reusability usually results in reduced development costs and reduced cost of ownership which increases opportunities for use over time. Second, reusability results in reduced variability in assessment because the reused models are reliable "constants" that allow increased confidence in measuring dependent variables. This report will explore these user groups, their applications, how they are similar and different, what our Alliance partners are doing that is related to these objectives, and how we might pursue the use of Synthetic Environments for Assessment (SEA) on a grand scale that could benefit the international community.

Nations represented on RTG HFM-216 have been working in the general area of SEA for many years, but seldom in such a close, coordinated fashion. Our goal was to explore how SEA is being used by our member countries, what methods they use, what applications spaces are being exploited, and how we might take the next steps towards a coordinated multi-country demonstration of SEA and its value to acquisition, science and technology, training, and operations.

### 1.1 Organisation of this Report

This report will begin with a discussion of Synthetic Environments for Assessment, what SEA is and what it is not, and how SEA compares to other related concepts. From this high-level description, we will present a coarse architecture of what SEA should be in terms of components and capabilities. We will then describe potential use-cases and ways to measure the utility of SEA. Next, the report will describe a number of SEA-like activities being pursued by our RTG Member Nations. We will highlight the similarities between these programs in an effort to derive a detailed architecture with technical requirements. This will allow us to link SEA to two other NATO activities that have much to contribute to the end goals of SEA. We conclude with a summary and recommendations for future NATO efforts in this area.

## 2.0 SYNTHETIC ENVIRONMENTS FOR ASSESSMENT

### 2.1 What is SEA?

The operational environment is becoming increasingly complex. While automation continues to be an important part of the solution, the role of human operators has never been more important. What we seek is a synergy of manpower and equipment resulting in optimal performance and readiness – but the complexity of the operational environment limits our ability to predict second or third order effects, and how our design decisions will impact performance. Current practice relies heavily on corporate knowledge, experience, physical prototypes, and intuition, resulting in a slow-paced evolutionary progress. Leap-ahead capability often eludes us because incremental improvements in system design are like hill climbing; every iteration is a little better than the last, but a limited perspective makes one unable to see the much larger hill nearby. It could also be argued that this evolutionary approach limits the ability for materiel developers to be strategic. The argument that we continue to fight the last war holds for our acquisition practices as well as our strategic thinking. SEA is a framework for the development of tools supporting *non-linear innovation*. Put another way, **SEA is meant to facilitate disruption and disruptive ideas** by providing a new way to explore unconventional designs. SEA is not a product, but rather an approach with a corresponding architecture to support a large ecosystem of components.

Warfighter needs are addressed by:

1) Requirements;
2) Science and Technology (S&T);
3) Materiel development; and
4) Procurement.

Each of these steps is meant to blend one into the other, leading to a validated and effective solution. However, requirements are often vague, poorly expressed, and sometimes are written to an already assumed "solution". In these cases, the requirement is written to a product rather than to a capability or a desired outcome. Capability development is not needed in every warfighter solution, but in cases where a technology gap exists to meet a desired goal, it is their responsibility to develop new products or knowledge to fill that gap so that a materiel solution can be developed. But S&T is often not warfighter scenario driven. Certainly, basic science should be given a pass on knowing exactly how it fits into future defence products, but as S&T becomes more applied and closer to transition to the materiel developer, it should be driven by valid warfighter scenarios and performance metrics that will tell us how good of a solution it is. Furthermore, procurement can often dictate the selected solution path regardless of the capability required or the "leap ahead" innovations available. Consequently, what happens too often is that S&T develops new concepts, processes, and capabilities that can't be procured or adopted to meet future needs.

What is needed is a way to close the gaps between these four critical groups. If S&T could look ahead to new potential conflicts, force structures, and constraints in a way that provided direct input to requirements, our ability to think and act strategically would be greatly enhanced. If S&T had calibrated scenarios and performance metrics that were developed and validated by the warfighter, they could use these to explore trade-offs in the design space that would result in more useful transitions to the acquisition community. Science and technology also needs a better way to communicate ideas, concepts, and proposed solutions to the materiel developer and the warfighter that are believable and testable. Otherwise, S&T has a tendency to oversell and the materiel developer, consequently, has a tendency to under believe. We need to close this gap so that S&T is consistently exploring ideas that are operationally credible and materially achievable.

Similarly, procurement needs calibrated scenarios and tools to assess competing designs throughout the procurement cycle, not only in the early phases when design decision are being made. Procurement also needs better ways to mitigate risk in their processes. This is achieved through continuous assessment of design alternatives, similar to what we believe SEA can provide. Training and education will look to evaluate trade-offs between training and other ways to improve overall system performance. They will also want to predict the training value of a proposed training system as well as assess the design of training assets. Lastly, Test and Evaluation (T&E) is about measurement and assessment. SEA provides inexpensive alternatives to T&E processes and should add value to live fire T&E because they can do more within SEA than they ever could using other types of simulation. In all of these cases, and for all of these user groups, we see SEA as a valuable alternative to "business as usual" that mitigates risk, explores more of the design space, and provide substantive data to decision-makers at the appropriate time.

## 2.2 A Working Definition

Our working definition of SEA is:

*A modeling and simulation approach to assessing human-system performance and trade-offs in representative mission scenarios.*

SEA allows a radical expansion in our ability to assess new alternative designs in the infinite design search space. Throughout the system acquisition cycle, SEA facilitates an expansion (as new ideas arise or new requirements are identified) and pruning (as decisions are made or priorities are set) of the design space. A list of trade-off domains could be presented in terms of DOTMLPF:

- ***D**octrine*: Can the problem be solved by a change in doctrine alone? Use SEA to explore changes in doctrine with measurable outcomes.
- ***O**rganisation*: Can the problem be solved by changing the organisational structure? Use SEA to explore how changes in organisational structure impact the same measurable outcomes.
- ***T**raining*: Can we train our people better as a way to solve the problem? Use SEA to explore if improved human performance will resolve the problem.

- *Materiel*: Can the problem be solved by an acquisition – a new device, platform, or improvement? This could be a better interface, automation, computation, improved sensors, or communications. Use SEA to insert these into operational scenarios and measure the same variable outcomes.
- *Leadership and Education*: Can the problem be solved by improved leadership or education (new knowledge)? Probably the most abstract use-case for SEA, but we could explore cause and effect of education on personnel, then apply it to an operational scenario provided by SEA.
- *Personnel*: Can the problem be solved by adding people or changing the people available? Use SEA to measure the effect of personnel changes on the operational scenario.
- *Facilities*: Can the problem be solved by adding or altering facilities? This can apply to materiel (facilities to acquire new systems) or training (new training facilities). Use SEA to determine if these improvements achieve measurable results that solve the problem.

All of these involve cost, but to optimize investment, we need to better understand how trade-offs between these competing designs impact overall system performance.

For many domains of interest, capability requirements shift far too fast to be addressed adequately by the conventional "research-design-build-test" cycle of development. For example, we might wish to know what the impact might be of a new capability on training, or team performance, or retention. When faced with a new unanticipated mission, how do we determine what new capabilities are required to meet published performance standards?

It may appear that these are the same questions that Simulation-Based Acquisition (SBA) was intended to address. SBA is described as a process enabled by robust, collaborative use of simulation technology that is integrated across the phases of the acquisition lifecycle. It is not specific to what technologies are used or how those technologies are connected. The "vision" of SBA was specifically to leverage simulation technology to improve the acquisition process.

SBA achieved limited success for a variety of reasons, most important among these being a failure to implement interoperability standards to meet specific SBA goals (as opposed to other modeling and simulation goals). SBA was successful in programs that had the capacity to develop their own systems to address their specific concerns. Smaller programs found little that could be reused or repurposed for their use.

SEA is unique in that it is an architecture that allows for interoperable models to be reconfigured in infinitely many ways to test any hypothesis or evaluate any design feature. Trade-off analysis should be far more reliable if models can be reused so that factors being held constant are really held constant.

SEA is a new approach that does not demand new technology. Little, if anything, is ground breaking in SEA *as a new technology*. What is new is the way SEA seeks to unify efforts through strategic architectures that encourage collaboration and reuse of data, software, models, metrics, scenarios, and analyses. This report will document several ways in which our international partners are accomplishing this.

## 2.3 SEA: A New Approach

SEA provides a cost-effective approach that focuses on reuse and validation. In Figure 2, the user input is really a need statement or question. These needs likely relate in some way to the DOTMLPF trade space we discussed in the previous section, but any question involving design to improve system performance would be relevant and appropriate. The user must also specify or characterize what a "good" solution looks like (assessment criteria).

How is it to be measured? This can be as vague as a heuristic, or as specific as a numeric measurable outcome – but it must be applied to outcomes for feedback to the decision-maker.

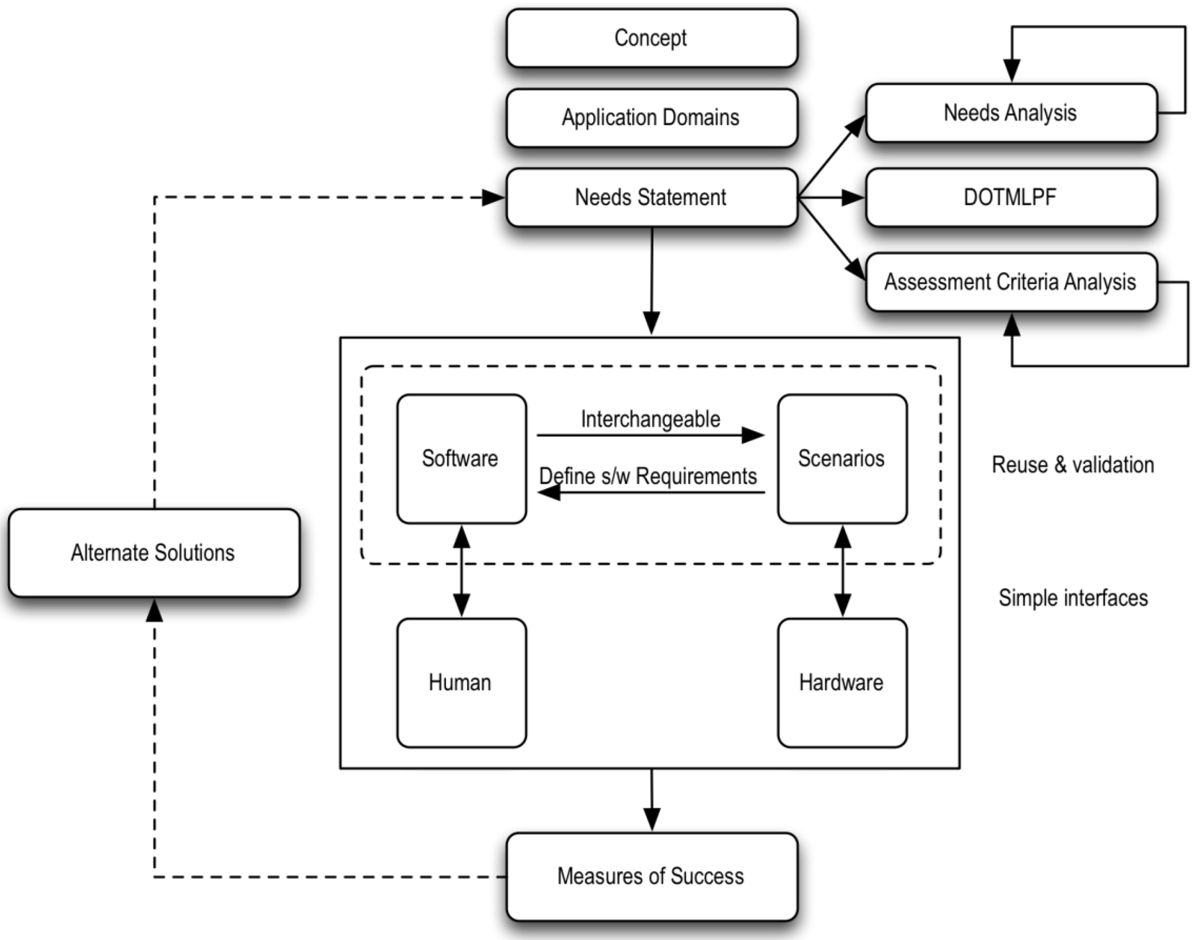


**Figure 2: A Schematic Diagram of SEA.**

Inside the SEA "box" we observe that there are four key elements of concern that work together in concert in a very flexible way. The two most flexible elements of SEA are software and scenarios:

- *Software* represents the independent modules that fit together to address a specific question or set of questions. Modularity and the use of data standards and protocols ensure maximal reuse. Software modules are interchangeable with validated scenarios. Figure 3 lists some of the types of software modules that SEA may contain.
- *Scenarios* represent a wide array of validated configurations that stress the appropriate points needed to produce results that the decision-maker can use. We want to examine the boundary conditions to determine where improvements can be found and what the costs are to develop those. Scenarios identify what software modules are needed. Figure 3 lists some of the variables that an SEA scenario might specify.

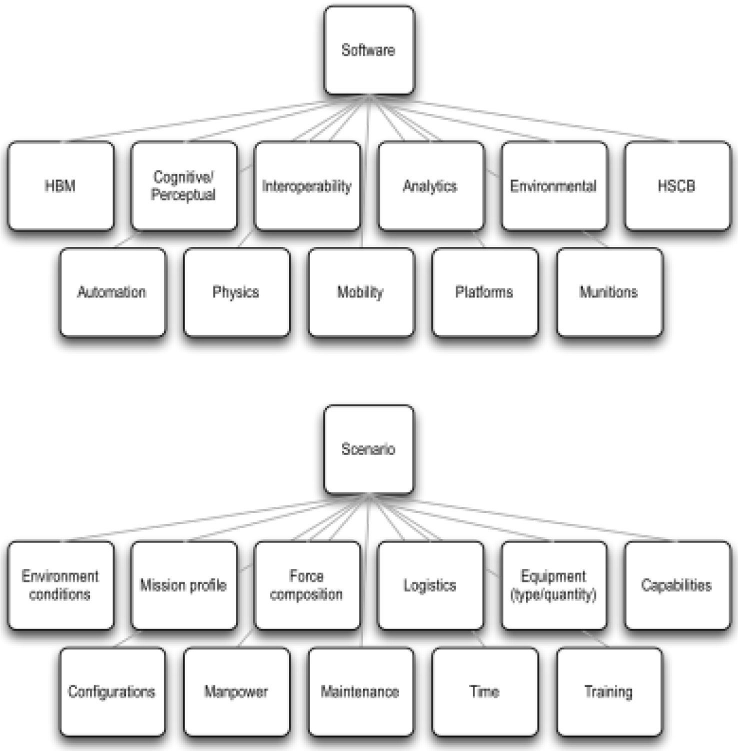


**Figure 3: Elements of Software and Scenario.**

SEA is not meant to be a closed-loop system. It is intended to incorporate humans in the loop as well as actual hardware systems and surrogate hardware mock-ups:

- *Human* represents individuals or teams of people interacting with the system. They may be operators of equipment, role players, instructors, or evaluators.
- *Hardware* represents actual systems or mock-ups meant to "stand in" for actual systems where necessary.

SEA requires standardized approaches to make all these parts fit together easily and in a predictable way.

The outcome is some measure of success as defined by the user input. These data points can be visualized or communicated in whatever way best helps the decision-maker to understand the trade space around the questions that we initially asked. We compare the output to what was described initially as a "good" solution.

## 2.4 A Conceptual Architecture

At a conceptual level, and without yet describing the detail of how SEA could be implemented, we refer back to Figure 2 above. Requirements from each of the domains (customers, users, suppliers, coordinators, or advisors within acquisition, training, or operations) drive the specifications of what the synthetic environment must support. The purpose of the SEA is to allow for data driven trade-off analyses in each of the areas described earlier. This is where science and technology becomes important; these trade-offs and the implications of design decisions are at the heart of what S&T contributes to the enterprise.

As we attempt to take the next step and define what the essential parts are that comprise SEA, we need to look through each of the primary domains as a lens. Each domain asks unique questions and demands unique answers. Expanding what we discussed in Figure 2, we now focus on three primary elements (see Figure 4):

- *Scenario* defines the inputs to the SEA that are enabled by the software. These are very different depending on what domain this is and what questions are being asked (see Figure 3).
- *Metrics* defines the outputs from the SEA. These are also dependent on the domain, but there is greater overlap here since the SEA is usually measuring some aspect of performance.
- *Method* is the way the SEA links inputs to outputs. The technical solution lives here. These are all the individual technologies (many from the M&S discipline) that are aggregated in unique ways to answer specific questions.

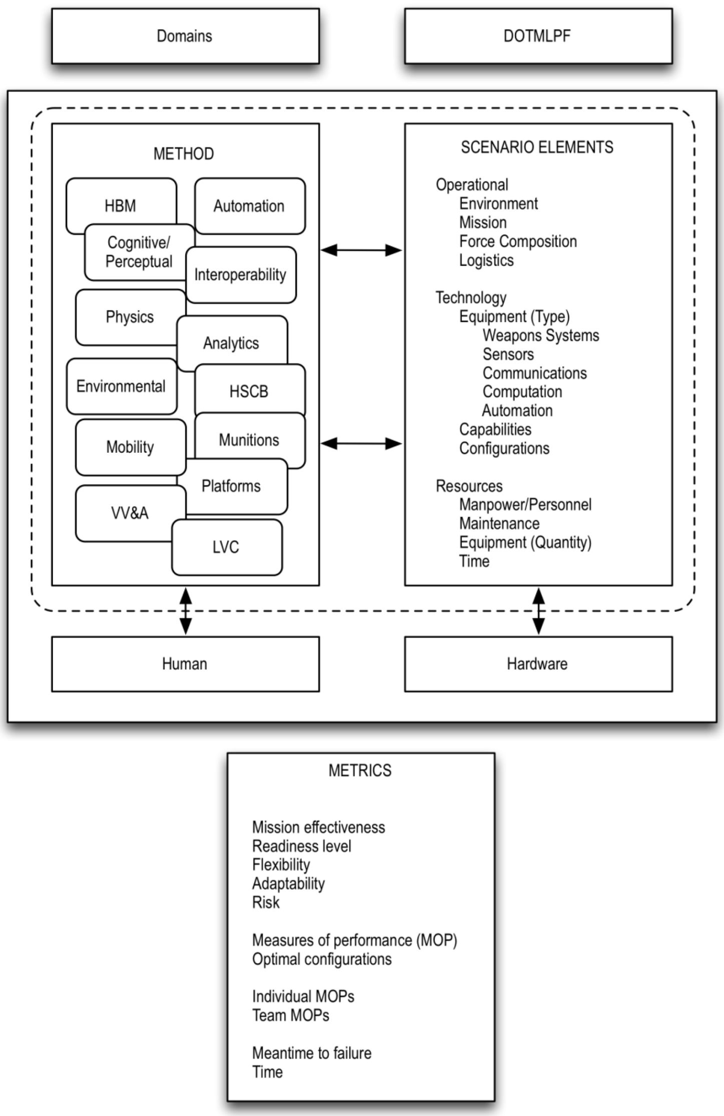


**Figure 4: A Conceptual Breakdown of SEA as Defined by Each of the Primary Domains.**

The procurement community is interested in technology or assets. Their scenarios would include different types of equipment, weapon systems, sensors, and communications. They may also experiment with capabilities that may not yet exist. For example, "What is the impact on effectiveness if this sensor had 10% greater range?" They may also study new configurations of existing equipment to determine if a new acquisition is even required. Here, metrics include measures of performance and risk reduction. Use-cases might include building confidence in radical designs through iterative test and evaluation, modular decomposition with test and evaluation, and cost-benefit analysis of competing designs.

Support of operations is interested in manpower issues. These too are addressed by SEA. Support of operations experimentation might involve altered manpower models, changing training requirements, and staffing procedures while measuring readiness as a dependent variable. Use-cases might include validating benchmarks with metrics, and blurring the distinction between training and operations, especially if SEA efficiently encompasses live training.

Test and evaluation examples abound within SEA. Almost everything SEA does has some component of test and evaluation embedded in it. If we consider the use of simulation as a precursor to live fire test and evaluation, we might use SEA to study the boundary conditions of the flight parameters of a proposed missile system, for example. SEA would also be used to "pre-test" live fire exercises to ensure that the operational plan and metrics will yield a result that answers the operational questions it was meant to address.

As a support function, science and technology touches all aspects of the other domains, but adds a number of distinct requirements specific to hypothesis testing, discovery, and transition to application. It is desirable to have "portable" SEAs with selectable fidelity, so that a facility in one location that might include high-end simulators, live equipment, and real operators, can be shared with another location that has only a network of laptops. SEA accomplishes this via its modular approach that separates each component into individual parts that may be modeled several different ways. For example, a sonar model at a facility with supercomputing capabilities might use a very high fidelity signal propagation model, while another facility would run a low fidelity abstraction on a laptop computer. This would not affect other aspects of the SEA, but may impact what questions can be studied at each facility.

To support the S&T community, we not only need easily distributable SEAs and component parts, but we need scenario authoring tools, model building, and theory testing capabilities. Also consider that S&T is inherently multi-disciplinary, so we cannot assume that everyone has programming skills readily available.

Of course, the boundaries between all these domains are "soft." In order to ask trade-off questions such as "What are the training implications of introducing this new weapon system?", we must look across two domains – procurement and training. This, again, is the power of SEA. In the past, that question likely would have been answered by two different communities using two different systems resulting in data that could not be compared fairly in order to make a decision. SEA would use the same simulation components to ensure that the analyst was able to make an "apples-to-apples" comparison (see Section 2.5).

Finally, the list of components that SEA must aggregate in order to connect the inputs to the outputs includes:

- *Physics*: At variable levels of fidelity, we need models to approximate physics – statics, dynamics, friction, deformable surfaces and materials, etc. – that can be coupled to visual models for analysis.
- *Environmental*: Models that represent weather, vegetation, soil types, and other environmental phenomena will be needed for many SEA analyses. Physics and environmental models are both a part of mobility models that are critical to vehicle analysis for question concerning how a specific vehicle will perform under certain conditions.

- *Platforms and Munitions*: These are the most obvious types of components that SEA will use, as they represent equipment that may be the focus of a test or evaluation, either in isolation or as a part of an aggregate system.
- *Automation*: Questions concerning what level of automation might be achievable, or what the impact of automation might be in a particular combat scenario demand models that accurately represent the automation itself.
- *Interoperability*: An essential ingredient that allows modules that may have been developed independently of one another to function together. Common data models are a key means to interoperability because they circumvent the use of Application Programmer Interfaces (APIs) which can be brittle. This also allows heavy leverage of ongoing work in the M&S community.
- *Artificial Intelligence (AI)*: We use this term very broadly to include all aspects of AI such as Human Behavior Models (HBM), Human, Social Cultural, Behavioral (HSCB) models, agent models, production systems, intelligent tutoring systems, etc.
- *Virtual Humans*: Any form of human model that could be anthropometric, cognitive, perceptual, physiological, etc., which is meant to simulate human capabilities for testing.
- *Analytics:* For large studies, the number of design permutations may be in the thousands or even higher. SEA requires ways to analyze and visualize the outputs so that the analyst can make sense of the data.
- *VV&A*: From the M&S community, VV&A is Verification, Validation, and Accreditation. Since SEA is made up of models, the validity of those models is key to the success of SEA as an approach. An important factor here is that, while we may be able to validate models A and B, when we aggregate A+B, we may not know if the aggregate model is valid as well.
- *LVC*: We use the idea of simulation components without stating what those components can be. They may be simulations of individual assets or personnel controlled by individuals (Virtual). They may be software simulations of individual assets or personnel controlled by a computer (Constructive), or they may be data feeds from personnel in a live exercise using real equipment (Live). This is why LVC is one of the other NATO focus areas of interest to SEA (see Section 5.1).

We do not claim that this list is complete. In fact, we are sure it is not. It is only meant to identify several fundamental technology areas on which SEA depends. More will be added as SEA continues to mature.

## 2.5 Use-Cases

Synthetic environments are used by a number of different groups for a number of different reasons. The one thing all uses have in common is that they are intended to determine some configuration, apparatus, policy, etc., that will optimize performance. In identifying who these groups are and what their needs are, we must first look at a simple model of the acquisition process (see Figure 5). While this is an illustration taken from the US Department of Defense, it generalizes functionally to international, industrial, or other applications.

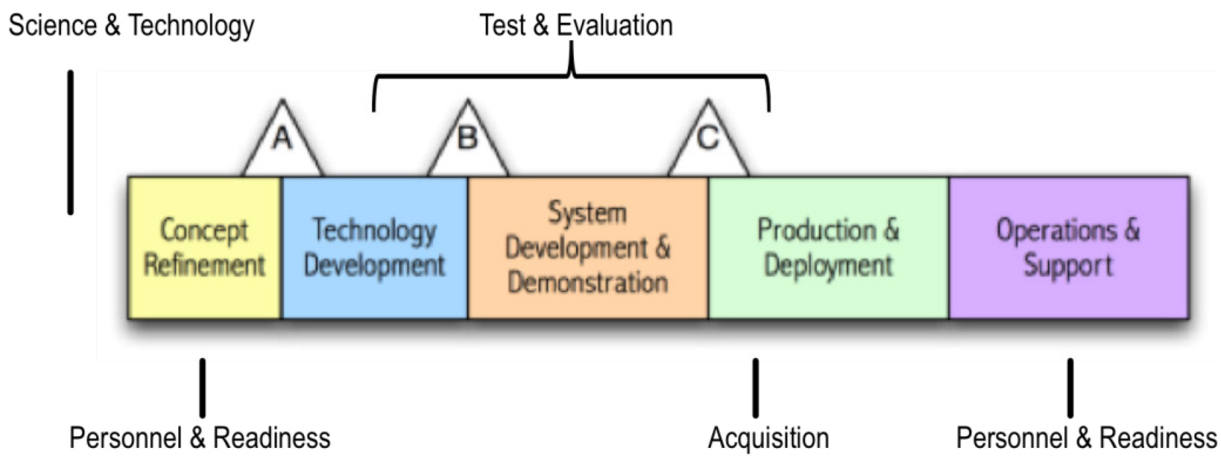


**Figure 5: Acquisition Cycle Phases and Milestones.**

The key parts of the cycle we are interested in are at the beginning of the process. While it may appear that the process is linear and sequential, in practice, it functions two ways. The first way is that a concept is identified, gaps are addressed, and the system is developed and deployed. In this case, requirements are often provided by the procurement process itself. However, the capabilities development community also develops new concepts independent of the procurement process. New concepts that may be completely disruptive to current doctrine or policy must be tested before being considered. The need to explore a complex design space is implied with the ability to test and evaluate plausible solutions for consideration. This procurement process and the many different perspectives it entails motivates the need for SEA.

Throughout the procurement process, SEA enables an expansion and pruning of design alternatives. In Figure 6, the green nodes represent active designs that are subsequently expanded; the red nodes represent designs that have been discarded (likely because they were found lacking in some way when the assessment criteria was applied); and finally, the yellow node represents the evolved "best" design for this need. Of course, it is never guaranteed to be the "best" design, but through the process, it is guaranteed to be better than its predecessors.

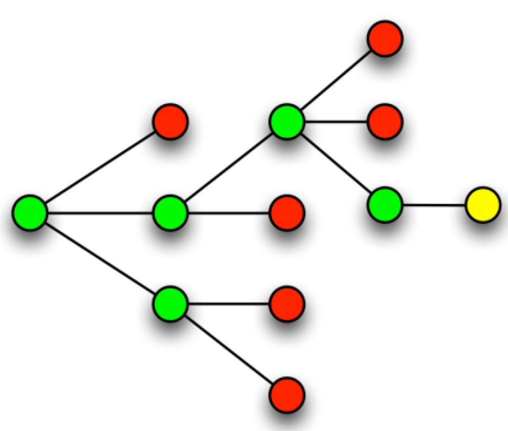

**Figure 6: Expanding and Pruning of Design Considerations Throughout the Process.**

**Table 2: SEA User Groups and Potential Use-Cases.**

<table>
<tr><th>User Groups</th><th>Application Domain</th><th>Uses</th></tr>
<tr><td rowspan="5">Customers<br>Users<br>Suppliers<br>Coordinators<br>Advisors</td><td>Support to Operations</td><td>Doctrine analysis<br>Testing new organisational structures</td></tr>
<tr><td>Capability Development</td><td>Doctrine validation, Operational analysis, Operational requirements definition, Research and technology, Concept development and experimentation</td></tr>
<tr><td>Mission Rehearsal</td><td>Mission planning<br>Risk identification<br>Trust building</td></tr>
<tr><td>Training and Education</td><td>Plan and conduct training</td></tr>
<tr><td>Procurement</td><td>Design risk reduction<br>Test and Evaluation</td></tr>
</table>

### 2.5.1 Capability Development

Within capability development, one of the most common uses for SEA is in hypothesis testing and discovery. When a theory is proposed, often the most plausible way to test it is through a simulation, especially when the real-world task is too expensive, too dangerous, too inaccessible, or too complex for practical use. However, this immediately creates a natural friction between realism and control.

The conundrum lies in the fact that real-world tasks are often too complex to yield definitive results from experimentation. Yet simplification of the task for laboratory study is often criticized as not real or too sanitized to be believed. What is a researcher to do? We often create simulated environments that mimic real tasks, albeit at lower fidelity. But how does the researcher validate the task set and environment, even under limited realism conditions?

Because SEA is a collection of simulation components, each of which models some aspect of a situation of concern, it offers experimental opportunities not possible in the real world because we are able to isolate components for study. The conventional scientific method calls for theory to be validated via hypothesis testing that requires that a set of dependent variables be measured against a set of independent variables. In HSI, for example, this is often an empirical study with human subjects. What SEA facilitates is the use of a modified scientific method where simulation is used preceding live tests as a more cost effective and rapid way of exploring more combinations of dependent and independent variables. Then, we take good options and explore these in more detail with more expensive live tests.

In Figure 7, conventional experimentation tests a hypothesis by measuring dependent variables as independent variables are manipulated. What simulation has enabled is the use of simulation as the test environment. While this isn't unique to SEA, what is important is that SEA allows a researcher to manipulate a single component (for example, a display interface or a sensor), measure the effect on performance, and then iterate. More importantly, the iteration can be done in more than one laboratory and we can compare results because the SEA was the same – the simulation components were the same and operational scenarios were the same.

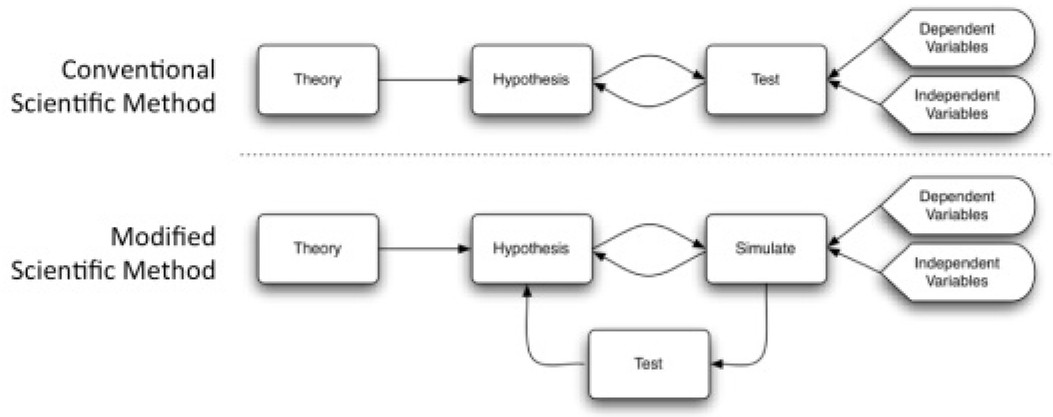


**Figure 7: A Modified Scientific Method Enabled by Simulation.**

### 2.5.2 Procurement and Analysis

One of the key assumptions driving the requirement for SEA is that design spaces are becoming more complex and our ability to explore them is not improving at a reasonable pace. The only way this can be addressed and managed is if SEAs are rapidly reconfigurable and if searches into large portions of the design space can be automated, or semi-automated. There is precedent for this idea: the FACT program (US Marine Corps) is an online tool supporting acquisition that does automated assessments within certain parameters and reports the "best fit" outcomes that can then be independently analyzed. Other systems also facilitate some sort of "Monte Carlo" technique for pseudo-randomly exploring design alternatives for "goodness of fit." However, these are systems, not architectures, and consequently they do not help us when we change domains or organisations.

A conceptual solution (see Figure 8) is to start with an architectural framework (DODAF, MODAF or some other tool might be useful but are certainly not the only tools that fit this description) that allows for functional decomposition of a complex problem space. This is a "model" of the problem with appropriate metrics that will allow us to assess design alternatives. The functional decomposition would then be used to select an appropriate set of simulation modules which, when configured, accurately represent the model. At this point, the SEA applies the metrics to each proposed solution and visualizes the results. Constraints can then be applied and the process iterates to produce more solutions for consideration.

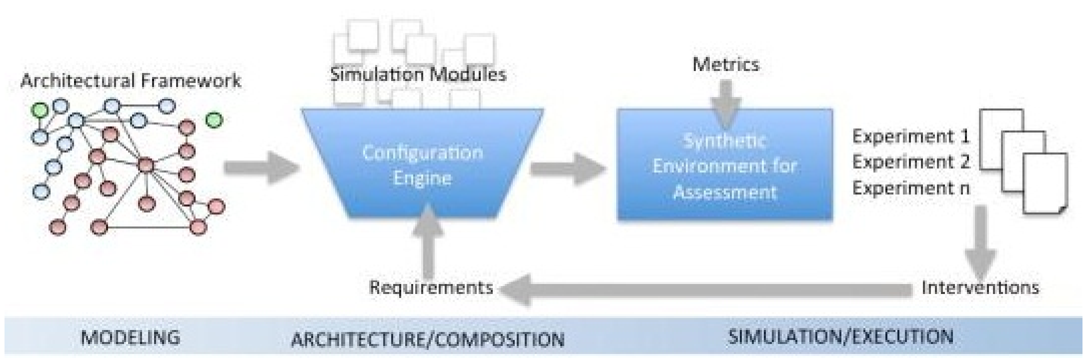


**Figure 8: Simple Model of SEA Use in a Conventional System Engineering Process.**

For a more concrete example, consider the case shown in Figure 9. This is an anti-submarine warfare scenario. Note that the SEA is a set of independent models (submarine, towed array, SH-60, dipping sonars, DDG, sonar operator) that communicate through a centralized common data model (1). The scenario (2) is a validated scenario that allows for the testing of performance under realistic operational conditions.

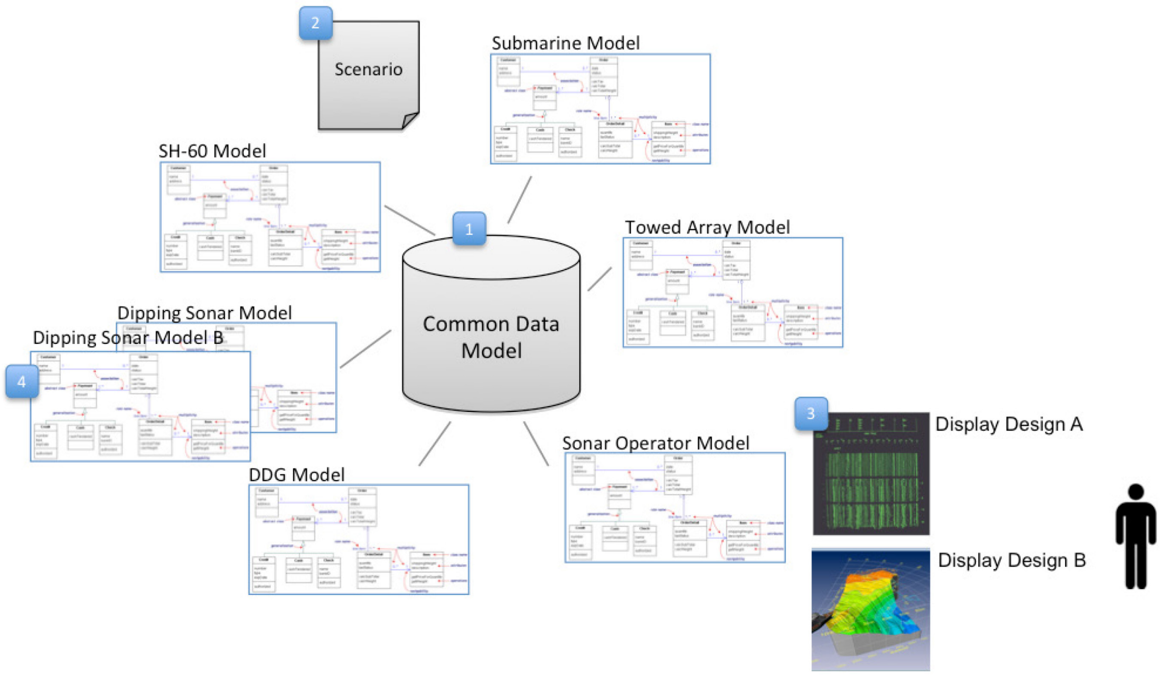


**Figure 9: A Detailed Use-Case for SEA in an ASW Application.**

The first question we want to ask with this SEA is, “Which results in a better probability of detection, Display Design A or Display Design B?” (3). We obtain a suitable user group and test performance on measures related to probability of detection based on the given scenario. One of the designs should emerge as the better of the two, but it likely has a price tag associated with it so a decision will have to be made as to whether or not the improvement is worth the cost.

But we could ask a different, albeit related question that focuses on an immediate solution decision. There is a vendor who claims their dipping sonar sensor is 15% better than the one we are currently using. What if we want to know “Which results in better probability of detection, a new dipping sonar sensor or improved operator display?”. We need to hold everything else constant and compare performance using the same user groups against the same scenario, but now we will test the two sonar models (4) against the displays (3). The resulting performance data will allow the decision-maker to fairly compare the improvements of each alternative, taking into consideration its respective cost. This is what acquisition managers and analysts need.

## 2.6 SEA Performance Metrics

These use-cases illustrate the immediate and long-term impact of SEA. However, we still need to understand how to measure the added value of SEA as compared to today’s best practices. A reasonable initial set of criteria for SEA would include:

- Measurable reduction in cost and time associated with the use of simulation in assessment;
- Measurable reduction in overall lifecycle costs;
- Direct linkage from SEA scenarios to operational tasks and mission effectiveness metrics;
- Calibrated performance metrics with actual operators;
- Distributable to a broad community (capability development, procurement, analysis); and
- Variable fidelity as required by the problem set.

Not all of these are easy to measure, but they highlight the areas where SEA is expected to have the greatest impact.

## 2.7 Manage Risk, Increase Trust

At the onset of a program, we assume a design meets stated requirements, the technology gap is eliminated through the use of up-to-date products and trust (or confidence) on the part of program management that the product will meet stated goals is high (see Figure 10). As the program moves into development and deployment (Milestone B and beyond in Figure 5), the design inevitably falls out of step with reality. Requirements change, budgets change, and schedules change, all of which require modifications to the program execution plan and design. The further along in the cycle, the more expensive the change and the lower the trust in management that the change will not adversely impact the entire program (or at least that the impact is known). If SEA were used throughout the program lifecycle, design trade-offs could be analyzed constantly. The objective is to raise trust in management while lowing costs and consequently making it easier to close the technology gap throughout program execution, not just at the onset.

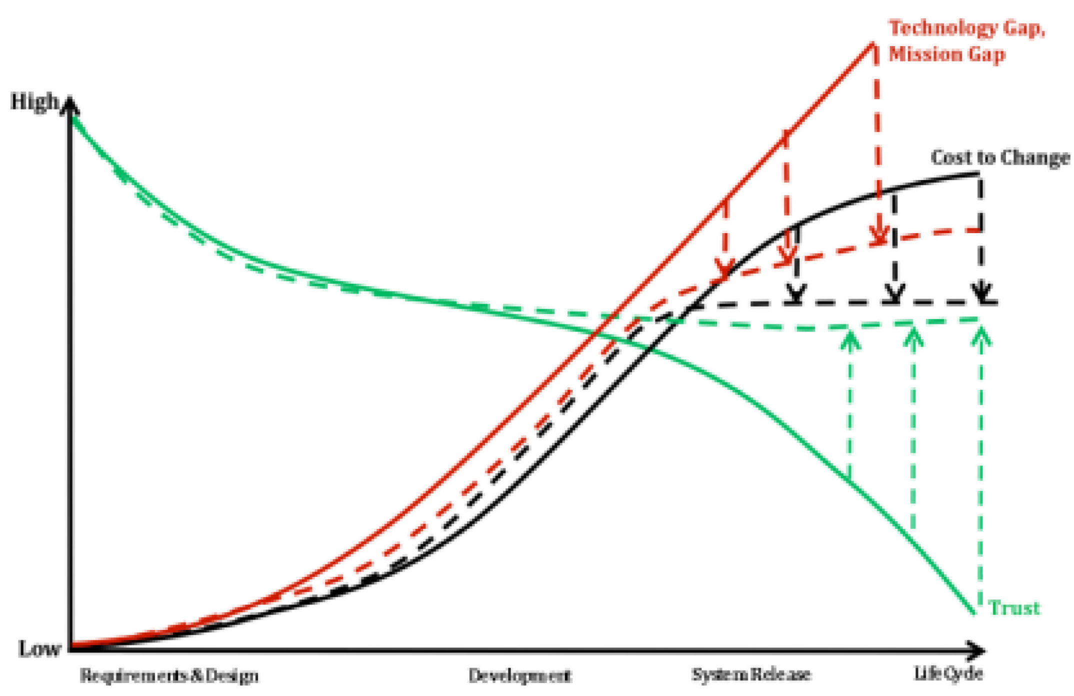


**Figure 10: SEA Closes Gaps in Technology, Costs, and Trust.**

Furthermore, this same methodology is useful when capability development explores new, disruptive concepts. If capability development wants to explore a concept that radically alters force structures or the use of limited assets, SEA will be the way that this will be explained to decision-makers and materiel developers. It will also be how measurable benefits of the new approach will be evaluated and compared against competing solutions. This is currently most often done via presentation and notional data; consequently, these critical decisions are made based on instinct rather than good data.

# 3.0 CORE COMPONENTS AND REFERENCE ARCHITECTURE

How do our initial ideas about what SEA is and how it should be implemented (see Section 2.4) match up to what our NATO members are doing? We'll first identify common elements and components and then put the parts together into a reference architecture that can be useful in thinking about an international SEA capability to be shared by all.

## 3.1 Common Components, Unique Components

We reviewed each of the summaries of SEA efforts for each of our NATO members to identify common elements. Since there currently are no shared efforts among the members, we had to allow for a broad definition of components in terms of their function, not their implementations, which are certainly different. Table 3 shows the results of that comparison.

**Table 3: Common Elements Among NATO Members SEA Efforts.**

| Core Elements | Germany | Canada | France | UK | Netherlands | USA |
|---|---|---|---|---|---|---|
| Multiple User Communities | x | x | x | x | x | x |
| Human Models | x | | x | x | x | x |
| Model Aggregation | x | | | x | | x |
| LVC | x | | | x | x | x |
| External Data Sources | x | x | x | x | x | x |
| HPC | | | | | | x |
| Architectural Framework | | | | x | | x |
| Common Data / Backplane | | | | x | | x |
| Physical Mock-ups | x | x | x | | x | |
| Full Simulation Integration | x | x | x | x | x | x |
| Extensible Computing | | x | x | | | |
| Visualization of Results | x | | x | x | x | x |
| Reusable Models | x | | | x | | x |

All countries, in some fashion, were addressing multiple user communities in their efforts. The most common "customer" was the acquisition community, but training was also typically included. Not every Nation has as robust of an S&T community as the US, so much of that work was unique to the US.

Most countries also had some notion of a human model – both at the individual and group levels. Germany had the most sophisticated work in human modeling that we observed, but France was very detailed in the specific areas of concern to their work (cognitive and perceptual).

We considered a very loose definition of model aggregation, which would be the use of multiple sub-models to make a bigger, more complex model. Not every country was using these types of models.

LVC is another area that is more common than we anticipated it to be. Most countries have some form of LVC in use within their SEA efforts. Even Canada has virtual and constructive simulators in use in their vVic system.

All countries facilitate the use of external data sources in their models and simulations. That data could come from any number of sources, from static databases, to live data feeds, to high performance computing.

Only the US highlighted the use of HPC in the ERS initiative, but it was apparent that the Canada, Germany and the UK are all planning for HPC in the future (if they aren't doing so already).

The UK and US are the only countries currently using architectural frameworks to statically define systems before they even build the simulator. The UK and the US are also the only two countries with plans or efforts to synchronize multiple models, simulators, and data sources via some sort of common data model or "backplane" as it is called in the AMIE program in the US.

Many efforts use physical mock-ups, and Canada is a leader in this area. All countries allow for the integration of full simulators in their SEA work. Full simulator integration is the obvious precursor to model integration.

Both Canada and France have constructed architectures that allow for easily scalable computing capabilities. They add computation by adding servers, without the need for system integration.

There was some form of results visualization for all countries, but clearly some are ahead of others. We'll point out the work in Germany and the UK in this area.

Finally, there are hints of reusable modeling efforts everywhere, but only Germany, the UK and the US have efforts underway that touch on this capability, which most of us feel is central to the SEA concept.

## 3.2 A Reference Architecture for SEA

Now that we know what is common to all the efforts described in this report, we can attempt to further refine the very coarse architectural model proposed in Section 2.4 into something that might be implemented.

Figure 11 shows the model we have created based on all the inputs we received from RTG HFM-216 members. We divided it into six categories:

- *Resources* are the external resources that are probably not even meant specifically for SEA that can be integrated as needed – we include architectural frameworks here as well as HPC and other data sources, be they static or dynamic.

- *Models and Systems* are the individual systems (could be actual fielded hardware), constructive simulators, live data feeds, virtual simulators (either whole systems or those built from components), virtual humans, and cost models.
- *Common Data/Backplane* is the very important mechanism for allowing models to interoperate at the model level. Recall that this is what AMIE is attempting to do. It facilitates reuse and aggregation, both of which are essential features of SEA.
- *Inputs* refers to calibrated scenarios and metrics. Users need to supply both of these. Scenarios can focus on capability gaps, novel concept exploration, equipment testing, comparative analysis, or any of the other objects we have discussed in this report. Metrics directly tie into the outputs since they specify what will be captured and reported.
- *Outputs* are the results as specified by the metric inputs, but also include visualization of results for sense making, and then finally decision support tools to aid the decision-maker in understanding trade-offs and their implications.
- *User Communities* are the different user groups that SEA is meant to serve. We add these just to remind us that each community has different needs that SEA needs to accommodate. SEA will not be successful unless all of these communities find value in it.

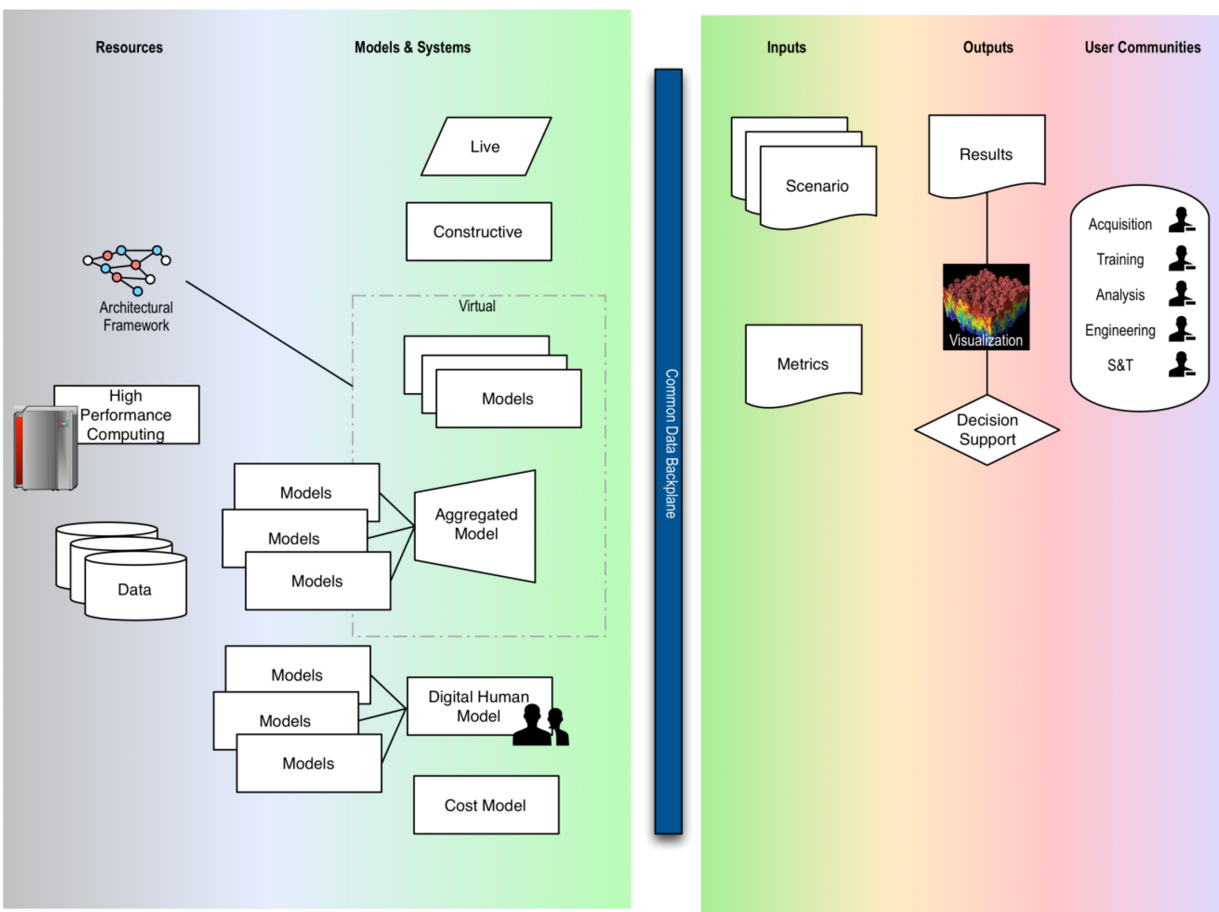


**Figure 11: A Detailed Architectural Model for SEA.**

Architectures are about how the pieces fit together. For complex software systems like SEA, they are about protocols, data models, file formats, and service contracts. We made the statement earlier in this report that there was very little in SEA that was ground breaking, *as a new technology*. It is the architecture that is new, which is driven by a novel way of thinking about the use of simulation to explore complex design spaces for a variety of purposes. Below is a partial list of existing technologies on which SEA depends:

- Common data models;
- Interoperability protocols;
- VV&A;
- LVC;
- Cost modelling;
- HPC;
- Authoring/modding tools;
- Architectural frameworks;
- Data visualization; and
- Decision support tools.

Each of these is and has been a major worldwide science and technology investment for a number of years. SEA seeks to leverage that investment in new ways to build simulation environments that have unprecedented flexibility, agility, and robustness.

## 3.3 Technical Requirements

Making the statement that SEA doesn't need to invent any key technologies in order to be successful does not imply that all of these technologies are at the necessary level of maturity or are ready to perform their duty in an SEA today. We list below some of these areas and our ideas for improvement needed in order to make SEA function the way we envision:

- *Common Data Models*: The work done in the M&S community is excellent, but SEA may require dynamic extensibility of models given the breadth of problem spaces it will operate within. For example, a simulation typically needs to be aware of everything that can possibly occur at runtime. What if it could learn about new assets, events, and capabilities on the fly?
- *Interoperability Protocols*: This is fairly robust but, for example, the shortcomings of HLA have been well documented. That is not to say that HLA has no place in SEA, but rather that new protocols (also dynamic if possible) may be needed.
- *VV&A*: We gave an example earlier where a validated Model A is aggregated with a validated Model B. What do we know about the new Model A+B? Is it valid?
- *LVC*: This is one of the areas where SEA will leverage another RTG (HFM-221). Synchronization issues are key to LVC. Also, SEA allows for the use of multi-resolution models, from high fidelity to low depending on application and available resources. Live is the ultimate fidelity and should be considered another model in the SEA framework.
- *Authoring/Modification Tools*: Many of the analysts who need SEA do not have programming skills yet they need to be able to carefully craft scenarios to suit their purposes. In gaming, modding tools are

becoming more sophisticated, but in M&S, we are lagging behind. This is an area ready for significant improvement.

- *Architectural Frameworks*: These are "languages" that allow one to fully describe an application or system in documentation before it is prototyped or built. What we'd like is a way to go directly from the description language into an executable environment for testing. Some aspects of this capability exist now.
- *Data Visualization*: As sophisticated as data visualization is today, there is always room for advancements. The types of data we expect to result from SEA explorations of complex design spaces are unknown. We don't know what they look like or how we will view them to find the best candidate designs.
- *Decision Support Tools*: Once we have ways to look at the data to help us understand it, we next need these to be integrated into tools that help the analyst make a decision that could involve a very large investment. "What if" games might be useful here to allow the analyst to play with the variables, possibly including multiple forms of sensitivity analysis.

## 4.0 RTG HFM-216 MEMBER SEA ACTIVITIES

In this section, we will briefly describe the SEA activities ongoing in each of the RTG HFM-216 Member Nations. The discussion will focus on application domains, architecture, and possible relationships to other projects, either within that Nation or with other partners.

### 4.1 Canada

Defence Research and Development Canada discussed the Virtual VICTORIA (vVic) project and the Maritime Capability Evaluation Laboratory (MCEL). This is an interesting case for SEA because the objectives of the program are very SEA-related, but they are currently leveraging extensive use of physical mock-ups and prototypes. They see an increased use of simulations for assessment, but it would likely be integrated into their efforts with physical prototypes given their investment in this area.

The vVic project uses a plywood submarine mock-up fitted with video games to assess user interface options. In Figure 12, the physical mock-up shows a series of consoles each running a version of the "Dangerous Waters" video game[1]. In the bigger picture, the MCEL is intended to include two reconfigurable spaces for vVic-types of projects. All of this work is for measuring team performance.

[1] http://www.sonalystscombatsims.com/dangerous_waters/.

Figure 12: The Physical Mock-Ups Used in vVic.

Architecturally, they use virtual machines and off-the-shelf workstations for their hardware to reduce costs. The schematic in Figure 13 shows that any set of devices (which could be anything from a video game workstation to a handheld device) can be connected to the network and be driven by their compute servers that run specific models as needed. This approach simplifies their configuration management but does present some limitations in what they can exercise. They archive all data and can scale to any size event just be adding more devices or servers.

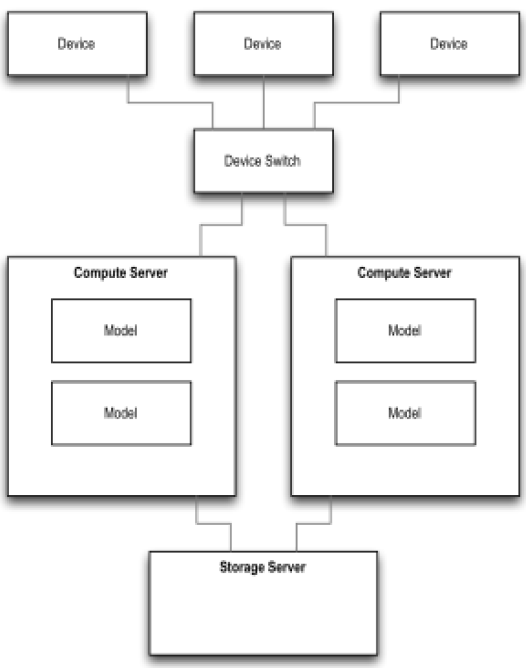


Figure 13: A Simple Schematic of the Key Components Planned for MCEL.

The uses cases for MCEL are exactly what SEA is meant to address – testing system interoperability, integration, performance, demonstrate new technology, measure operator performance and team performance, and test the experimentation process. It allows them to “go to sea” before they go to sea.

## 4.2 France

The French Armed Forces Biomedical Research Institute (IRBA) has a number of human factors projects utilizing synthetic environments. Some are interested in perception (sensor vision, 3D vision, 3D sound, multi-sensory perception), while others are using Force simulations to focus on psycho-ergonomics dimensions (stress management, mindfulness, crew work). A basic concept behind SEA, lowered costs through modular design, would be helpful in designing future studies in a controlled and realistic synthetic environment.

With the quickening evolution of technology, the needs for military simulation in training have changed. There has been a shift from models to drive complex systems (aircraft, ship, etc.) to using tactical training in distributed simulated environments. This evolution has been mainly driven by the need of the French Army (Armée de Terre) who, for most training situations, do not need the same high-cost simulators and high degree of realism required by the Air Force (Armée de l’Air). The Army wants low-cost devices to train basic tactical team skills. These low-cost simulators change the economic policy of simulation and push to industrial partners to optimize the techniques and dependences to fit the Force’s need. Today, distributed simulation has expanded thinking in terms of autonomous simulation capabilities with modular architecture, and highlights the problem of data governance. Compared with other Forces, the French Army is well ahead in its use of distributed simulation with reusable modules. This evolution to a tactical level of simulation with many different entities permits training many users in large exercises, utilizing multiple sites with multiple platforms in a joint or multi-national exercise. These exercises can use real and simulated entities and IA. Simulations no longer stand alone. The French Army seeks to develop centralized, basic shared data for simulations and to expand that into an architecture for all defence simulations, both internal and shared with Allies.

The evolution of simulation in French Defence was assisted by ADIS, a group formed in 1994. ADIS is a French corporate organisation gathering the Armed Forces, DGA (the MoD Procurement Agency) and the Defence industry in order to promote, explain and facilitate the use of simulation for the benefit of the French Defence community. This group is governed according to an organisational charter approved by the DGA and the Armed Forces. The goal is also to improve the interoperability of simulation applications and tools, as well as the reuse of simulation components.

The global factors that drive architecture of simulation in French Defence have to be taken into account at the level of basic synthetic environment questions. In design, using simulation (synthetic environment) is used extensively in industry. For HMI design in defence, DGA has developed platforms to help operational users define the technology they want to use tomorrow. IBEO (Illustrateur de Besoin d’Exploitation Opérationnelle) are platforms that are developed to specify and assess new tools, new HMI and new work organisation. These platforms are a part of a more global human centered design approach performed at the DGA.

For example, the process applied to the IBEO “Military Integrated Bridge System” for the French Navy was as follows:

- **Goal**: The Navy needs to reduce the number of people on warships.
- **First Step**: Analyze the present situation and define human-machine function allocation.
- **Second Step**: Conduct task modeling to define work organisation and user roles.
- **Third Step**: Simulate different tasks, devices, and work organisation in a realistic scenario.

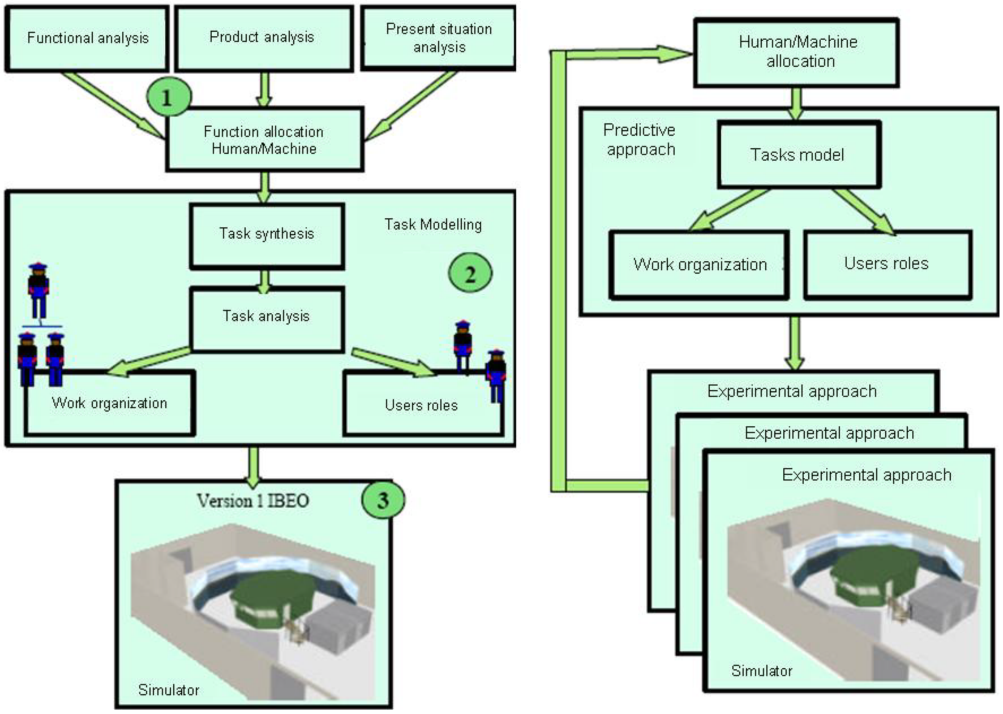


**Figure 14: An Example of this Process Applied to Ship Design. (Adapted from Pellen-Blin, Bry and Chouvy, DGA)**

This method is based on user-centered design and is intended to be iterative and assess solutions in realistic scenarios. Assessment is based on system performance, user collaboration, communications, attention, workload, or whatever is appropriate to the scenario. Moreover, this methodology can facilitate new ideas as they emerge.

Whether the focus is on research, training or design, assessment of the use of synthetic environments is needed to adapt simulation to the human and improve performance.

## 4.3 Germany

Fraunhofer FKIE has a number of related projects on the use of modeling and simulation for human-systems integration that are very closely aligned with SEA concepts. There is a specific focus on soldier modernization and core support for the warfighter. Topics related to readiness, C4I, mobility, survivability, and sustainability are of interest. They use a spectrum of simulation products ranging from low realism, high variability (like constructive simulations) to high realism and low variability (like live exercises) to address these topics.

Key modeling and simulation topics in support of these efforts include virtual human modeling, information visualization, game technologies, and authoring tools. A notional architecture is presented in Figure 15. The digital human can be considered the centerpiece since this is about HSI. It needs to be capable of supporting ergonomic as well as performance studies. Weapons, armor, and other equipment are modeled and integrated with the digital human as required by specific scenarios. Ergonomic studies might include interior designs of candidate vehicles for testing. They include extensive use of constructive simulations and SAFs for simulation support for their scenarios. Finally, they use visualization as a key part of understanding the massive data that their studies generate in order to make effective decisions.

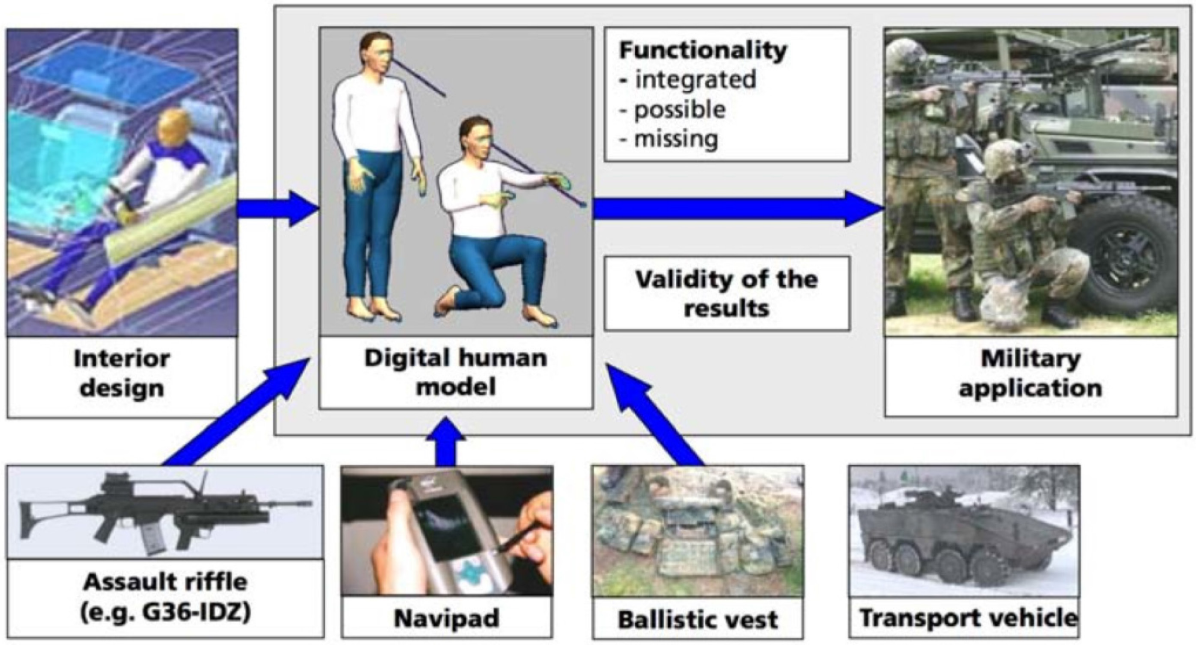


**Figure 15: A Simple Schematic Diagram of the Fraunhofer Efforts.**

Germany uses simulation as far as they can, but relies on field testing for final evaluation. This is similar to what we saw with most member countries. They also see agent technology and human behavior modeling as a fundamental enabler to how they will use simulation in the future for SEA like activities.

## 4.4 Netherlands

There are several SEA-related efforts underway in the Netherlands. One of these involves the use of simulation in the development and maturation of complex concepts. These types of activities overlap well with the domains outlined earlier for SEA – specifically acquisition as in assessing new weapons concepts, doctrine analysis as in assessing the effectiveness of a new missile define approach, and organisational analysis as in assessing the effectiveness of command leadership organisation. In all of these cases, they use these techniques to experiment, assess, and to iterate their ideas towards a more mature concept that can be developed and deployed.

They seek to meld the operational and scientific communities in a shared virtual workspace that creates a vision, provides a framework for experimentation and subsequent exchange of ideas, and then revision of ideas. The solution is not purely technological, however. They use a mix of conventional workshops for brainstorming and idea generation, but then they also use table-top gaming and simulations to experience the concept in order to understand its capabilities and limitations.

Figure 16: Table-Top Gaming and Exercises.

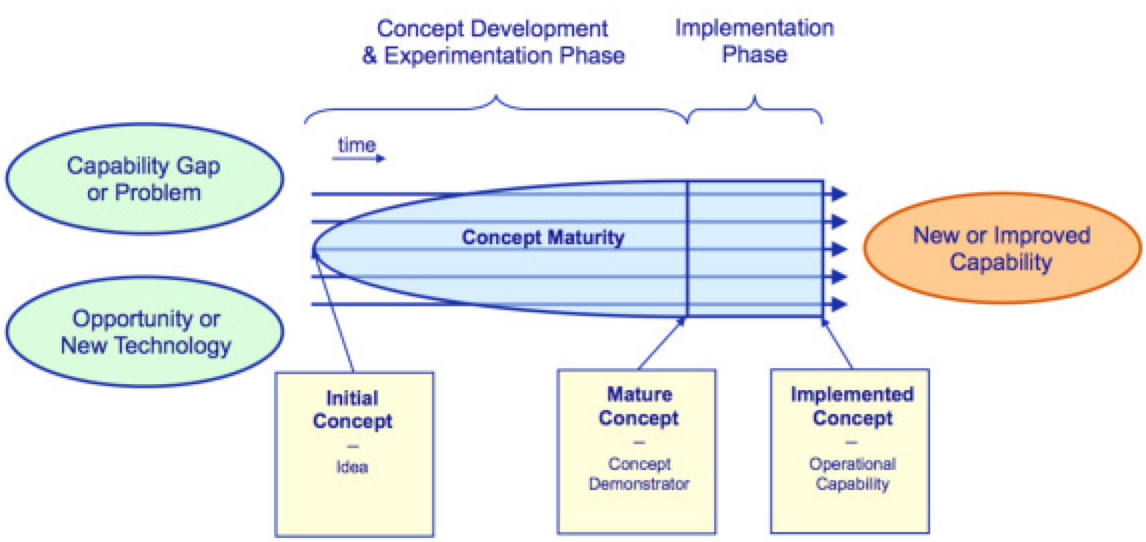


Figure 17: A Model for Capability Development.

## 4.5 United Kingdom

Cassidian, a subsidiary of EADS, has a number of efforts that are related to SEA. In particular, they have done extensive work in architecture to support SEA activities that we can leverage as we think about how SEA can evolve into an international framework supporting the use of simulation for assessment.

Their process has four key stages (see Figure 18). They first use static modeling techniques as a way to capture requirements and communicate with the customer so there is a clear understanding before they proceed. This also involves the use of case studies and conceptual frameworks. The dynamic model is able to model the interactions between independent components as well as the influence of one part on another. They use system dynamics modeling tools, among other techniques, to capture this. Before they move on to full-fidelity simulation, they first use a simulation emulation phase that does not involve users but emulates them in some way. It could be considered a coarse evaluation that is meant to assess risk as it relates to system capability so that design decisions can be made earlier. Figure 19 shows a simulation capability at the emulation phase that models interactions both symbolically as well as literally (in 3D). Finally, real system simulation tries to model the full system at whatever level of fidelity is needed to make design decisions for the final product.

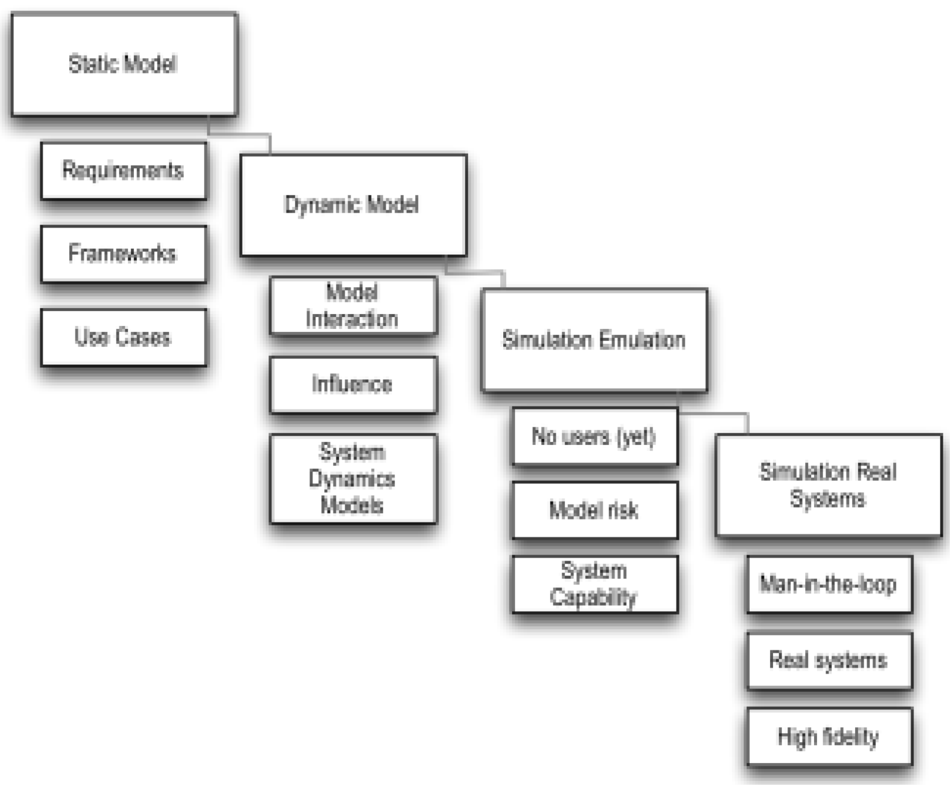


**Figure 18: Simple Architectural View Used by Cassidian.**

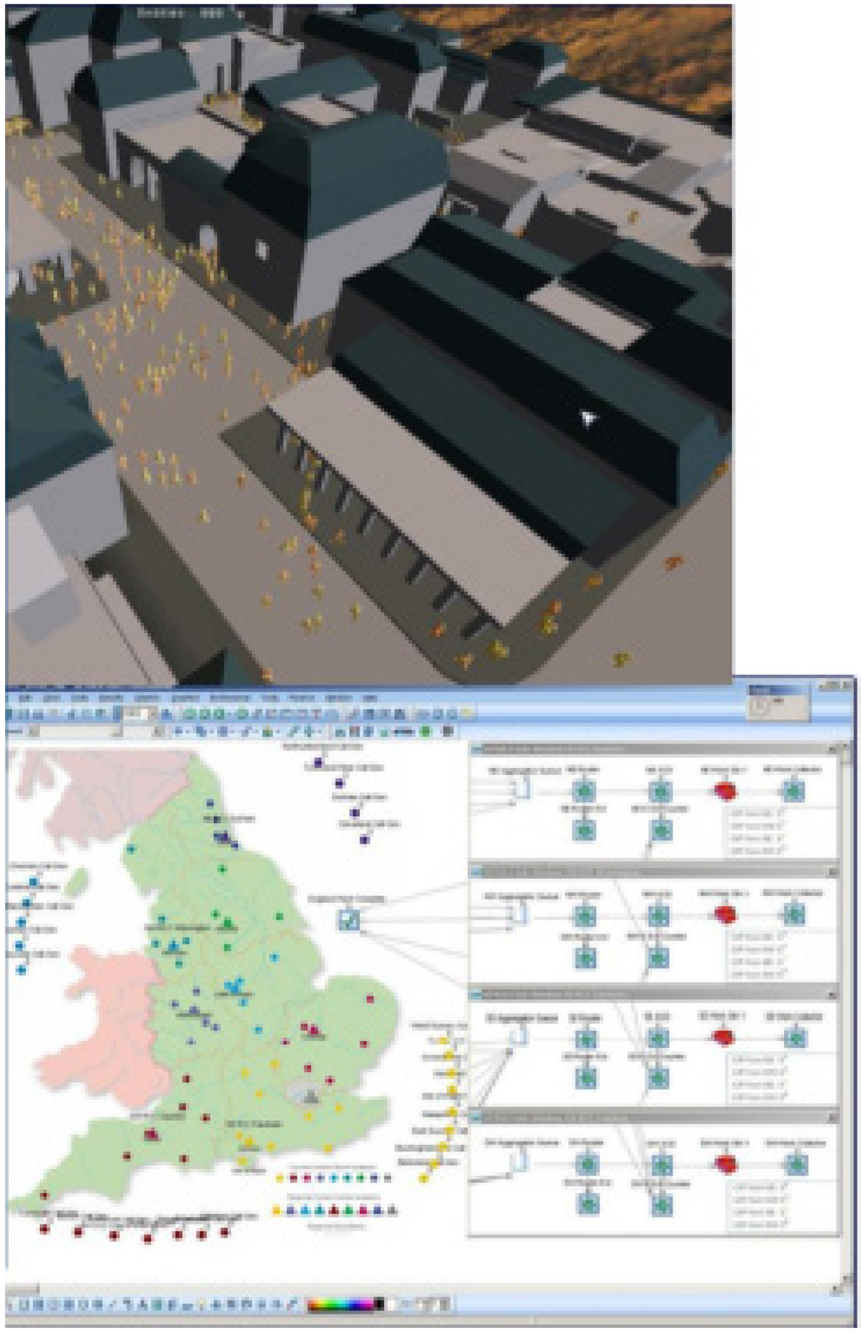

**Figure 19: Human Behavior Models Used for Operational Planning.**

## 4.6 United States

The United States has a number of large efforts in the area of SEA. For many years, individual programs have seen the value in using simulation to study designs and concepts as they relate to the overall performance of a complex system. Until very recently, there was little acknowledgement that the common goals among these programs could be used to develop new tools and capabilities specific to SEA. In fact, as we pull the lens back further, this is a goal of RTG HFM-216 for the international community.

The Fleet Integrated Synthetic Training Facility (FISTFAC) program, (COMPACFLT, sponsored by the Office of Naval Research) seeks to develop an integrated training, test and evaluation system for a variety of naval mission sets. It is meant to be an end-to-end testing and training capability. The primary facility maximizes fidelity via large reconfigurable spaces that allow different simulators or deployable systems to be integrated as required by a training or evaluation scenario. This capability enables some of the most complex command-and-control problems to be assessed, and experiments involving new equipment or procedures to be executed. Current focus is on anti-submarine warfare, but the facility is by no means limited to that domain. The schematic below shows a configuration typical of this facility. Not only does it integrate multiple users, but also multiple systems. Because each of the parts are independent, variations of this facility can be replicated elsewhere at differing levels of fidelity.

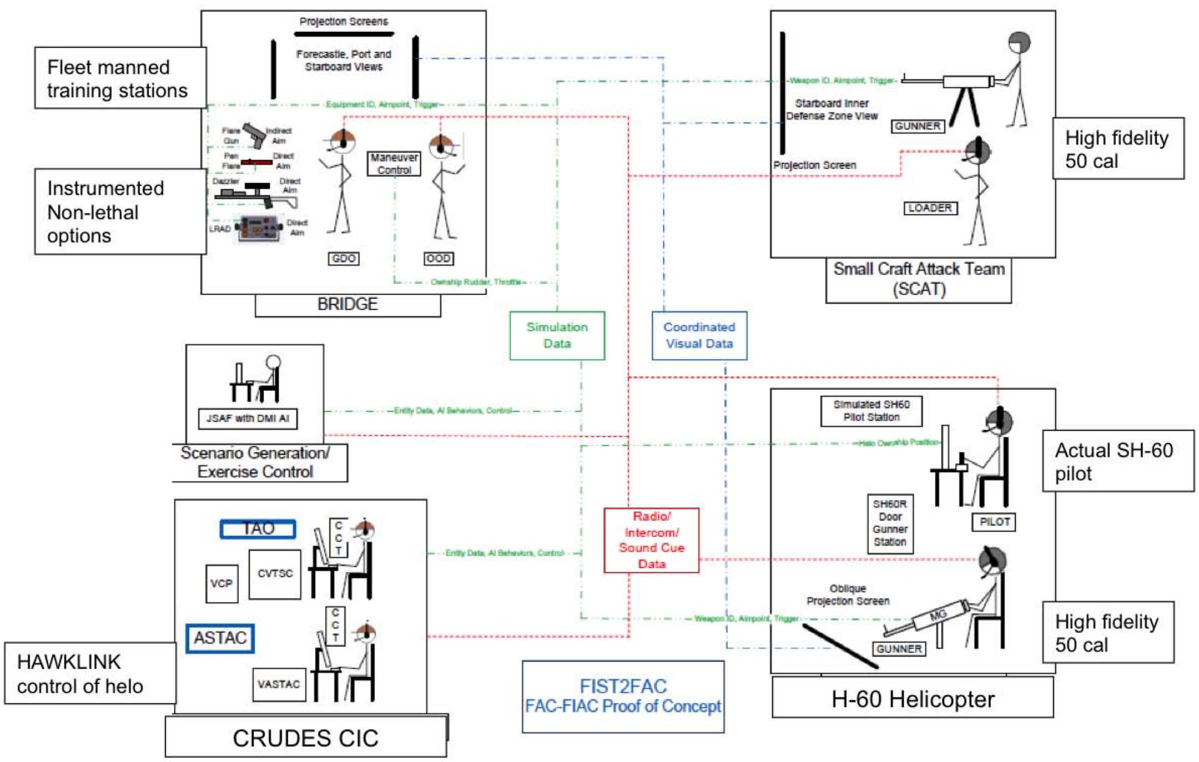


**Figure 20: The FIST2FAC Schematic Showing Various Simulators and Operators on a Shared Network.**

Another related effort in the United States is Engineered Resilient Systems (ERS). ERS is meant to address problems associated with changing requirements over the full lifecycle of a program. A resilient system is defined as one that is effective over a wide range of situations and that is readily adaptable through reconfiguration or replacement with graceful and detectable degradation of function. The goals of ERS involve detailed trade-off analyses across multiple mission contexts that can be fed into requirements generation and refinement. Also, the ability to consider a much wider range of options is desired. While ERS itself is not specific about the use of simulation, clearly, simulation will play a large role. A current effort at ERDC is developing an architecture capable of integrating simulation, life systems, and people for the purposes of exploring and assessing alternative options.

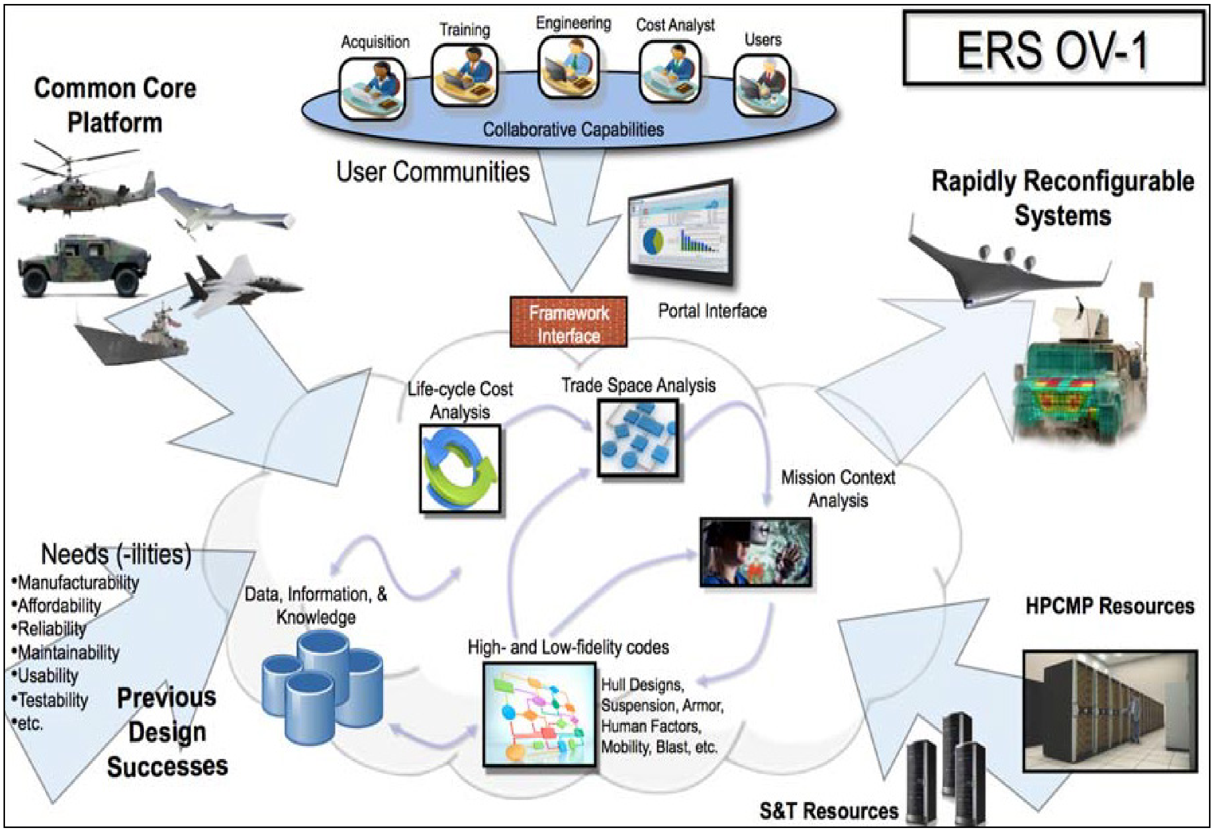


**Figure 21: ERS Architectural Plan (from ERDC).**

The Architecture Management Integration Environment (AMIE) being developed by the Naval Air Systems Command is an open architecture to support SEA-like systems. With the increasing importance of major joint programs that must share systems and models of systems among different stakeholders, an architecture is needed that is capable of unifying these into a coherent system for evaluation. AMIE is largely an interface standard that enables components to communicate and synchronize.

Figure 22 shows how AMIE is meant to unify models developed for a wide variety of purposes by a wide variety of developers. These are adaptable and extensible in their own right. They are aggregated via a standardized "backplane" that forces a common format so that the analyst can author a test and evaluation simulation by "snapping" components together as needed. This relies heavily on common data standards (many of which are reaching maturity now) and protocols. The backplane must be an open, non-proprietary interface. AMIE reduces redundant effort and increases reliability through reuse. It also forces the government to be the lead integrator and architect which is entirely appropriate (and needed), but also may demand skill sets the government does not necessarily have in abundance.

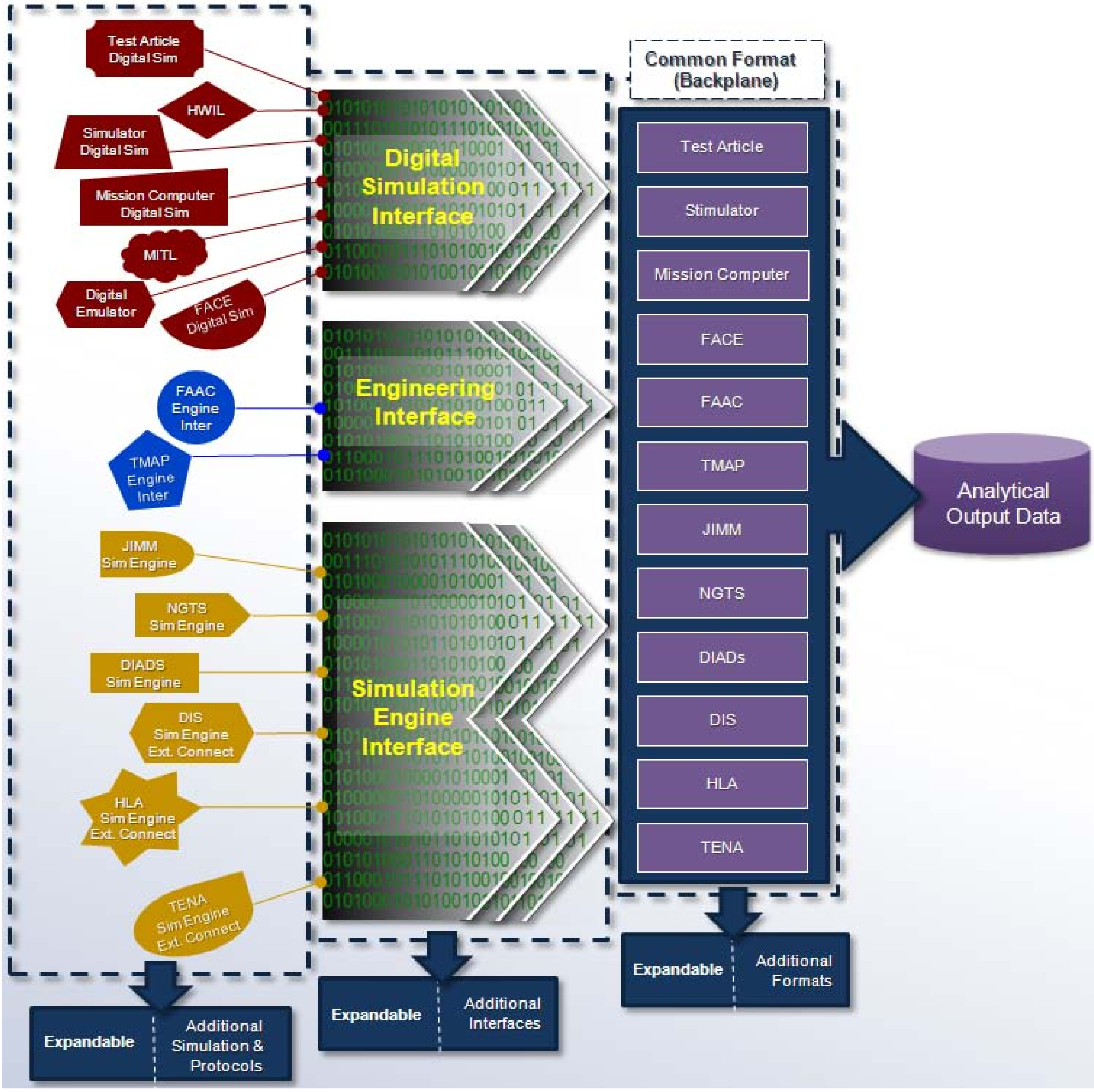


**Figure 22: Schematic Diagram for AMIE Showing Different Input Models Unified on the Backplane.**

Finally, Figure 23 shows how these efforts relate to each other. SEA is unique to complex systems with human operators. The introduction or inclusion of humans into any analysis brings with it a number of issues that may not be present in other problem spaces. ERS can be viewed as a wider scoped initiative focused more on the acquisition cycle. The intersection of SEA and ERS is where decision support capabilities are developed that facilitate the exploration of design options related to overall system performance, systems and personnel. AMIE is mainly a way to put the pieces together. It is a key enabler. The intersection of AMIE and SEA is where we develop software architectures for LVC and man-in-the-loop simulations that also integrate complex models for analysis. The intersection of AMIE and ERS is similar but with a broader scope, looking at very large design spaces that must include automated design of experiments, visualizations for sense making, and other analyst support tools. Finally the intersection of all of these is a component level architecture for interoperable simulation that enables plug-in models of system modules (which can be people, equipment, or process). It is tailored to the acquisition cycle and includes cost models, synthetic test and evaluation, and iterative design refinement.

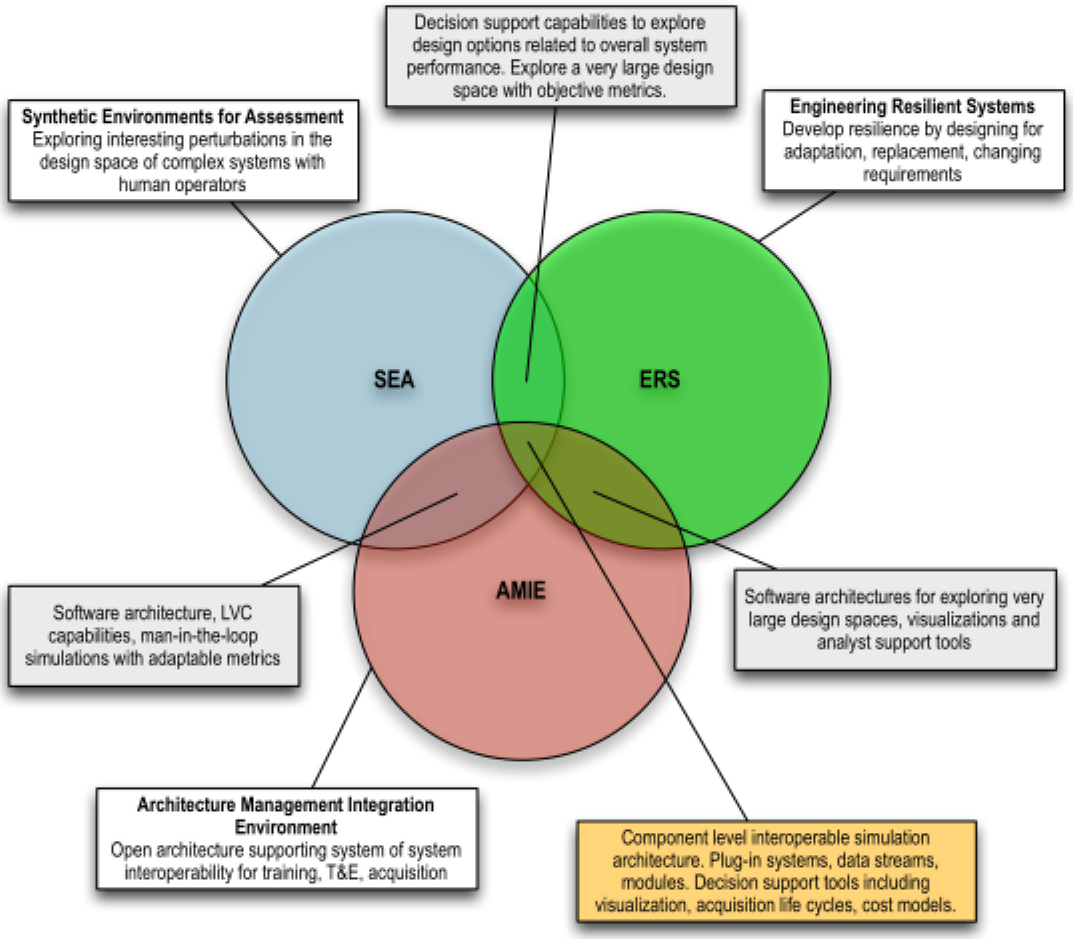


**Figure 23: The Intersecting Domains of SEA, ERS, and AMIE.**

# 5.0 RELATIONSHIP TO OTHER NATO STO ACTIVITIES

## 5.1 Live-Virtual-Constructive Training (RTG HFM-221)

### 5.1.1 LVC Agenda and Objectives

LVC is becoming pervasive in the international training and mission rehearsal community due to the maturity of enabling technologies and the push to drive costs down. However, RTG HFM-221 recognizes that there is still little agreement as to what constitutes L, V, and C or what the aggregate LVC means in terms of training and mission rehearsal. The lack of agreement in definition as well as tools for interoperability and synchronization are also barriers. A key objective of RTG HFM-221 is to seek common goals and opportunities across NATO partners that will enable joint exercises and training as well as the sharing of technologies where appropriate.

A current focus is on what it will take to develop a continuous learning (or training) environment that integrates LVC as a seamless and persistent part of all training. If it can be shown that learning can be accelerated in this manner, then the international community can leverage this in many ways. Other objectives include identifying best practices for LVC across Member Nations, methods of measuring performance in LVC environments, exploring the differences of LVC training as compared to other methods, and identification of candidate exemplars that can be shared among members and could be expanded into an RTG LVC demonstration.

### 5.1.2 LVC + SEA Opportunities

We have mentioned a number of areas where LVC fits into the SEA ecosystem – specifically in terms of thinking about LVC "components" as any other component that can be aggregated within SEA for a specific assessment. For example, if we wanted to use SEA to study the trade-offs of a new SOP for ASW scenarios, we might easily include live operators on live equipment possibly in a live exercise as part of that assessment, even though other parts were purely simulated. This will require a full integration of LVC standards as part of the SEA architecture.

## 5.2 Human Behavior Modeling (HBM) (MSG-107)

### 5.2.1 HBM Agenda and Objectives

HBM is looking at modeling and simulation technologies that model humans at the individual and small team levels. There is an immediate tie to LVC in that HBM seeks to solve problems associated with the use of HBM models in exercises that include live players. They are looking at a wide variety of warfighting domains, from ground force applications, to air, and multi-service domains. Much of the work of HBM will deal with standards development that will allow them to utilize the many investments in HBM worldwide that currently cannot be unified into a single system. This same motivation for reusability of models is common to SEA. This is likely an area for collaboration.

The main objective of HBM is to develop a reference architecture for HBM that can be used in any military application. They will begin with conceptual modeling that crosses cognition, decision-making, planning, and emotions. The plan calls for investigation of the architecture at the sub-level first working up to an overarching architecture that might be capable of unifying all sorts of models that already exist today. Finally, HBM will make recommendations as to the use of the architecture in practical applications.

### 5.2.2 HBM + SEA Opportunities

HBM is but one of the groups in MSG working in areas of interest to SEA. There are certainly more. SEA needs to pay attention to the reference architecture developed by HBM because it must be compatible with what we develop for SEA since these HBM models are going to be common candidate models for use in SEA assessments. In all likelihood, the HBM architecture may need to be more general than we need to be in SEA, which implies that letting HBM get out ahead of SEA may be useful.

# 6.0 SUMMARY AND RECOMMENDATIONS

## 6.1 Summary

Not only does SEA provide a workable way to solve the practical problems involving the use of simulation in the capability development and procurement processes, but it creates opportunities we have never had before. Calibrated scenarios from one lab can be used in another, resulting in data that can be fairly compared. Researchers can have realistic test environments available to test and compare theories of human performance in a variety of disciplines without having to expend precious resources learning the domain or building "throw away" simulations. Both researchers and acquisition professionals can explore a larger number of potential solutions to hard problems using trade-off techniques for comparison. Most importantly, capability development and the rest of the procurement community can use SEA as a communication mechanism. If capability development proposes that a new technology for the use of unmanned vehicles might have a specific benefit, they could communicate this to acquisition through realistic combat scenarios within SEA.

We defined SEA as a modeling and simulation approach to experimentation with models and operators that measures system performance under "interesting" perturbations. SEA is a new way to think about the use of simulation for conducting trade-off analyses, and for exploring very complex design spaces. SEA is how we will break out of the rut of sustaining improvements that we all invest in every day in favor of disruptive innovation – radically new ideas that change the rules of warfare and national defence. This is the goal of SEA at its highest level.

This report presented a conceptual model of SEA that we used to identify the key issues of concern. Use-cases were provided in capability development and procurement to show how SEA might be used with significant benefit to its user groups. We then described the SEA activities ongoing in all our Member Nations, where there are many similarities but also many differences. We found that SEA, in form if not in name, is everywhere. All of our member countries had many of the same ideas independent of each other before RTG HFM-216 ever began. What was missing was a unified attempt to bridge our efforts in order to share experiences, technologies, and results. This is where RTG HFM-216 needs to go next.

We used the descriptions of ongoing SEA activities to derive a detailed architecture for SEA that identifies resources, models and systems, input, outputs, and user communities. Finally, we listed each of the core technology areas within SEA and the unique technical barriers we need to cross to realize SEA in its fullest form.

## 6.2 Recommendations

What is needed to realize SEA? We have developed prototype software environments to test out ideas of component-based architectures. The system engineering community has well-developed techniques for functional decomposition and task modeling that can be used here. The modeling and simulation community has been working on semantic interoperability through common data models. So many of the pieces are either in place or are being developed currently. However, SEA still needs:

- A core set of simple rules for modular interoperability that allow easily swappable parts to be aggregated;
- Common data models that support semantic interoperability (borrow from M&S);
- Scenario authoring and modification tools to quickly adapt applications to test new ideas;

- Metric specification (and authoring) to ensure that the right measures are applied and the correct data captured to test any idea;
- Visualizations to help analysts navigate complex design spaces and understand complex multi-variate output; and
- LVC (live-virtual-constructive) capability to incorporate live and virtual simulations into SEA test packages.

Some of these needs may be met by technologies already developed for the training community that provide simulation of realistic integrated missions. Still other advances in the virtual world community offer promise for needed realism and complexity.

The next step should be an international demonstration. Given the common interests with HBM and LVC, it probably should be a collaborative effort since many of the same objectives are shared among all three groups. There was immediate recognition among RTG HFM-216 members of the redundant work each of us appears to be doing regarding SEA because there is no architecture to allow us to share models and components. From a practical standpoint, the ideas behind SEA resonate with the community. We also need to monitor the technology "wish list" given in Section 3.3 and summarized earlier in this section. These items require significant resources to accomplish, but they are common desires among all our Member Nations. As progress is made, a clearing-house (or reference repository) for these technologies needs to be developed, so they can be shared and integrated into international demonstrations that show the power of SEA.

The promise of SEA is great. The technical risks to realize SEA are small. In fact, most components have been developed and demonstrated in some form already. SEA-like projects are ongoing worldwide without the benefit of standards and cooperative interoperability that SEA will offer. The ability of synthetic environments to positively impact how we discover and develop new technologies for supporting human operators is too good to pass up.

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| Model | Transition |
| Performance metrics | |

**14. Abstract**
This report describes a modeling and simulation approach to experimentation that utilizes models and operators, performing their mission-oriented tasks, within a simulated version of their operational domains, in order to measure system performance under targeted key perturbations. This approach, called Synthetic Environment for Assessment (SEA), is a new way to use simulation for conducting trade-off analyses and for exploring very complex design spaces. SEA has the potential to progress systems from simply sustaining incremental improvements in favor of disruptive innovation – exploring radically new ideas that change the rules of warfare and national defence. Use-cases from member Nations were provided to show how SEA could be used with significant benefit to its user groups. This report presents a conceptual model of SEA that can be used to identify the key issues of concern, and provides a detailed architecture for SEA that identifies resources, models and systems, input, outputs, and user communities resulting in the core technology areas within SEA and the unique technical barriers that need to be crossed to realize SEA in its fullest form.

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