APPLYING VIRTUAL PROTOTYPING AND ADVANCED DISTRIBUTED SIMULATION TO WARFIGHTING NEEDS

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ABSTRACT

With the fiscal constraints placed upon DoD, Advanced Distributed Simulation (ADS) and virtual prototyping can be combined to refine requirements, improve system design and flesh out a concept of operations for both acquisition managers and Warfighters. Through a structured process of systems engineering and integration, the linking of virtual simulations and prototype systems designs allows for the analysis and trades in technology, cost, schedule, and risk to support acquisition guidelines to "simulate before building" and enables more thorough and comprehensive assessments of the impacts and improvements for the Warfighters.

By coupling simulations and prototypical systems, a new era of Advanced Information Technology begins. Now, simulations transition into being applications that support real world operating missions. The concept of "train as we fight" begins to be applied even in the complex world of Command, Control, Communications, Computers, and Intelligence (C4I). We begin to move into a synthetic world that no longer assumes away difficult tasks by just allowing software to stimulate a Warfighter's monitor, but requires the operator to execute the mission task in the context of a real world environment.

DoD can no longer afford one system or simulation for training and another for fighting. Through experience in designing, developing, and integrating virtual prototypes with simulations, knowledge is being gained as to the applicability of today's distributed simulation standards for solving real world communication needs as well as their continued impact on tomorrow's systems. This paper will discuss the efforts in virtual prototyping linkage with ADS and the future impact that DIS ++ and High Level Architecture will have on this emerging technology.

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INTRODUCTION

Statement of Purpose

The purpose of this paper is to discuss ADS and virtual prototyping as information age technologies to address Warfighter and acquisition manager needs. This paper will discuss the opportunity present in DoD for virtual prototyping and ADS through evidence of its need and the positive impact it can create. After defining the opportunity a literature review of the technologies as well as a representative case using virtual prototyping and ADS will be discussed. The next step is to focus on an approach and methodology for using virtual prototyping with a discussion on the potential of using HLA. The final part of this paper is a summary discussion.

Discussion of the Opportunity

"The Department of Defense, in response to excruciating budget pressures, recurring system integration problems, and the continuing remarkable growth in computer capability and high resolution graphics, has seized on the promise of advanced distributed simulation technologies (including virtual prototyping) as a means for improving efficiency in developing integrated defense system products." (Brown and Lavender 1995).

The statement above was presented to the International Council of Systems Engineering in 1995. It is an example of the impact that ADS and virtual prototypes are having in the Department of Defense. Inorder to realize the potential of ADS and virtual prototyping, we need to understand the current conditions of the U.S. military. Today, the United States has the smallest combat force since before World War II. At the same time, the U.S. Army has experienced a 300 percent increase in operational deployments since 1989. This tremendous imbalance makes a challenge for today's U.S. Army leadership to pursue its primary mission "to fight and win our nation's wars" (Office of the Chief of Staff of the Army, 1995, p. 6). This is not just an Army problem but a Navy, Air Force, and Marine problem. The problem presented to the U.S. military leadership is the increase in the number of military deployments, with a reduced force structure, and still meet the mission of compelling "any adversary to do what he otherwise would not do" (p.7), all within a context of being a deterrent force. Currently, on "any given day over 21,500 soldiers are deployed from their home station all over the world" (p.8). Not only are we doing more with less as shown in Figure 1,

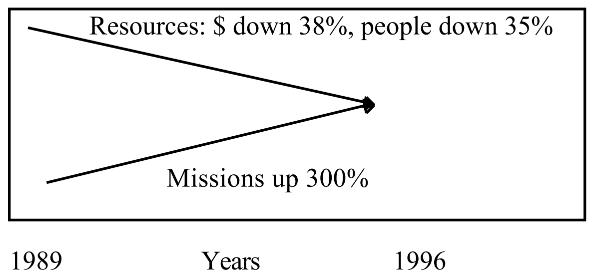


Figure 1. US Army Deployment vs. Resources

but the mission requirements are also expanding. Our armed forces not only need to be able to combat large conventional forces, but also deal with low intensity conflicts, peace keeping, and humanitarian activities. These complex, concurrent, tasks for today's military leadership are daunting, but not impossible to meet. So how can all this be accomplished? A potential solution is to leverage information age tools such as virtual prototyping and ADS. However, there are limitations to force reductions beyond which the U.S. military cannot meet its primary mission, even when leveraging information age technologies. As the U.S. Army transitions it force structure, from being a threat based force to a capability based force, to meet these new demands the need for ADS and virtual prototyping is essential.

Observables/evidence. The time is appropriate to address Warfighter needs and how to apply the emergent advanced information technologies such as ADS and virtual prototyping to meet the challenges facing them today. "To meet these challenges our Army is changing aggressively, challenging all assumptions of the past, leveraging technology to become more efficient and effective in order to remain relevant"(p.13). This is a very powerful statement by the Chief of Staff of the Army and similar quotations can be found from the other service Chiefs'. A 1992 Defense Science Board (DSB) summer study examined not only the value of simulation and modeling techniques applied to training, but the potential this technology could have on the acquisition process. The DSB stated (Office of the Under Secretary of Defense for Acquisition [OUSD-A], 1993): "We believe that Advanced Distributed Simulation (ADS) technology is here today and that this technology can provide the means to:

1. Improve training and readiness
2. Create an environment for operational and technical innovation for revolutionary improvements
3. Transform the acquisition process from within"(p.4).

These statements clearly provide the opportunity to leverage virtual prototyping and ADS technologies to meet the challenges of the military today and on into the 21st century.

Impact. ADS and virtual prototyping are enabling technologies in the information super highway, however, just providing access to more information faster, does not in itself provide benefit to the Warfighters. The information super highway is beginning to change the US military by moving the tactical operation centers (TOC) from industrial age based technologies into the information age technologies.

ADS and virtual prototyping as information age tools provide the ability to more effectively and efficiently train soldiers in an environment that is realistic enough to have a profound impact on our warfighting capabilities. The development of a virtual prototype system integrated with ADS provides benefits to the Warfighter, the developer, and military leadership. With this process, we bring together training with early systems development to reduce the cycle associated with development and fielding of new systems. This "spiral" approach provides an alternative to the traditional "water-fall" approach, figure 2.

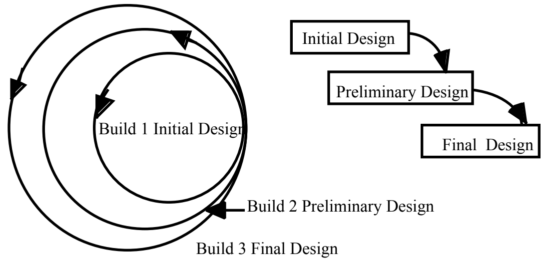


Figure 2. Spiral verse Waterfall Development

This provides the Warfighter with a continued technology edge and overall force projection leverage. With the US Army as the eighth largest army in the world, this force projection advantage is critical in meeting the primary mission. We begin to see the impact the use of these integrated technologies can have for the Warfighter.

LITERATURE REVIEW

The Institute for Simulation and Training (IST) is a primary source of information on ADS. One of the best documents produced by IST is The DIS Vision– A Map to the Future of Distributed Simulation (DIS Steering Committee, 1994). The Distributed Interactive Simulation (DIS) Steering Committee prepared The DIS Vision. The steering committee is the responsible agent for guiding the development of the DIS standard through user working groups. The DIS Vision document provides a comprehensive and up-to-date understanding of ADS and the supporting DIS infrastructure. IST also publishes the Standard for Distributed Interactive Simulation Application Protocol (Version 2.0.4).

The term "ADS" was defined in 1992 by the Defense Science Board summer study addressing the Impact of Advanced Distributed Simulation on Readiness, Training and Prototyping (OUSD-A, 1993). So what are ADS and DIS? The answer to this question is "The movement to create large virtual worlds[1] is called Advanced Distributed Simulation"(DIS Steering Committee, 1994, p. ix). To achieve this requires the development of a "standard infrastructure . . . to make the individual simulations interoperable" (DIS Steering Committee, p. ix). This standard infrastructure is DIS. Before the development of DIS, only homogeneous simulations or simulators could communicate. Using the IEEE 1278 standard DIS protocols, heterogeneous simulations and simulators are now able to interoperate.

When the development of distributed simulation was born over tweleve years ago, its original purpose was to support training. As the technology matured, more applications for its uses were defined. As Burns (1993) described in his book, there are technological flash points which "are points in time when technology clears major hurdles" (p. 163) for its usage. The hurdles, as defined by Burns, are feasibility, application, and price. The feasibility point for a technology is the first time when "realistic

[1] The creation of large virtual worlds is accomplished by linking real hardware systems (live), human-in-the-loop simulators (virtual), and computer wargames (constructive) together.

and practical"(p. 164) applications can be developed. These applications are very expensive and limited to large organizations that can afford the investment. The SIMNET project in the mid 1980s provided the feasibility flash point for ADS through the investment of Defense Advance Research Project Agency (DARPA) and the U.S. Army. From SIMNET, the first realistic and practical distributed simulation technology was born. The application point is when more organizations are able to afford the technology. Keystones to the application point for ADS are the development of the DIS standards and the expansion of ADS into systems acquisition. During the same period in the mid 1980s, the cost of computing dropped nearly a "thousandfold" as described by Burns (p. 164).

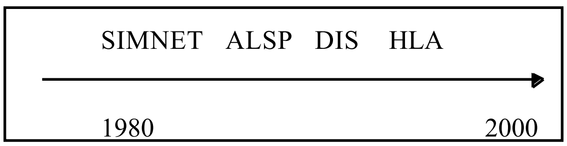


Figure 3. Development of Distributed Simulation

In the continuing development of distributed simulations the next step in the process is the High Level Architecture (HLA). HLA is planned to "establish a DoD wide high level architecture for modeling and simulation, applicable to a wide range of functional applications" (Defense Modeling and Simulation Office 1996, p. 1). "The purpose of this architecture is to facilitate interoperability among simulations and promote reuse of simulations...." (p.1). HLA consists of a set of specifications for creation of an compliant architecture. These specifications consist of rules, interface specifications, object model templates, and a glossary. The rules provide the technical principles upon which a common technical framework for ADS can be created. The HLA is developed to serve a number of domain specific areas from analytical simulations to engineering level simulations. This is accomplished through the interface specification which defines the linkage between the run-time infrastructure (RTI) and the federates, figure 4. These federates consist of a common set of federations object model (FOM) classes such C4I systems, data collection systems, or simulator systems.

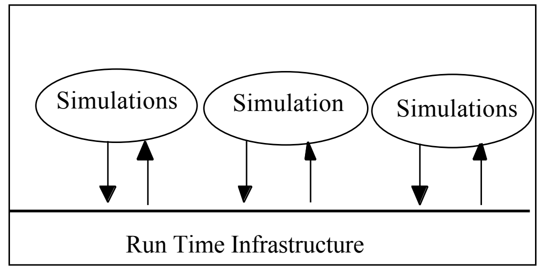
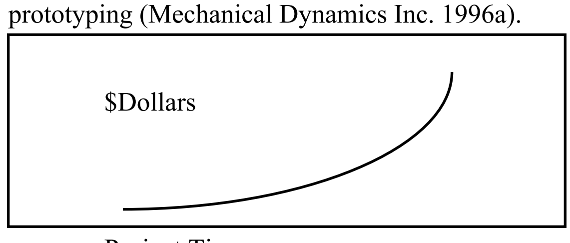


Figure 4. Run-Time Infrastructure of HLA

The federation is a set of these simulations or systems interacting together through a common RTI. This architecture provides support to virtual prototyping within an ADS environment. In the HLA, the virtual prototypes would be simulation objects in a federation.

Virtual Prototyping is a "software-based engineering discipline that entails modeling a system, simulating and visualizing its behavior under real-world operating conditions, and refining/optimizing the design through iterative design studies...prior to building the first physical prototype" (Mechnical Dynamics Inc. 1996b). Virtual prototyping provides a method to look at a "system instead of focusing on components" (Cole 1996). Dr. Cole goes on to discuss the benefits that virtual prototyping provides to the engineers and designers. Virtual prototypes allow them to visualize a system operating in real world condition to help them "find design mistakes early ... produce better systems" (p. 1). He further postulates the positive impacts of reducing the number of hardware prototypes and creating a optimal design faster using virtual prototyping to conducting "hundreds of tests on thousands of designs" (p.1). Figure 5 below shows the cost impact of design changes over the life of a project. Eaton and Ford Motor corporations use virtual prototypes to enhance their systems. Eaton has claim a marked improvement in "solving their design problems faster...producing better designs" using virtual prototyping (Mechanical Dynamics Inc. 1996a).



Project Time

Figure 5. Cost associated with design changes over time

The earlier you can address design flaws to include ambiguous requirements has a significant impact on the cost of the system. For years, DoD has been urging more Warfighter involvement in the development of new systems. Previously, it has been difficult to involve the Warfighter because the period of time from design to a hardware prototype is on the order of several years. By the time the prototype is ready, the original military representative has rotated to another duty station. With a virtual prototype, the Warfighter can be involved in hundreds of design tests in realistic battlefield environments within months of a new concept and not years.

With ADS, virtual prototypes provide a powerful means of tightly coupling the Warfighter's need with the acquisition process. "From the perspective of a weapon systems contractor, benefits of virtual prototyping include: (a) tighter coupling of operational requirements with developer implementation concepts, (b) introduction of a rapidly re-configurable tools for refining system requirements early in the systems development cycle, and (c) a means for improving the visibility of the system requirements analysis process" (Brown and Lavender 1995).

Representative case

Commercial companies have been developing and using virtual prototyping in many parts of industry. The DoD has been developing and using ADS technology in a concurrent cycle with commercial companies use of virtual prototyping. The merging of these two technologies is beginning to occur within DoD. A representative case of virtual prototyping and ADS is the High Altitude Endurance (HAE) Unmanned Air Vehicle(UAV). Beginning in 1994 and continuing through 1996 DARPA's Joint Project Office (JPO) for HAE UAV has been utilizing virtual prototyping and ADS for the purpose of evaluating a Mission Control Element (MCE) for the HAE system. This MCE system emulation is a evolving functional representation of an operational HAE MCE. The purpose of using virtual prototyping is to provide the HAE JPO and the User Communities with insights into issues of operational feasibility. Specific interest was in the areas of functionality, workload, manning for an HAE MCE, design of the workstations, and human factors issues.

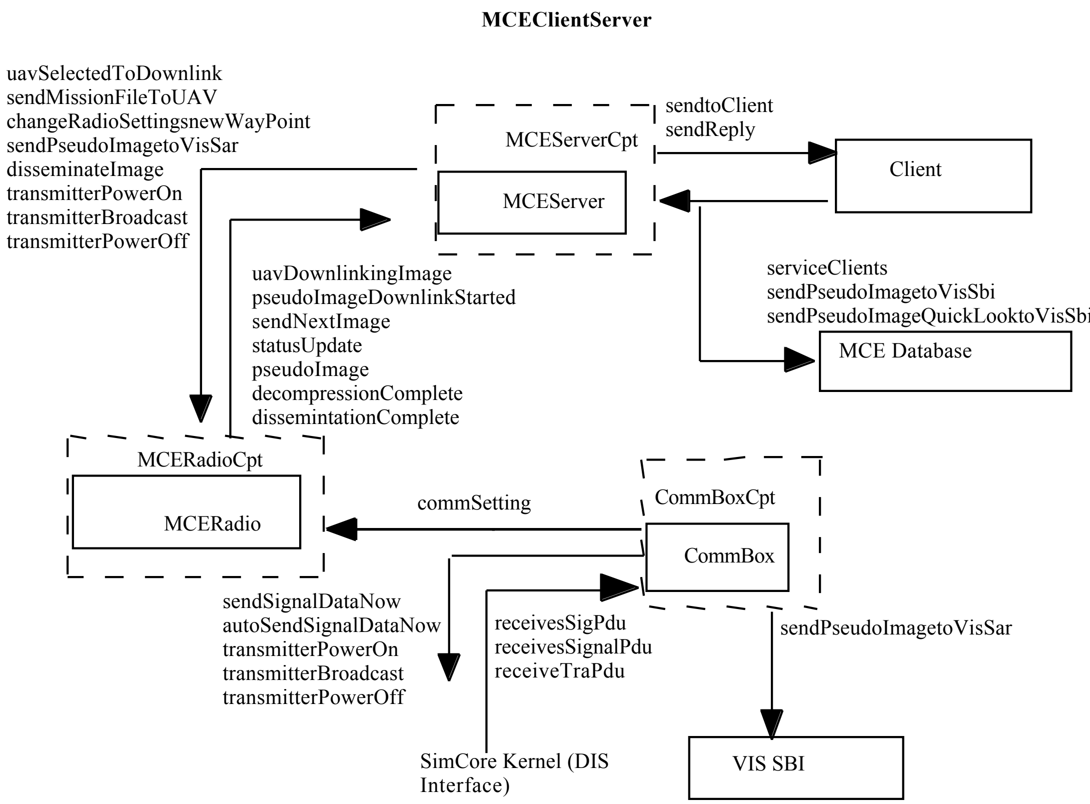


Figure 6. MCE Server Data Flow

In 1994, the project developed a functional prototype of the HAE MCE prior to any contract award for such a system by DARPA. The results from these tests provided data and user feed back that influenced both the requirements and contractor designs. The follow on efforts have focused more at the actual contractor designs. These test using Warfighters provided feedback to the contractor and HAE JPO on the system effectiveness. This has all been conducted using virtual prototypes and ADS prior to any MCE hardware prototype being built. A future opportunity is to exploit the experience gained to date with the HAE project by integrating the virtual prototype HAE MCE into a JTF military exercise in 1997.

The HAE MCE is currently using DIS protocols version 2.0.4 to transmit entity state, transmitter, and signal PDUs between the air vehicle and the MCE. The UAV simulation is written in C++ utilizing OOD methodologies. The UAV simulation contains a simplified 6-DOF kinematics model, Synthetic Aperture Radar (SAR) model, and electro optical/infrared (EO/IR) model. The sensor models are not physics based in that no phenomenology or signal processing calculations are performed to determine images or the quality of the images. Since the main purpose of the early test was to collect Warfighter inputs, it was determined that the cost and time associated with integrating a physic based SAR simulation would not be practical. The model is not physics based, but does return the image boundaries in the correct orientation with respect to the UAV as if the sensor had swept the given target location. Information about the sensor image is sent as a PseudoImage message embedded in a DIS Signal PDU. This information is used by other applications to generate a representative SAR image for graphical display.

The MCE simulation is composed of an MCE Server, an MCE Database Server, and HITL stations that communicate internally and externally via the MCE Server. The MCE Server, figure 6, is written in C++.

The MCE Database server is written in C and compiled under C++. Three of the HITL stations are written in C/ C++ and X/Motif with operator station intracommunication via UNIX sockets to the MCE server. The exception to this is the Mission Planner station which is comprised of two government furnished equipment (GFE) operational software, AFMSS and ETRAC.

APPROACH/METHODOLOGY

Approach

At the initiation of the HAE project, HLA was just beginning to be addressed by DARPA and was not a viable architecture to be used for this project. As part of this section HLA and DIS++ capabilities will be addressed with respect to there application to virtual prototyping.

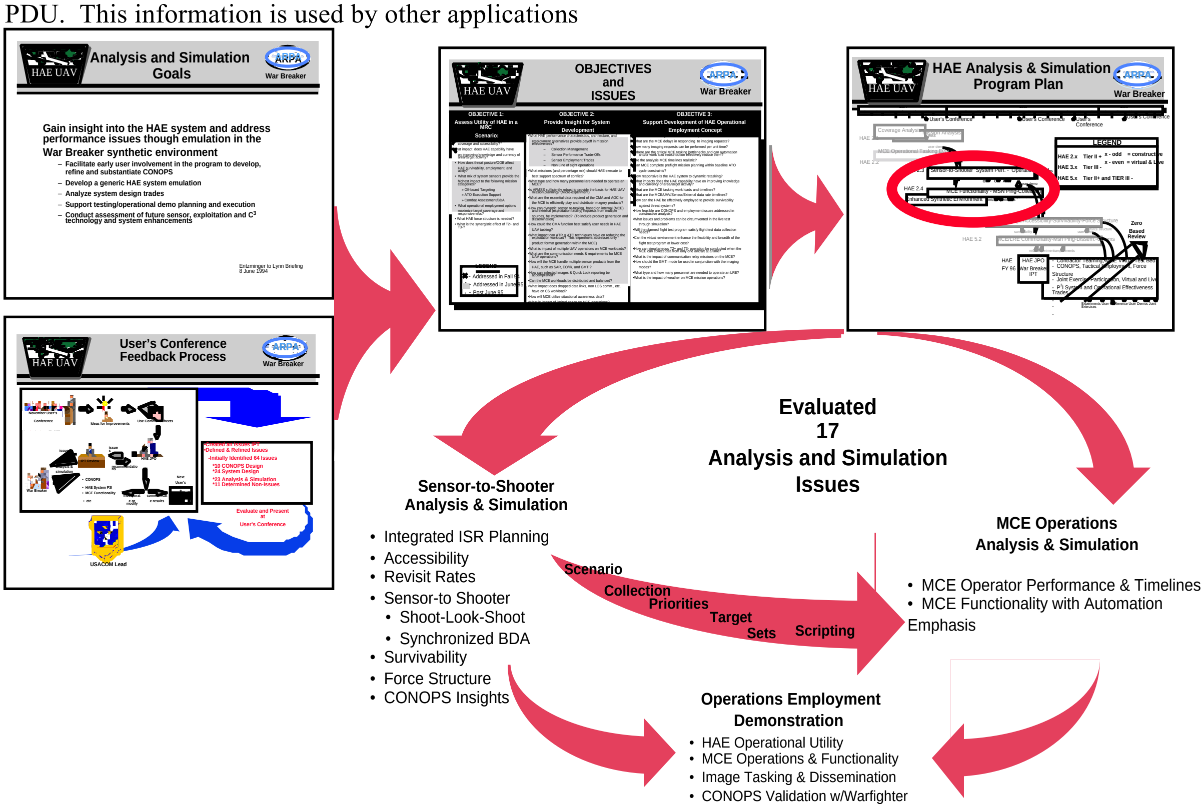


Figure 7. Virtual Prototype High Level Development Process

The development, figure 7, of the HAE MCE virtual prototype began with defining the objectives of the system. This was accomplished through the Warfighter inputs/recommendations, and DARPAs HAE Systems Capability Document (SCD).

The SCD was the defining technical specification on the performance of the system. The SCD and Issues/Objectives provided the primary inputs for the development of the virtual prototype requirement specifications.

Methodology

The first step of the development was to define the system, figure 8. The System Definition was an integration of the SCD requirements and the User Objectives. From this was the development of the functionality matrices which allocated the required functions to each workstation as well as defining the data structure, formats, and data sources for each workstation. The data structure defined in the above step lead to creation of the MCE database. The MCE database had the MCE server and the workstations as clients. The Functionality Matrices along with the Workstation Requirements defined the screen designs. The final step in this process is the requirement specifications for the simulation software.

The requirement specifications defines the screens, workstations, as well as the functions of the virtual prototype. From the requirement specifications an architecture for the virtual prototype was designed. The MCE architecture is based upon a client server design. Figure 9 below provides a top level view of the architecture. Since the original effort, the MCE has integrated the Tier 2+ contractor screens into the virtual prototype.

Once the initial system was constructed, a series of acceptance tests were conducted to validate the systems and make sure it met the original requirement specifications. Once this was completed, the systems were ready for a series of Warfighter tests.

The design and development time for the first HAE MCE virtual prototype was approximately 16 weeks of which 8 weeks was devoted to software development activities. The end result was a virtual prototype system that met or exceeded the JPO expectations. The data generated from both objective and subjective data provided insights for the JPO prior to Phase II contract award and continues into the contractor design phases. A similar approach has been recommended to US Army Space and Strategic Defense Command (SSDC) to support Aerostat and Boost Phase Intercept projects.

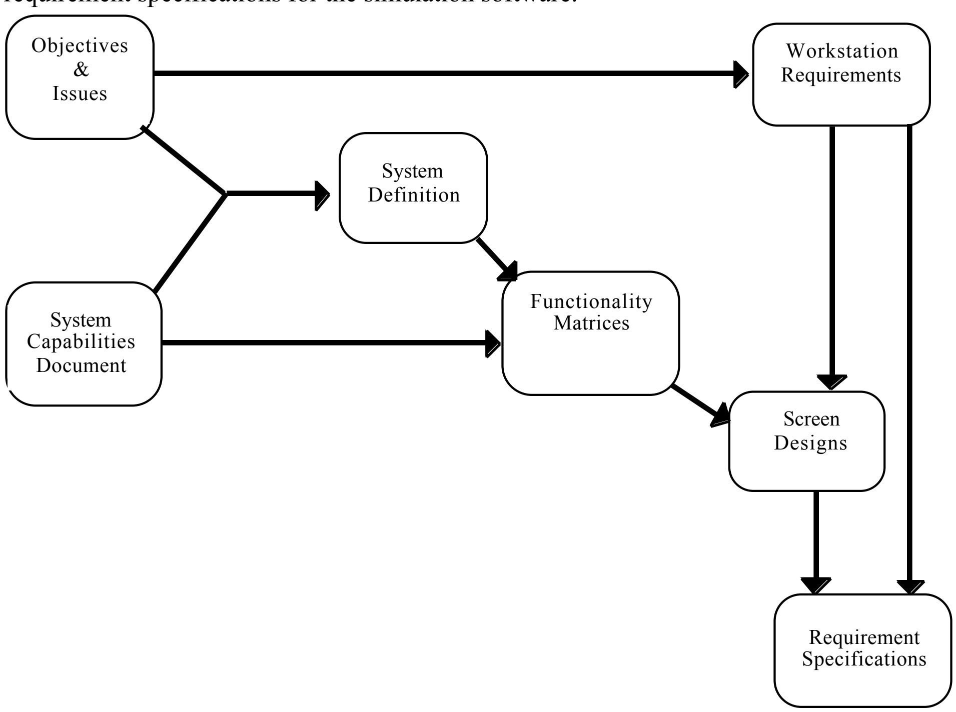


Figure 8. Virtual Prototyping and ADS development process for MCE

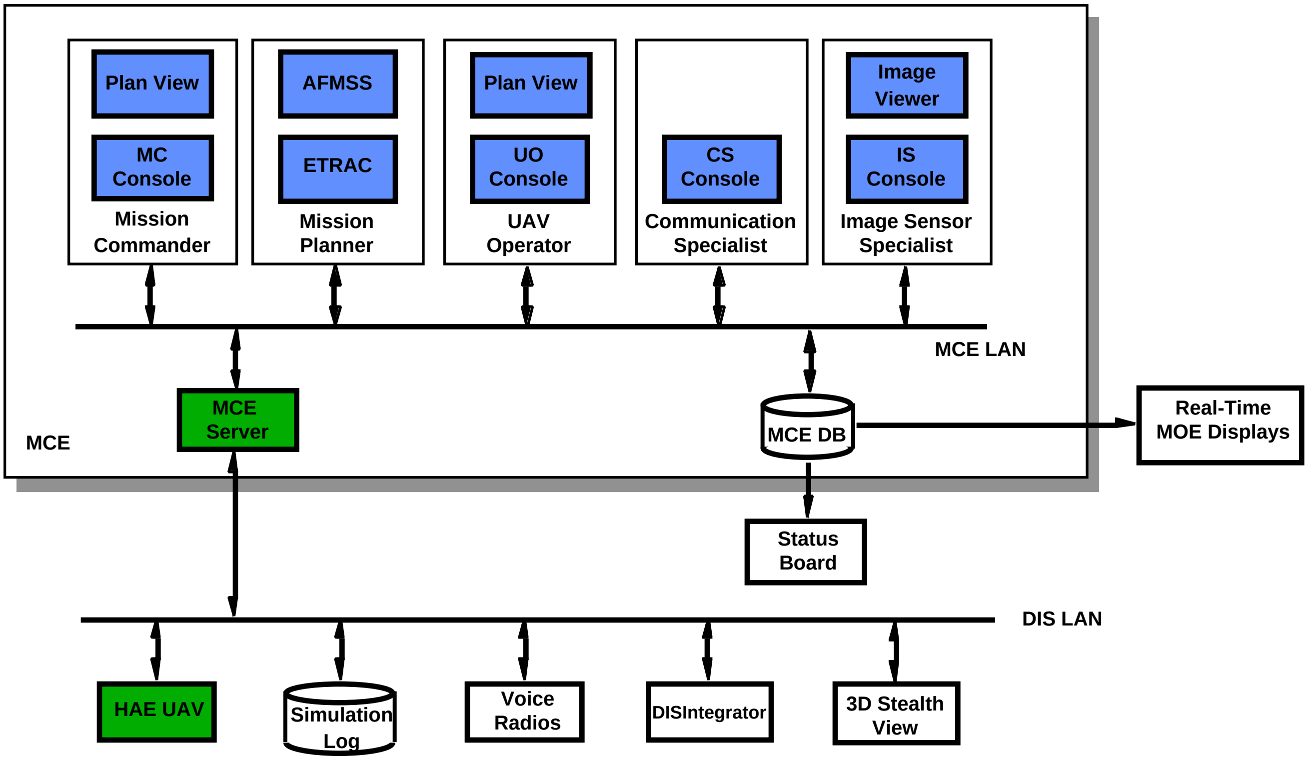


Figure 9. HAE MCE Simulation Architecture

Limitations of the Architecture

The current architecture for the HAE MCE virtual prototyping was found to have limits in supporting a technical approach of rapid integration of new HCI's. Since the original technical approach, for the earlier simulation architecture, did not intend to leave a legacy system much of the MCE virtual prototype software has limited reuse. Most of the non-recoverable software is incorporated in the MCE Server which was based upon DARPA SIMCORE product. This product is maturing and has limited support and maintainability. The simulation architecture currently used for HAE MCE is insufficient for supporting the assessment of next generation of HCIs and HAE system capabilities for the JPO. With the need to apply a different software architecture what is the potential of using HLA to support the development of the MCE virtual prototype? HLA provides a good method for future virtual prototyping. So where does DIS++ fit in this picture? HLA is an formal structure to interface simulation, real world, and data collection systems, DIS ++ is the standard by which communication occurs. DIS++ will provide the integration of Aggregate Level Protocol System (ALSP) and current DIS functionality to support the HLA. Current virtual prototypes within an ADS environment use DIS as the protocol to exchange data between simulated systems. It is fully expected that DIS ++ will also support the virtual prototyping environment in ADS.

For HAE the MCE would be a simulation object model. In the MCE the mission planning is provided by real world systems, Air Force Mission Support System (AFMSS) and Enhanced Target Radar Acquisition Correlator (ETRAC). Each of the virtual prototypes for the MCE control element and Launch Recover Element (LRE) would be object models part of an MCE and LRE federate object. The architecture would allow the virtual prototypes to quickly interface into JTF military exercises. One of the current shortfalls in the MCE design is the lack of red force threats and ground moving targets. With the current MCE server design to incorporate these capabilities would require a complete redesign and development of the server. With a design using the HLA, figure 10, the re-design would be limited to only those objects affected. If for example you now had a surface to air missile radar the affected objects would be the UAV for threat avoidance and the UAV operator for threat detection. Much of the graphical user interface and simulation would be reusable even when converting to HLA.

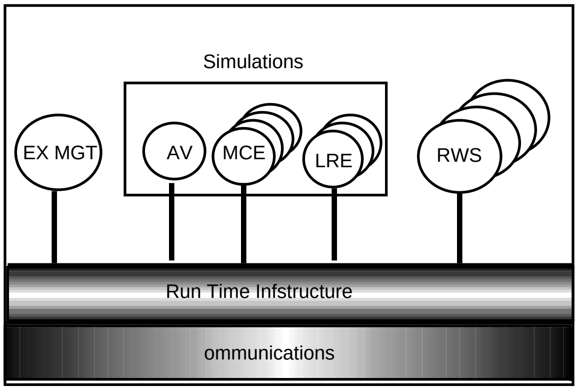


Figure 10. Next generation virtual prototype HAE MCE using HLA

The main design and development changes would be in the data structures and data handling to the workstations. The benefit of the redesign toward an HLA complaint MCE would be the enhanced ability to provide a virtual prototype HAE MCE to Warfighting exercise before the first hardware system is built. This would continue the effort to provide Warfighter context for the HAE program. Another benefit would the development of a virtual prototyping test bed. With a common framework as defined by HLA, a test bed could be created that would provide the Warfighters and acquisition managers with an ADS environment for developing the capabilities of real systems for evaluations.

SUMMARY

From the experience gained in the HAE project and the research on virtual prototyping, the impact of using ADS and virtual prototyping to support the Warfighters into the 21st century is a sound and viable approach. The budget for DoD is not expected to continue to decrease, however, it may never reach the funding levels of the early to mid 1980s. The federal government and industry need to leverage the most out of its resources to continue to maintain a stalwart defense force for the United States. As America moves into the 21st century the number and type of military actions involving the U.S. is not likely to decrease. We have the potential to use virtual prototyping in a high level architecture ADS environment to address some real concerns of the Warfighters today. With these technologies, we can provide the decision makers with critical data on choices of what to buy, when to buy, and how many to buy to create an effective and efficient power projection force. With these information age technologies, we can provide a synthetic battlefield environment of the future that integrates current technology with virtual prototypes to help our decision maker begin to see the impact of decisions in context to the Warfighters needs. There do not seem to be any foreseeable problems with the use of HLA and virtual prototyping. In fact, HLA may provide an optimal environment for the technology. Currently, DIS does support limited use of virtual prototyping in ADS, however it must be remembered that DIS was intended to be a solution for training simulation systems. The HLA does have the capability to provide the added benefits of linking engineering and analytical simulations through the RTI, and to provide a more robust environment. During the maturation of HLA, virtual prototyping using DIS and DIS++ is a viable option. Virtual prototyping can be used within ADS to create a test bed for the design and development of advanced concept systems prior to hardware manufacturing. This will provide the Warfighter and acquisition managers an environment to evaluate and identify requirements and design flaws from a systems and not a component perspective.

“The nation’s resources available for defense are limited, but the uncertainties of today require a ready force capable of responding quickly and decisively to protect our nation’s needs” (Office of the Secretary of the Army 1996). If done correctly virtual prototyping and ADS will provide a significant leverage for the Warfighter in a fiscally constraint DoD environment.

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