Simulation Components

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INTRODUCTION

The fundamental concept of simulation dates back thousands of years to the ancient Egyptians and the famous Chinese war strategist SunTzu. Notwithstanding these initial attempts at replicating ancient battlefields, current day *machine-based* modelling and simulation (M&S) found its roots in the early 20th Century. During this dawning era, the majority of M&S efforts were carried out in isolation. One may not find this so surprising when one considers the fundamental definition of a model: *a representation of an element of the real world for a specific purpose*. Working in isolated domains on specific applications, M&S developers created bespoke solutions to precise problems.

Modelling and simulation has undergone a significant maturation process over the past few decades. Early on, the M&S realm represented only a very small portion of the real world (see Figure 1(a)). Systems such as flight simulators, SimNet[1] and operational analysis (OA) models, although based on real world requirements, had no direct physical connection to the real world domains. Technology growth led to an expansion within the M&S realm, allowing practitioners to address a larger subset of real world applications with more comprehensive and complex representations (see Figure 1(b)). Today, the M&S realm has achieved an overlap with the real world wherein simulation information is viewed coincident with the real world[2].

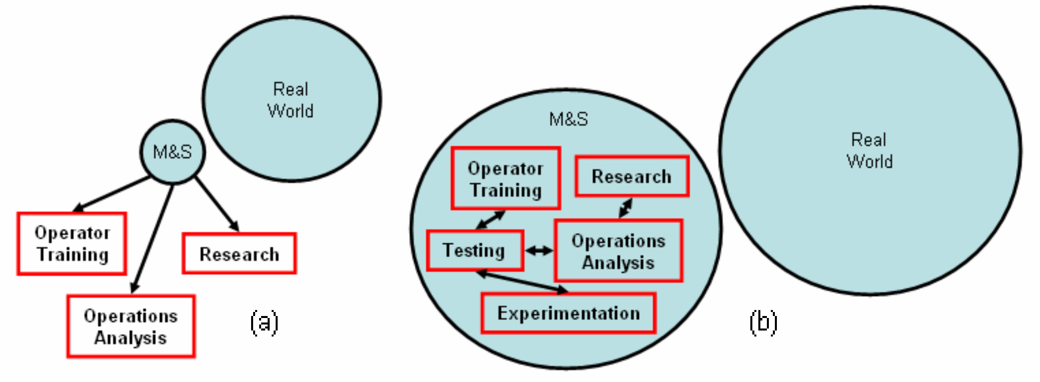

Figure 1: Growth in Modelling & Simulation.

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[1] SimNet (Simulation Networking), considered to be the birth of distributed simulation, was the result of a DARPA project to create a network of real time, man-in-the-loop simulators for the US Army. See http://www.peostri.army.mil/PRODUCTS/PC_BASED_TECH/ for more information.

[2] This concept is referred to as *augmented* or *mixed reality*. For more information see http://www.informationinplace.com/ .

Searle, J.; Brennan, J. (2007) Simulation Components. In *Integration of Modelling and Simulation* (pp. 6-1 – 6-12). Educational Notes RTO-EN-MSG-043bis, Paper 6. Neuilly-sur-Seine, France: RTO. Available from: http://www.rto.nato.int/abstracts.asp.

The advances and growth referred to above has resulted in a virtual explosion in the elements and components associated with simulation. These components can be divided into two categories: those associated with the science and technology of simulation itself; and those more closely related to the human and cultural aspects of the M&S community. The first section of this paper introduces the concept of synthetic environments as a means of establishing some common ground for further discussion. The remainder of the paper will take a closer look at some of the technical and non-technical components of simulation.

SYNTHETIC ENVIRONMENTS

There is a variety of ways in which one can categorise the many models and simulations in use today. One of the most common, top-level taxonomies used by the military is the live, virtual, constructive (LVC) triplet (see Figure 2). This categorisation addresses the method of simulation conduct by specifying the role and representation of people and equipment in the environment. Another way of looking at models and simulations is the application domain for which they were developed. In this instance, one can conceivably classify models into one of the following categories: analytical, engineering, training, and testing. These two methods of categorisation do not preclude underlying fundamental groupings such as mathematical, 3-dimensional and process models. Furthermore, one must remain aware of the potential to use or reuse models (or components thereof) across multiple domains, where applicable[3]. Regardless of the taxonomy used, one must understand that there is a large array of models and simulations; some models exist to serve a very specific, narrowly focused purpose, while others were designed to be more flexible and address a range of options within their domains. Thus, categorisation can serve as a management and understanding aid, and it must be approached with an open mind.

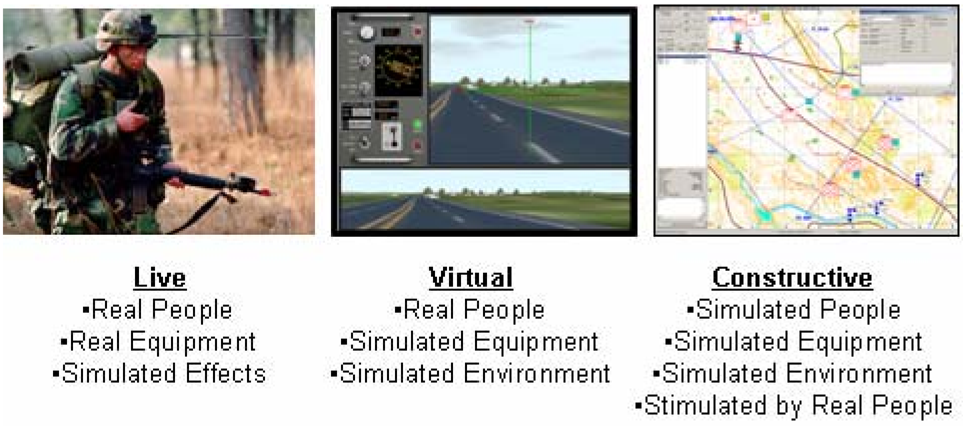

Figure 2: Live, Virtual and Constructive Simulation Definitions.

The precise understanding of the phrase synthetic environment (SE) can vary from organisation to organisation. The US DoD typically interprets this phrase as meaning the representation of the real world environment (terrain, ocean, atmosphere) in simulation. The UK MoD and the Canadian DND view a SE as a gathering of simulations, people and equipment via a distributed network in a common representation of an element of the real world. The UK MoD definition of a SE is:

> *"A computer-based representation of the real world, usually a current or future battle space, within which any combination of 'players' may interact. The 'players' may be computer models, simulations, people or instrumented real equipments."*
>
> http://www.mod.uk/issues/simulation/policy.htm

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[3] The practice of reusing a model for purposes other than for which it was developed must be approached with caution – detailed research must be undertaken to ensure valid and usable output will be generated for the newer application of the model.

The Canadian DND definition of a SE is:

> *"The linkage of models, simulations, people (real or simulated), equipment (real or simulated) into a common representation of the world."*
>
> http://www.drdc-rddc.gc.ca/seco/library_e.html

The key point to keep in mind is that there is no single SE. Synthetic environments, similar to models, are established for specific purposes (e.g. a synthetic environment for allowing C-130 pilots to mission rehearse in tactical air lift would be quite different from a synthetic environment that would be used to conduct developmental test and evaluation on a towed array sonar system).

To assist in generating a more detailed understanding of the simulation components that comprise a synthetic environment, it is helpful to examine the elements that are involved in a real world exercise or operation. Figure 3 lists the typical elements of a military activity on the left. These elements are mapped to simulation components that are applicable to the discussion to follow in this paper (not an exhaustive list). Note that there are technical and non-technical elements components within the simulation realm, much like there are operational and non-operational elements in the real world. The remainder of this paper will examine the technical and non-technical simulation components.

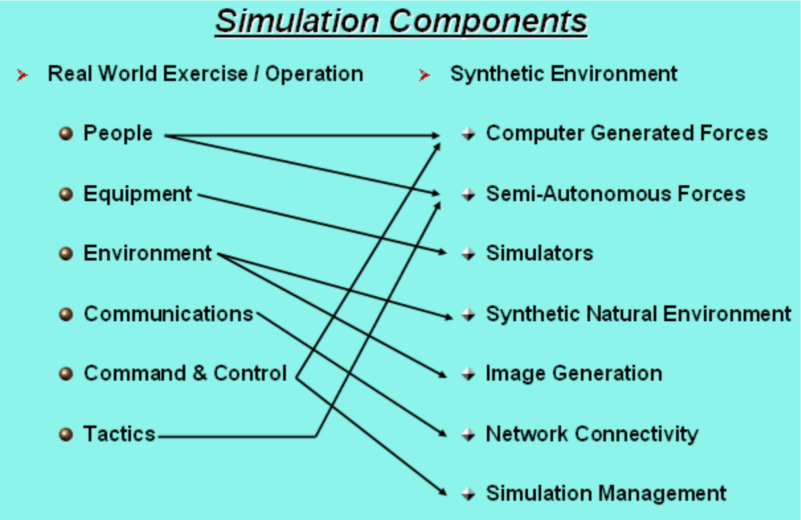

Figure 3: Simulation Component Mapping.

THE TECHNICAL COMPONENTS

When one encounters the term simulation, particularly in a military environment, typically the first image that enters one's mind is that of a high-tech computer-based simulator primarily used for skills training for a single individual. Advances in technology are increasing the scope of technology application, which in turn is helping to broaden this first impression. Nonetheless, it is normal for one to think of the technical aspects (or components) of simulation in the first instance due to the highly technical nature of the subject.

An aspect of military simulation with which many people are unaware is the existence of countless elements which are out of sight of the typical user or observer. This section will focus on these types of components, addressing each category one at a time, and finish with a brief look at a typical simulator as a means of leading into the next section.

Computer Generated Forces

Computer Generated Forces (or CGF) is a broadly applied term for the most part. In the literature, it is commonly interchanged with synthetic forces (SF), semi-autonomous forces (SAF), intelligent forces (IFOR), command forces (CFOR), command agents (CA) and many more like terms. One way of looking at it is that all of these alternate terms imply a specialist application (for example command & control for CFOR or CA), while CGF is a more general term.

Essentially, a CGF is a computer-based representation of a participant within a given scenario. The participant being represented can be at one of a selection of different levels (i.e. platform or aggregate[4]); however, the individual element represented is typically at the lowest level of command & control relevant to the scenario. For example, in a tactical level simulation, a CGF entity might be an individual soldier or aircraft, while in a strategic level simulation, a CGF entity might be a naval task force consisting of six to ten different vessels, clustered together and represented by a single icon.

Regardless of the level of representation generated, CGFs are typically defined and designed from two perspectives: physical and behavioural. The physical representation of a CGF entity is the representation one would normally imagine when considering such a component. It is also, by nature, the easier of the two representations to define. Physical representation consists of elements such as dimensions, manoeuvrability and sensors. The more difficult element of representation is that of behaviour. This is typically accomplished by identifying the knowledge and decision making abilities that the parallel real-world entity would possess, drawing on such things as military doctrine, techniques and procedures. One could also allow for the entity to be assigned tasks and the sense of responsibility for completing mission objectives. Another option would be for command forces to *understand* their position within the command & control structure and conduct certain activities based on this perceived position.

Finally, CGFs offer a means by which military organisations can ease the burden of the need to provide skilled and trained operators in large numbers to conduct simulation based activities. By leveraging the power in CGFs, one operator can conceivably control a multitude of friendly, enemy or neutral entities given a proper user interface and provided the CGFs possess sufficient behavioural characteristics.

Image Generation (Graphics)

Image generation (IG), or computer graphics, is a topic that is receiving considerable attention as of late. Rapid advances in 3-D graphics processing have taken the computer-based gaming world by storm. It is important to note that real-time 3-D graphics is not the only means of computer generated imagery (CGI); however, it is arguably the most difficult to design and the most computationally intense to produce. Therefore 3-D real-time (or near real time) IG will be the focus of this segment.

Most people will be somewhat familiar with Moore's Law that states the processing power (or transistors in a CPU) will double approximately every two years[i]. Somewhat lesser known is the fact that IG technology is growing at an even faster rate; on average, graphics processing units (or GPUs) double their capability every six months. Figure 4 depicts a comparison between the growth rates of CPUs and GPUs. Furthermore, while the capability of IGs has been improving, their associated costs have been declining.

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[4] Aggregate being the grouping or combination of individual platforms or participants into a cohesive element or entity represented by a single icon or symbol within the simulation space.

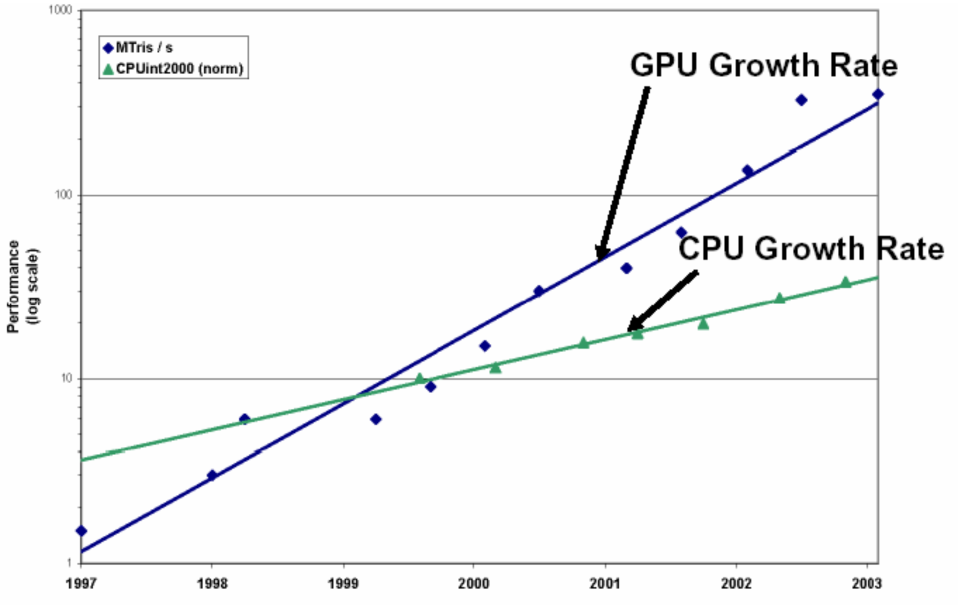

Figure 4: GPU versus CPU Growth Rate (University of North Carolina).

To illustrate this apparent explosion in value for money, one can examine the hardware from the UK Defence Academy Simulation and Synthetic Environment Laboratory (SSEL) over the past 10 years. Table 1 lists the platforms used for 3-D IG and their associated price-performance index. Using 1995 as a baseline, one can see that over a 10 year period the SSEL has seen a 4000 times increase in price-performance.

Table 1: Graphics Processing Price Performance

1995	2001	2004
SGI Onyx RE 256 MB RAM £250,000 Performance X 1 PricePerf : 1	Dual CPU P III – 1 GHz 512 MB RAM £4,500 Performance X 10 PricePerf: 500	Pentium 4 HT 3.2 GHz 1 GB RAM £1,300 Performance X 20 PricePerf: 4000

As has been mentioned, this rather dramatic increase in capability has evolved over the past two decades through multiple generations of IG hardware[ii] (Figure 5):

- 1st Generation (up to 1980s) – First generation real time IG hardware allowed primarily wireframe models to be built and manipulated (e.g. computer aided design applications.
- 2nd Generation (1980s to 1992) – Second generation hardware saw the implementation of shaded solid objects.
- 3rd Generation (1992 to 2000) – Third generation hardware gave rise to texture mapping, wherein more detail could be applied to 3-D objects by *painting* them with more complex *images* rather a single colour.
- 4th Generation (2000 to ?) – Current generation real time IG hardware allows one to program the image generation *pipeline*.
- 5th Generation (?) – The next generation IG hardware has the potential to implement correct lighting physics, which until now has not been possible in the real time realm.

Figure 5: IG Advances.

One can confidently state that image generation has become one of the primary components in the realm of simulation, particularly in the military training and education arena. Continued progress in this area will no doubt greatly influence the manner in which future forces train and educate their personnel.

Synthetic Natural Environment

Although relatively new terminology, the concepts represented by the phrase synthetic natural environment (SNE) are not new. In the past, the data that was used to represent some element of the natural environment (i.e. terrain, ocean currents, and atmospheric profiles) was collected, stored and used in isolation. Today, the data is largely still collected and stored separately; however when it comes to processing and applying the data in simulation, a variety of types are typically aggregated for use in a cohesive SNE. Some of the typical items that are of interest to the general simulation realm include:

- Terrain – elevation (with respect to a particular *datum*); composition (i.e. rock, soil, asphalt, forest, etc); features (rivers, trees, roads, buildings, etc).
- Water – temperature; pressure; currents; salinity; depth.
- Atmosphere – temperature; pressure; wind velocity; moisture content; altitude.

The environment that has greatest applicability to most military situations is terrain representation, especially regarding visualisation of the environment. As mentioned before, the primary elements that comprise a typical 3-D terrain database (3DTDB) are the terrain skin (or surface) and the features that rest upon it (such as railways, power lines, fields and lakes). In addition to defining the presence of terrain and any applicable features, one might have the need to define and specify other *descriptive* properties such as material composition and emissivity characteristics. These additional properties become important if the interacting simulations are attempting to represent such things as radar systems or thermal imaging sensors.

Within the context of interoperability and integrating M&S, a critical issue with SNE's is correlation. One must ensure that all participants within a distributed simulation activity have not necessarily identical, but correlated databases. To illustrate this concept, consider the situation depicted in Figure 6. Platform B's simulator has the data and the ability to display multiple, individual trees; Platform A's simulator does not. As such, Platform B is under the impression that it is well concealed in an ideal firing position. However, Platform A, unable to display the trees, perceives Platform B as being exposed. This results in what is commonly termed an *unfair fight*. The key point regarding SNE's, particularly for distributed, networked simulation events, is to ensure that the environmental data and the method of portraying that data within the various simulations/simulators results in a common view and interpretation of the simulation space. Without this, the potential for generating undesirable results becomes much greater.

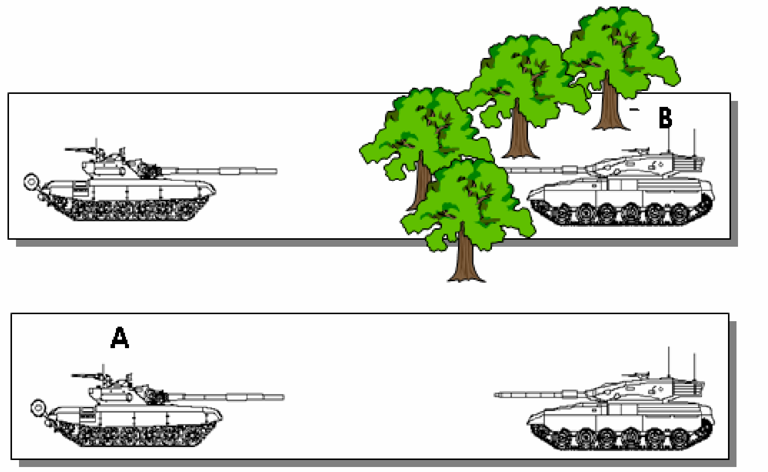

Figure 6: Terrain Miscorrelation.

Simulators

The final element in this section addresses a component which, in reality, is a combination of the previous components and some extra items not addressed directly in this paper. A simulator is generally accepted to be a "device that imitates the dynamic behaviour of a real system."[iii] Underneath the near to real human interface of most high fidelity simulators is a collection of multiple networked components, each of which might address one or more of the issues already examined in this paper, or some other function such as dynamics modelling.

Today, simulators can be found that represent air, land and ocean going platforms, as well as exoatmospheric vehicles such as the space shuttle. The remainder of this element will focus on flight simulators because they are considered to be the most mature and tightly governed subset of simulators today. The spectrum of available flight simulation devices is rather broad, encompassing 12 different categories according to regulations adopted by the Federal Aviation Authority (FAA), Transport Canada and the UK Civil Aviation Authority (CAA). It is within these categories where one can begin to see how the many components (both human interface and computational) can vary in fidelity. For instance, the FAA category of full flight simulators (FFS) (within which there are four subcategories) is differentiated from the category of flight training devices (FTD) (within which there are seven subcategories) in that FFS systems must possess visual systems and motion platforms; FTD systems are not required to incorporate a visual system or motion platform for certification. A third category is labelled PC aviation training devices (PC ATD), wherein the simulator consists of a desktop style PC that incorporates one (or more) monitors, an instrument panel and flight controls. A final component that bears mentioning is the instructor or monitor station that almost invariably accompanies FFS and FTD systems. This component facilitates the instruction and education for which the simulator was designed; the instructor station will also likely possess specialist capability to allow it to fulfil its role. In the end, a simulator, whether viewed as a single component or as a collection of many components, consists of several elements, each of which can vary in fidelity. It is this variance that must be assessed and managed, and which lead us into the next section that addresses non-technical components of simulation.

THE NON-TECHNICAL COMPONENTS

Most often, and quite understandably so, when addressing the topic of simulation, one immediately thinks of the technical aspects. Nonetheless, in addition to the hardware and software, there are a number of other issues, which, when examined, can be grouped into what one might term non-technical components. Quite often the non-technical issues are not given enough attention; one could argue that if they were, many M&S efforts would be better off. Most simulation specialists are familiar with the non-technical components, and in their defence, there are dedicated working groups whose objectives are to progress and educate in these issues. That said, the typical user or observer may not be aware of the significant effort that goes on behind the scenes to enable smooth operation of the technical components. This section will look at three general groupings: standards, processes and management.

Standards

There are many standards that govern the information technology realm. Likewise, a number of simulation specific standards have emerged over the past decade. Standards provide significant benefit towards achieving interoperability among disparate simulation systems and integration of simulation into many defence related processes. Given the context of this paper, this element will primarily address the relatively mature simulation interoperability standards. The interested reader is encouraged to visit the Simulation Interoperability and Standards Organization (SISO) website for more detailed information[5].

The two primary current day standards concerned with interoperability and integration of networked, distributed simulation systems began as US DoD developed and supported standards. Over time, the US DoD developed and implemented an acquisition policy that calls for and favours commercial standards.[iv] As such, the Institute of Electrical and Electronic Engineers (IEEE) currently manages these two standards: Distributed Interactive Simulation (DIS) as IEEE 1278 and the high level Architecture (HLA) as IEEE 1516.

The DIS standard is a communications protocol that facilitates information exchange between simulation applications. It defines data transfer formats as well as coordinate systems and units of measure amongst many other items. As such, one might say it provides an ad-hoc interoperability process. Data exchange occurs via fixed format protocol data units (PDU), which are broadcast using a best-effort network protocol[6] between simulators. DIS was designed for real-time platform level simulations and simulators, focused on technical level interoperability. The standard has a heavy dependence on man-in-the-loop simulations as it originated in the training domain.

The HLA standard specifies a formal process to design, develop, document and execute *federations*[7] of simulations. The process (covered in the next element) is auditable and is supported by tools to assist, enhance and enforce conformance with the standard. Each federation requires object models both at the federation level and at the simulation (or *federate*) level. The simulation object model (SOM) for each federate specifies (among other things) the data it requires from other participants and the data other participants have requested of it; this is known as the *publish* and *subscribe* process. For more information, the interested reader should visit the Defence Modeling and Simulation Office (DMSO) website at https://www.dmso.mil/public/transition/hla/.

Regardless of the type of simulation or the application domain within which the simulation is applied, standards aim to increase the chance of successful integration. Like many other engineering or science disciplines, standards provide proven, widely accepted frameworks within which designers and developers can achieve a higher level of interoperability than if they were to create simulation applications without any guidance whatsoever.

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[5] SISO can be found at www.sisostds.org.

[6] This is the User Datagram Protocol (UDP) – see http://en.wikipedia.org/wiki/User_Datagram_Protocol for more detail.

[7] Here the HLA-specific term *federation* refers to a single execution/instantiation of a collection of simulations in a common, cooperatively designed and developed synthetic environment.

Processes

Much like standards, there are many processes within the IT realm. The software engineering world has adopted many of the elements of sound engineering principles and processes. Within the military domain of distributed simulation, the primary process that dominates the field today is the process associated with the HLA (mentioned above).

The Federation Development and Execution Process (FEDEP) is essentially a systems engineering process model tailored for HLA federation design and development. Graphically the FEDEP resembles a classic software engineering waterfall model (see Figure 7); however, as one looks closer, one discovers greater detail wherein multiple feedback loops and detailed checklists exist to help ensure a high quality output is achieved as quickly as possible. Nonetheless, experience has demonstrated that the FEDEP process can take many months (perhaps as long as a couple of years) to unfold, particularly for activities large in scope.

As a follow on to the HLA FEDEP, the European Cooperation for Long-term In Defence (EUCLID) spent three years (November 2000 to November 2003) modifying and expanding the FEDEP into the Synthetic Environment Development and Exploitation Process (SEDEP).[v] The objective of this pan-European effort was to provide a process and associated tools to mitigate the obstacles to the effective use of SEs within Europe. One element of the SEDEP is the use of generalised wording and definitions so as to not be solely dedicated to HLA technology. The SEDEP currently has no governing body; some have suggested that NATO or SISO should assume responsibility for the SEDEP. This concept of governance leads us into the final element of this section.

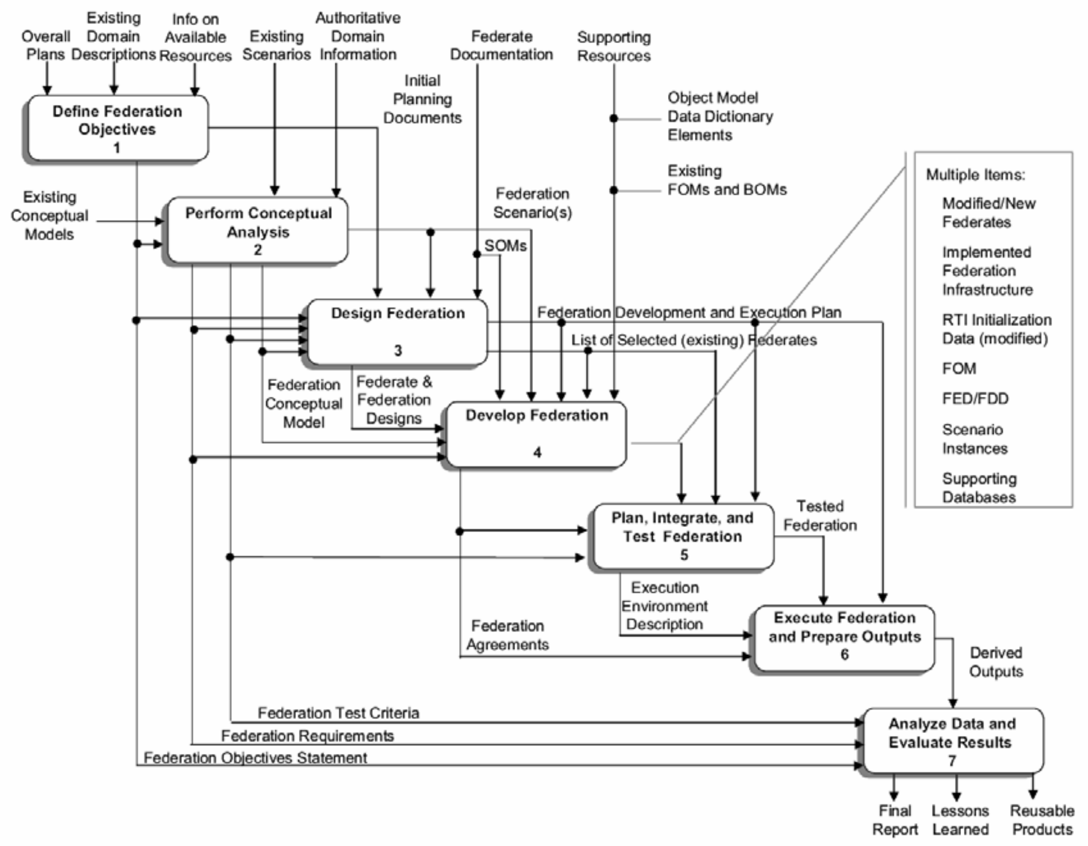

Figure 7: The HLA FEDEP (www.dmso.mil/public/transition/hla/).

Management

The overall management of simulation is, in itself, a critical component to the successful integration and application of M&S. Management of simulation projects, systems or components can flow logically from some of the standards and processes already established. Unfortunately, even more so than some of the standards or processes, simulation management can often be forgotten in the frantic efforts to get the technical bits working. Nevertheless, management of simulation activities and material is a cradle to grave requirement if one aims to successfully leverage every last bit of power that simulation has to offer.

This brings forth a concept that has received considerable attention in defence organisations around the world as of late: the idea of through life simulation support or simulation/synthetic environment based acquisition. As was alluded to in the beginning of this paper, initial use of simulation was essentially *stove-piped* – that is, the various stages of systems acquisition and maturation may have employed simulation, but they did so in relative isolation. Within the acquisition world, cross-discipline collaboration was introduced, and thus was born the concept of integrated project teams (IPTs). Recent success within IPTs is owed largely to sound management of the information and resources associated with a project.

Modelling and simulation should essentially be treated as another tool in the toolbox; it requires careful planning, use and management. If leveraged appropriately and managed properly, the application of M&S to acquisition has the potential to enhance the early optimisation of a system or capability[8]. As such, some defence organisations are beginning to examine and implement what the Canadian DND has termed Simulation Support Plans (SSPs).[vi] Essentially, the requirement to produce a SSP for major acquisition projects ensures that the project team has examined and assessed the potential of employing simulation tools to enhance their processes – they will be required to manage M&S!

DATA HANDLING

One final element worth mentioning as a component of simulation falls partially in the technical realm and partially in the non-technical realm. Data handling, which in this case encompasses data collection and data analysis, is critically important to most applications of M&S. Without data handling of some sort, any M&S activity would really serve no purpose. Therefore, it is important that planning for data identification, collection and analysis begin early in the process; it must be planned as an integral element of any application of synthetic environment from the outset.

SUMMARY

This paper has emphasised the fact that there are many individual components that comprise the synthetic environment realm. The components have grown in number and complexity over time as the M&S world expanded, pushing closer to and eventually merging with the real world. The technologically focussed components no doubt form a significant part of the M&S discipline. Nonetheless, it is vital that we do not ignore the complementary components on the non-technological side – those of standards, processes and management. Without these, the use of M&S as an enabler and enhancer has the potential of losing its focus.

REFERENCES

[i] See http://www.intel.com/technology/silicon/mooreslaw/ for details.

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[8] History has shown that 80% - 90% of total ownership cost is determined early in the life cycle (i.e. prior to actual acquisition beginning).

[ii] From Akeley & Hanrahan, http://www.graphics.stanford.edu/courses/cs448a-01-fall/

[iii] From DND SECO Lexicon http://www.drdc-rddc.gc.ca/seco/documents/MS_Lexicon_Apr02_e.html

[iv] Transition of the DoD High Level Architecture to IEEE Standard 1516, DMSO, 21 October 2005.

[v] See http://www.euclid1113.com/Euclid_Menu.htm

[vi] See Elliot & Gauvin, June 2004 http://admmatapp.dnd.ca/cosmat/dmasp/downloads/Modelling Simulation/Presentations/Elliot.ppt