Live Virtual Constructive Architecture Roadmap (LVCAR) Final Report

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September, 2008

Cleared for public release (Distribution A) by the DoD Office of Security Review
(Case No. 09-S-2412) / M&S CO Project No. 06OC-TR-001

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Extended Summary

Introduction

The LVCAR Study considered three important dimensions of simulation interoperability: technical architecture, business models, and the standards evolution and management process. Technical architecture received the greatest emphasis (i.e., schedule and resources). The architectures that were considered in this study include: Aggregate-Level Simulation Protocol (ALSP), Common Training and Instrumentation Architecture (CTIA), Distributed Interactive Simulation (DIS), High-Level Architecture (HLA), and Test and Training Enabling Architecture (TENA).

LVCAR workshop participants, study performers, and the study expert team members have described problems involving the procedures and technologies used to develop mixed-architecture LVC[1] environments today. Incompatibilities between these architectures require the development of point solutions which effectively integrate the various architectures into a single, unified set of supporting simulation services. Gateway solutions to these issues have frequently resulted in exercises restricted to using only the limited set of capabilities that are common across all of the architectures, resulting in a “dumbing down” of the more capable architectures.

The lack of high-level management oversight of all existing distributed simulation architectures (as a unified resource) results in a situation where the continued growth of architectural resources is not only possible but likely, and new (potentially redundant) architectures can emerge unchecked. Such issues must be satisfactorily resolved if long-term interoperability goals are to be achieved.

Much can be accomplished with the architectures that are available today and all of the existing architectures are being improved to better serve their communities of use. The various distributed simulation architectures in use within the DoD today have all been designed to meet the needs of one or more user communities. These architectures have continued to evolve and mature based on changing user requirements. Although the different architectures have different strategies and procedures for managing this evolution (as well as different funding streams, which in turn affects the pace by which the architectures continue to evolve), members of the various user communities seem to be generally satisfied with the features and capabilities provided or planned to be provided by their architecture of choice. The existence of multiple architectures allows users to select the architecture that best meets their individual needs and thus provides an incentive for architecture developers and maintainers to competitively keep pace with technology and stay closely engaged with emerging user requirements.

Given the current user-split across the architectures, no advantage has sufficient user impact to justify consolidation. Most users have individually accepted the advantages and disadvantages of one architecture as balanced for their needs. However, the current multi-architecture state admits some amount of redundant capability, all of which receives some form of funding support

[1] The term “LVC” dates back to 1989 (per 30 April, 2007 informal communiqué by Gen. Paul Gorman (USA ret.) and Gen. Larry Welch (USAF ret)) and was officially put forth by a Defense Science Board on advanced simulation (Braddock and Thurman, 1993). See Section A in *Appendices Volume II: Supporting Data to the LVCAR Study*. LVC may be composed of all or any subset of LVC capabilities (i.e., L, V, C, LV, LC, VC, LVC).

and often requires integration. A significant problem for the LVCAR roadmap effort is to navigate this trade space to arrive at an achievable solution that maximizes the benefit for all concerned while not exceeding the resources that will be necessary to realize that solution.

Current State

Each of the architectures supports a variety of requirements tailored to the needs of the community (communities) that they serve. A comprehensive analysis of these technical requirements (detailed in the *LVCAR Study Comparative Analysis of Architectures* document) illustrates that there is a high degree of commonality between the architectures, particularly concerning HLA and TENA. While there are a few key differences that have been indicated in the specifications of requirement for these architectures, a considerable amount of capability overlap (considering only major characteristics) is clearly evident (see the *LVCAR Study Comparative Analysis of Architectures* document). At the implementation level, however, there are substantive differences among the architectures. Such differences are characterized as "wedge issues", potentially becoming barriers to achieving cross-architecture interoperability and were investigated in detail. The study finds that none of the wedge issues introduce irreconcilable incompatibilities that prevent the integration of the different architectures into mixed-architecture events. However, achieving such integration is not without cost.

The standards and/or requirements for these architectures are evolved by one of two major types of forums: those sponsored by government organizations and those sponsored by commercial standards organizations. The standards forums sponsored by government organizations include: the TENA Architecture Management Team (AMT) and the CTIA Architecture Control Board (ACB). As government-sponsored forums, these types of standards organizations are typically composed of systems engineers and technical leads of major DoD stakeholders of each architecture. They discuss requirements, design trade-offs and costs associated with the architectures. Standards forums sponsored by commercial organizations outside of government control include groups such as: the Institute of Electrical and Electronics Engineers (IEEE), Simulation Interoperability Standards Organization (SISO), and the Object Management Group (OMG). These types of organizations are composed of users, vendors, academics, and architecture developers. Like government forums, they discuss requirements, trade-offs, and other issues associated with the architectures. However, they do not have contractor support for architecture implementation. Instead, these forums rely on contributing volunteer members to develop prototypes and provide technical feedback on the architecture specifications. Table 3.3 in the *LVCAR Study Comparative Analysis of Standards Management and Evolution Processes* document delineates some of the important differences between these types of standards creating bodies.

All of these architectures have different models for policy and funding support. These models are discussed in detail in Section 3 of the *LVCAR Study Comparative Analysis of Business Models* document. At present, there appears to be a correlation between business processes and standards processes. Specifically, the middleware for architectures whose standards are led by government organizations is typically developed through funding from government organizations, and the middleware for architectures whose standards are led by commercial organizations is typically developed through funding from the commercial sector.

Figure S.1 shows the historical and projected spending on the LVC architectures. Each architecture shows an initial cost surge, when the technology is being developed. The sustaining cost is significantly lower, usually less than 1/3 of the development peak. The

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Figure S.1 Historical and Projected Annual LVC Architecture Spending by DoD[2]

sustaining cost is shared between the users and the local (using) government office in DIS and HLA, but all this cost is borne by the DoD enterprise. Some HLA sustaining cost is absorbed by international parties, but it has been excluded from this chart. TENA has had an extended development phase, choosing to add more functionality over time. It may enter a pure sustainment phase in the future.

History shows that the number of available architectures tends to increase over time and that once a community of use develops around an architecture, that architecture is very likely to continue to be used regardless of new architectural developments. By definition, the inter-architecture communication problem only occurs during mixed-architecture events. While these are currently a small percentage of the number of all DoD simulation exercises, the number of mixed-architecture events is expected to increase over time (see Section C of the *Appendices Volume I: Supporting Analyses to the LVCAR Study*).

Fundamental Precepts

During development of the desired state properties, implementation strategies, and subsequent recommendations for LVCAR Study, the Expert Team converged on a core set of beliefs, axiomatic 'meta-recommendations' that underlie our approach and provide guiding principles for implementation and execution of the roadmap. These principles, presented below, represent the four fundamental precepts to the LVCAR Study Final Report.

Fundamental Precept #1: Do No Harm. The DoD should not take any immediate action to discontinue any of the existing simulation architectures. There is a considerable degree of

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2 These estimates are not comparable across architectures. There are differences in the fundamental assumptions of each, differences in the architectural boundaries, and differences in the user base size supported by each. The figure is best used to represent the lower bounds, projections and trends of LVC architecture expenditures at a gross level.

consensus within the LVC user community that a long-term strategy based on architecture convergence would benefit the DoD. However, it is also understood that there are many design issues that must be resolved prior to implementing such a strategy, and that the actual implementation needs to be a well-planned, deliberate, evolutionary process to avoid adversely impacting participating user communities. Because of these considerations, it would be unwise to eliminate support for any of the existing simulation architectures in the near-term. Rather, as the differences among the architectures are gradually reduced, it should be the users themselves that decide if and when it is appropriate to merge their architectures into some smaller set based on both technical and business concerns. Any attempt by the DoD to mandate a convergence solution on an unwilling user base is certain to meet strong resistance and likely to fail.

Fundamental Precept #2: Interoperability is not Free. The DoD must make the necessary investments to enable implementation of the activities described in the LVC Roadmap. LVC interoperability is not free. It is not reasonable to expect that LVC interoperability goals can be met with little or no investment. Since the return on LVC investments is nearly impossible to accurately quantify in the near-term, it is understood that major new up-front investments are difficult to justify. In recognition of this fact, the Roadmap has taken a long-term approach which requires only limited investment early in its implementation, with subsequent investments dependent on demonstrable progress. Without the necessary investments, the LVC Roadmap is nothing more than a blueprint of what is possible to accomplish, with no mechanism to realize the associated benefits.

Fundamental Precept #3: Start with Small Steps. The DoD should take immediate action to improve interoperability among existing simulation architectures. The vast range of technical problems currently associated with the development and execution of mixed-architecture LVC environments is well recognized. Such problems increase the technical risk associated with the use of these mixed-architecture environments, and require considerable resources to address. While architecture convergence would lessen (and even eliminate) several of these problems, it is not practical to expect any significant degree of convergence to occur for many years. Instead, LVC users need near-term solutions that reduce both cost and technical risk until such time as architecture convergence can occur. These solutions include actions such as improved gateways/bridges, common object models, and common development/execution processes. Many of these solutions can be implemented at low cost, and provide significant near- and mid-term value to the LVC community.

Fundamental Precept #4: Provide Central Management[3]. The DoD must establish a centralized management structure that can perform Department-wide oversight of M&S resources and activities across developer and user organizations. A strong centralized management team is necessary to prevent further divergence and to effectively enable the architecture convergence strategy. This team needs to have considerable influence on the organizations that evolve the existing architectures, and must also have influence on funding decisions related to future LVC architecture development activities. Without centralized DoD management, existing architecture communities will continue to operate in line with their own self-interests, and the broader corporate needs of the DoD will be treated as secondary issues that are likely to continue to be ignored as concerns that are not germane to the local problems.

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[3] The Government Management Team has supplied a separate report on management issues (see *LVCAR Study Execution Management*).

The LVC Architecture Roadmap

Nineteen activities spanning the architecture, business, and standards dimensions have been included for consideration in the LVC Architecture Roadmap. The execution of three of these activities is dependent on the results of earlier activities identified as Risk Reduction Investigations (RRIs). All of the architecture activities, except for the one dependent on an RRI, have been considered in light of their potential return given some estimated investment. The analyses supporting the development of an architecture activity's Return On Investment (ROI) can be found in Section C of *Appendices Volume I: Supporting Analyses to the LVCAR Study* and the results of the ROI analysis can be found in the activity description found in Section A of that same document.

Throughout the report, there are three different types of recommendations offered. These include: fundamental precepts, roadmap activities, and Expert Team tips. Table S.1 below characterizes these three recommendation types and explains the basis on which these recommendations are formed.

Table S.1 Categories of Recommendations in LVCAR Final Report

<table>
<tr><th colspan="2">Recommendation Type</th><th>Basis</th></tr>
<tr><td colspan="2">Fundamental Precepts</td><td>Consensus of Study Team and Expert Team</td></tr>
<tr><td colspan="2">Expert Team Tips</td><td>Expert Team agreed, but no cost estimate or value metric</td></tr>
<tr><td rowspan="2">Roadmap Activities</td><td>Architecture Activities</td><td>Focused on DoD-level investments and characterized by an ROI analysis based on expert data</td></tr>
<tr><td>Standards and Business Model Activities</td><td>Focused on DoD-level investments, but not supported by an ROI analysis</td></tr>
</table>

Provided below are the summary focus area recommendations that drive the investment roadmap activities along with general related recommendations. These recommendations are further elaborated with supporting rationale and data throughout the final report. The DoD should:

<u>Technical Architecture</u>

- *Take actions that can reduce or eliminate the barriers to interoperability across the architectures*
- *Direct efforts towards creating and providing standard resources, such as common gateways, common componentized object models, and common federation agreements*
- *Provide a free highly-customizable and well-documented set of gateway products to the LVC user community*
- *Move beyond the debate of technical interoperability and start focusing on the semantics of these systems*

<u>Standards</u>

- *Develop adequate spheres of influence in relevant standards organizations (e.g., SISO) and related communities*
- *Develop a standards evolution processes that can provide required stability, yet be flexible and responsive to users*

Business Model

- *Identify and establish an LVC Keystone[4] to gather and disseminate information across the DoD functional communities enabled by M&S, representing a unified consensus of opinion*
- *Remove cost as a user decision factor when adopingt a specific architecure ("Balance the marketplace" across architecture approaches") so that investments are made in terms of their overall benefit to the DoD enterprise*
- *Evaluate the potential impact of ongoing open source RTI efforts on the interoperability of M&S systems across the DoD and consider the suitability of open source as a mechanism for balancing the marketplace.*
- *Identify influential Federation Proponents (JNTC, NCTE, JMETC, large PEOs, etc) to integrate emerging developments in support of future architectural solution(s)*

General

- *Provide resources to address LVC issues that are not directly architecture-related (e.g., semantic interoperability, conceptual modeling, etc.)*
- *Lead efforts to standardize or automate translations of data/scenario inputs to simulations and data capture formats*
- *Provide technical positions in support of M&S enterprise decisions*
- *Develop and implement processes that support solid, performance-based decision-making to evaluate the efficacy of the roadmap, make mid-course corrections, and develop the next-generation of goals*

Table S.2 below focuses exclusively on DoD-level investments, the Roadmap Activities. These are seen as common goods particularly worthy of DoD-level attention. Table S.2's recommendations fall largely into three categories: architecture, business model, and standards[5]. Within each category, the table indicates the desirable investment and priority (highest: 1, medium: 2, or lowest: 3) for that investment. There is a correlation between calculated ROI for an activity and assigned priority for that activity. The table also recommends a likely coordinating agent and; estimates the amount of investment, immediate and recurring over 10 years, that might be needed. In line with Fundamental Precept #4, the central management must direct technical efforts to perform the roadmap activities. In most cases the study recommends that management use the Modeling and Simulation Steering Committee (MSSC), or, through the MSSC, contract engineers generically referred to as the Roadmap Execution Team (RET). Selection of performers is one clear central management responsibility. A few cases require independence from contractor profit motives, as would be found in a government laboratory, a Federally Funded Research and Development Center (FFRDC) or a University Affiliated Research Center (UARC). These efforts are generically assigned to a Trusted Agent Team (TAT) that is performing some RRI.

The Architecture activities are designed to enhance the interoperability of mixed-architecture events, while preserving options and positioning the community for some degree of architecture convergence in the future. The activities are founded on the idea that having multiple

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4 See the *LVCAR Study Comparative Analysis of the Business Models* document for a full explanation of the term. In a healthy ecosystem the keystone organism serves as the leader of the ecosystem.

5 While management is not the focus of this report, there is also one recommendation stemming from all three of these dimensions that applies to management.

Table S.2 Summary of Investment Recommendations

		Investments	Initial Investment	Bounds of 10-year Investment	Coordinated by
Architecture Activities	1	Common components of architecture-independent object models	TDB	TDB	RET
	1	Describe and document a common, architecture-independent systems engineering process	TBD	TBD	RET
	1	Create common, reusable federation agreement template	TBD	TBD	RET
	2	Analyze, plan and implement improvements to the processes and infrastructure supporting M&S asset reuse	TBD	TBD	MSSC and RET
	2	Produce and/or enable reusable development tools	TBD	TBD	RET
	1	RRI – Convergence feasibility determination and design	TBD	N/A	TAT
	3	Convergence plan	TBD	TBD	RET
	3	Convergence implementation	RRI dependent	RRI dependent	RET
	1	Produce common gateways and bridges	TBD	TBD	RET
	2	Specify a resource or capability to facilitate pre-integration systems readiness	TBD	TBD	RET
Standards Activities	2	Make IEEE standards more accessible to LVC community.	TBD	N/A	MSSC
	1	Engage SISO and the broader LVC community	TBD	TBD	MSSC
	2	Coordinate activities and fund participation in commercial standards development groups	TBD	TBD	MSSC
	1	RRI - Increase sphere of influence in SISO	TBD	N/A	MSSC
	1	Develop evolutionary growth path for LVC standards	TBD	N/A	MSSC
Business Activities	1	Identify and establish an LVC Keystone	TBD	TBD	MSSC
	1	RRI – Balance the marketplace	TBD	N/A	TAT
	3	Balance the marketplace	RRI dependent	RRI dependent	MSSC
Management Activities	1	Decision Support Data	TBD	TBD	MSSC

architectures available for use is desirable and that the best way forward is to take actions that can reduce or eliminate the barriers to interoperability between the existing architectures and protocols. More specifically, this strategy acknowledges that the existing architectures have been created, have evolved, and are being maintained to meet the specific needs of their constituent communities. Elimination of any architecture should only occur as a natural result of disuse. Modification and management of the existing architectures is left to the owning communities as the best option to ensure meeting the needs of the various user communities, both throughout the DoD and among the Department's coalition partners. To resolve the interoperability problems, efforts should be directed towards creating and providing standard resources, such as common gateways, common componentized object models, and common federation agreements, which can resolve the problems identified in the *LVCAR Study Comparative Analysis of the Architectures* document and render integration of the multiple architectures an efficient and nearly transparent process. In effect, these actions will create the perception of a single architecture that supports all the diverse simulation systems, even though the systems will actually be serviced by an "architecture of architectures", comprised of as many different architectures and protocols as are required to interconnect the participating simulation systems.

The Architecture work also places great emphasis on the need to expand the Department's vision for M&S interoperability by moving beyond the debate of technical interoperability and encouraging focus on the semantics of these systems. This more elegant focus will direct us to a path towards improving both the effectiveness[6] of LVC applications, as well as the costs of LVC applications. Technical interoperability has been a problem, but it is clearly tractable; solutions to the technical interoperability problems exist and they should no longer consume all of our attention. From this point forward, the technical vision for the next phase of LVC in the DoD must raise the bar.

Getting to the point where the bar can be raised, however, would seemingly be well served by a shift in business practices. Currently, M&S development and use is spread across a large number of program elements and authority for executing those funds is spread across an equally large number of organizations. There is no single organization which controls both policy and funding under a single mission umbrella. The differences in institutional investment and cost of entry for the users have resulted in a marketplace including an array of somewhat redundant key products that cannot compete on technical merit alone. The Business Model activities are designed to move the costs and control of the architectures and related tools to a common environment where access and risk are spread across a greater constituency. This also improves the potential for innovation and reduces barriers to entry. Thus, the Business Model work makes a case for harnessing the power of M&S intellectual capital and focusing diverse fiscal resources through the instantiation of a common workspace to share architecture and tool advancements and to serve as a unifying place for change to happen.

For change to propagate, however, adequate spheres of influence in relevant standards organizations and related communities (e.g., C4I, DISA, etc.) must be developed. This will better ensure that DoD interests are well served. Also, standards processes must be coordinated to provide the required stability, while preserving flexibility and responsiveness to users. The Standards activities are designed to develop this organizational influence, promote flexible standards evolution processes, and to build a sense of community.

[6] It will improve the validity of analyses and reduce the possibility of negative training.

Finally, to measure the effects of these changes and plan for the future, the MSSC requires improved decision-making data. This includes data from the technical domain, business domain, and standards domain. While this report does not focus on management or leadership issues, it does recognize and address the need to provide improved decision support data for management use.

Ultimately, the goal must be an environment in which the MSSC can leverage its millions to influence the billions spent on distributed M&S and LVC across the Department. This is possible. Microsoft, for example, has profound influence over the information technology (IT) marketplace; yet in "both its revenue and number of employees represent about 0.05% of the total figures for the ecosystem." (Iansiti and Levein, 2004) This example suggests that it is possible for a central M&S agency with a budget of merely $35M to have a substantial influence on the estimated $10B (Cuda and Frieders, 2007) spent annually on M&S in the DoD.

On 16 July 2007, the U. S. House of Representatives passed House Resolution 487, "recognizing the contribution of modeling and simulation technology to the security and prosperity of the United States, recognizing modeling and simulation as a National Critical Technology" and commending members of the modeling and simulation community in government, industry, and academia who have contributed. We believe that the House has a vision for M&S in the United States and we believe that the DoD, as a corporate entity, can either be a driving force in shaping that vision or can go along for the ride. The vision for this Roadmap is for the DoD, as a corporate entity, to be a driving force in the way forward for distributed M&S and LVC as a technology supporting the security and prosperity of the United States.

This document does not stand alone in that purpose. The LVCAR Study has produced thirteen documents: a main report with three volumes of appendices and 9 companion documents. In their entirety, they represent the study's final report. These items are provided separately. To facilitate the reader's ability to navigate these documents and focus attention on subjects of interest, a brief description of and pointer to each of these stand-alone documents is presented in this document.

Acronyms

ABCS	Army Battle Command System
ALSP	Aggregate Level Simulation Protocol
AMG	Architecture Management Group
AMT	Architecture Management Team
AMG	Architecture Management Group
API	Application Programmers Interface
AT&L	Acquisition, Technology and Logistics
BLCSE	Battle Lab Collaborative Simulation Environment
BML	Battle Management Language
C2	Command and Control
C4ISR	Command, Control, Communications, Computer, Intelligence, Surveillance and Reconnaissance
CD	Compact Disc
CDD	Capability Development Document
COA	Course of Action
COI	Community of Interest
CONOPS	Concept of Operations
COTS	Commercial off the Shelf
CTIA	Common Training Instrumentation Architecture
DDM	Data Distribution Management
DDS	Data Distribution Services
DIS	Distributed Interactive Simulation
DMSO	Defense Modeling and Simulation Office
DOD	Department of Defense
DODAF	Department of Defense Architecture Framework
DMO	Distributed Mission Operations
DOD	Department of Defense
DODI	Department of Defense Instruction
DTRA	Defense Threat Reduction Agency
DVD	Digital Versatile Disc
FEDEP	Federation Development and Execution Process
FOM	Federation Object Models
FOSS	Free and Open Source Software
GIG	Global Information Grid
GOTS	Government off the Shelf
GTRI	Georgia Tech Research Institute
HLA	High Level Architecture
HLA RTI	High Level Architecture Run Time Infrastructure
I/ITSEC	Interservice Industry Training Simulation and Education Conference
IDA	Institute for Defense Analyses
IDL	Interface Description Language
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IPR	Intellectual Property Rights
ISO	International Organization for Standardization
JBML	Joint Battle Management Language
JC3IEDM	Joint Command, Control and Consultation Information Exchange Data Model

JCIDS	Joint Capabilities Integration and Development System
JFCOM	Joint Forces Command
JHU APL	Johns Hopkins University Applied Physics Lab
JLVC	Joint Live Virtual Constructive
JNTC	Joint National Training Capability
JTEM	Joint Test and Evaluation Methodology
LVC	Live Virtual Constructive
LVCAR	Live Virtual Constructive Architecture Roadmap
LVC-IA	Live Virtual Constructive Integrating Architecture
M & S	Modeling and Simulation
M&S CO	Modeling and Simulation Coordination Office
M&S IPT	M&S Integrated Process Team
M&S SC	M&S Steering Committee
MLS	Multi-level Security
MOU	Memorandum of Understanding
MSDL	Mission Scenario Definition Language
NASM	National Air Space Model
NASMP	Naval Aviation Simulation Master Plan
NATO	North Atlantic Treaty Organization
NGA	National Geospatial-Intelligence Agency
NR-KPP	Net Read – Key Performance Parameter
OM	Object Model
OMG	Object Management Group
OSD	Office of the Secretary of Defense
OSS	Open Source Software
OTD	Open Technology Development
PFP	Partnership for Peace
RFI	Request for Information
ROI	Return on Investment
SAF	Semi-automated Forces
SEAS	Synthetic Environment for Analysis and Simulations
SDO	Standards Developing Organizations
SEDRIS	Synthetic Environment Data Representation and Interchange Specification
SISO	Simulation Interoperability Standards Organization
SOA	Service Oriented Architecture
SSO	Standards Setting Organizations
TDL	TENA Definition Language
TENA	Test and Training Enabling Architecture
UML	Unified Modeling Language
USD	Undersecretary of Defense
US JFCOM	United States Joint Forces Command
W3C	World Wide Web Consortium
WG	Working Group
XML	Extensible Markup Language

1. Overview of the LVCAR Final Report

> "After more than a decade of great achievements that have made interoperability possible, the concerns of standards writers and enforcers should surely include the rule 'First, do no harm.'"
>
> Dr. Paul Davis, RAND

1.1 Purpose and Scope

The purpose of the Live-Virtual-Constructive Architecture Roadmap (LVCAR) Study was to develop a future vision and supporting strategy for achieving significant interoperability improvements in LVC simulation environments[7]. To support the implementation of this strategy, this document, the LVCAR final report, specifies near-, mid-, and long-term actions that collectively delineate a roadmap to guide the evolution from the current state of LVC environment development and achieve the desired future vision. The Roadmap addresses three main areas of concern; the desired future integrating architecture(s), the desired business model(s), and the manner in which standards should be evolved and compliance evaluated.

The LVCAR Roadmap is intended to be a living document, to stimulate a process of continual improvement to guide actions and decision-making on the development and employment of LVC environments across the DoD. For context and scope, this Roadmap sets the course for achieving the Department's vision for LVC integrating architectures over the next 10 years. Understandably, in a field dependent on technologies and processes from so many other organizations, mid-course adjustments are anticipated.

1.2 Supporting Documents

This document does not stand alone in this purpose. The LVCAR Study has produced twelve documents: a main report with three volumes of appendices and 9 companion documents. In their entirety, they represent the study's final report. These items are provided separately to facilitate the reader's ability to navigate these documents and focus attention on subjects of interest, a brief description of and pointer to each of these stand-alone documents is presented in this document, a sort of "meta-document". The remainder of Section 1.2 provides a synopsis of the supporting documents.

1.2.1 LVCAR Study Functional Requirements and Use Cases

This document reports the current and projected LVC architecture functional requirements and presents a mapping between these requirements and the use cases analyzed. Additionally, the use cases are presented in an appendix to that document.

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[7] The term "LVC" dates back to 1989 (per 30 April, 2007 informal communiqué by Gen. Paul Gorman (USA ret.) and Gen. Larry Welch (USAF ret)) and was officially put forth by a Defense Science Board on advanced simulation (Braddock and Thurman, 1993). See Section A of the *Appendices Volume II: Supporting Data to the LVCAR Study*. LVC may be composed of all or any subset of LVC capabilities (i.e., L, V, C, LV, LC, VC, LVC).

1.2.2 LVCAR Study Comparative Analysis of Architectures

This document presents a technical comparison of the integrating architectures, forms a vision for a unified LVCAR architecture, builds a number of strategies for evaluation in an analysis of alternatives, prunes those strategies, and then develops a lower level of detail from the most promising strategies using a "best of breed" approach to achieve the LVCAR architecture goal state. Finally, it estimates return-on-investment (ROI) for each of the supporting activities and offers recommendations on how to implement them.

1.2.3 LVCAR Study Comparative Analysis of Business Models

This document identifies and compares the business models associated with the LVC Integrating Architectures considered in LVCAR Study, develops a goal state for the LVCAR business model, formulates a number of alternative strategies for evaluation to achieve that goal state, and offers a recommendation on selected strategy and its implementation.

1.2.4 LVCAR Study Comparative Analysis of Standards Management

This document presents the standards evolution processes being considered in LVCAR Study, characterizes the current state of these processes, details and compares attributes, formulates a goal state for LVCAR standards evolution and management processes, develops a number of alternative strategies to achieve that goal state, and offers a recommendation on selected strategy and its implementation.

1.2.5 LVCAR Study Workshop Reports

Over the course of the LVCAR Study, the Study Team conducted four Working Group Workshops. The details (e.g., agenda, attendance, presentations, major discussion points, survey feedback, conclusions, etc.) of four LVCAR Workshops 1-4 are documented as informal deliverables.

1.2.5.1 LVCAR Study Workshop #1 Report

This document presents the details of the 17-18 July, 2007 LVCAR Study Working Group Workshop #1 conducted in Annapolis, MD. This workshop, formed largely around a grass-roots requirements collection effort, revealed that the LVC user base believes that the existing architectures adequately meet existing requirements, identified a number of future requirements for consideration, and importantly, indicated that a number of these desired capabilities could be implemented in the existing architectures without the need for a major redesign.

1.2.5.2 LVCAR Study Workshop #2 Report

This document presents the details of the 10-11 September, 2007 LVCAR Study Working Group Workshop #2 conducted in Suffolk, VA. At this workshop, the Architecture, Business Model, and Standards Management dimensions conducted individual breakout sessions. A few major themes gathered across the sessions and panel discussion included the need to focus on improvements in terms of efficiencies, the need for active enterprise-level management in promoting interoperability and enforcing policies, and the need for improved semantic interoperability.

1.2.5.3 LVCAR Study Workshop #3 Report

This document presents the details of the 19-20 February, 2008 LVCAR Study Working Group Workshop #3 conducted in Virginia Beach, VA. At this workshop, the Architecture, Business Model, and Standards Management dimensions conducted individual breakout sessions. Also, an additional dimension, Management was considered. Of significance was the Architecture

Breakout discussion of how the Architecture strategies were pruned, the discussion of a number of potential business scenarios during the Business Model breakout, the determination that the Hybrid approach being considered by the Standards Team had strong endorsement of the workshop participants, and recognition that the management dimension of LVCAR also deserves attention.

1.2.5.4 LVCAR Study Workshop #4 Report

This document presents the details of the 24 June, 2008 LVCAR Study Working Group Workshop #4 conducted in Suffolk, VA. At this workshop, each workshop participant was provided a package of survey instruments to be completed during the breakout sessions and returned at the end of the day. For each proposed activity, a survey gathered participant opinion on the overall desirability of the activity, the utility of the Business Actions, and the utility of the Standards Actions. Free comment questions provided a means for the participant to share other feedback on the activity and its actions. Importantly, none of the proposals were rejected out of hand, and even the lowest consensus levels were favorable by 2 to 1. Many specific concerns were raised. The combined community insight captured in the workshop improved each of the proposed recommendations and guided their combination into an LVCAR roadmap that is expected to have strong support.

1.2.5.5 LVCAR Study Execution Management

This document presents on management organizational and procedural options that will be necessary to impkement the LVCAR roadmap. While the information provided herein was not required by the terms of the study, it became obvious that a discussion of management recommendatiosn was necessary for completeness.

1.2.6 Appendices

There are three volumes of appendices accompanying this document: one on supporting analyses, a second on supporting data, and a third on all of the meeting documentation. These are provided in some detail, in the spirit of promoting transparency and openness in the analysis, which have been guiding principles during the conduct of the study.

1.2.6.1 Appendices Volume I: Supporting Analyses to the LVCAR Study

This document includes 6 sections that detail the LVCAR Activities, Runtime Infrastructure (RTI) Subsetting Case Study, ROI Methodology and Results, Definitions, Relationship to Other Work and Crossroads Issues. Throughout the remainder of the LVCAR Final Report, sections of the subject appendix document are referenced as “Section X of the *Appendices Volume I: Supporting Analyses to the LVCAR Study”*, where “X” represents the section where the referenced material resides within Appendices Volume I.

1.2.6.2 Appendices Volume II: Supporting Data to the LVCAR Study

This document includes 9 sections that detail a number of formal and informal data calls, literature search results, Expert Team surveys, requests for use cases, etc. Throughout the remainder of the LVCAR Final Report, sections of the subject appendix document are referenced as “Section X of the *Appendices Volume II: Supporting Data to the LVCAR Study”*, where “X” represents the section where the referenced material resides within Appendices Volume II.

1.2.6.3 Appendices Volume III: LVCAR Expert Team Meeting Documentation

During Phase I, the LVCAR Study conducted 12 formal Expert Meetings. The details (e.g., agenda, attendance, presentations, major discussion points, etc.) of each of these meetings are documented in Sections 1-12, each of which is characterized below. Throughout the remainder of the LVCAR Final Report, sections of the subject appendix document are referenced as "Meeting X Section of the *Appendices Volume III: LVCAR Expert Team Meeting Documentation"*, where "X" represents the meeting where the referenced material resides within Appendices Volume III.

1.2.6.3.1 9 May 2007 LVCAR Study Expert Team Meeting

Available for review in the *Appendices Volume III: LVCAR Expert Team Meeting Documentation* - Meeting 1 Section, this document presents the details of the 9 May, 2007 LVCAR Study Expert Team Meeting conducted at the Hampton Roads Convention Center, Hampton, VA. This was the kick-off of the Expert Team Meetings, was largely introductory in nature, and discussed general planning concepts and the way-ahead.

1.2.6.3.2 15 June 2007 LVCAR Study Expert Team Meeting

Available for review in the *Appendices Volume III: LVCAR Expert Team Meeting Documentation* - Meeting 2 Section, this document presents the details of the 15 June, 2007 LVCAR Study Expert Team Meeting conducted at the Institute for Defense Analyses, Alexandria, VA. This meeting focused around an introduction to a number of the architectures by inviting briefs from the architectural experts.

1.2.6.3.3 20 August 2007 LVCAR Study Expert Team Meeting

Available for review in the *Appendices Volume III: LVCAR Expert Team Meeting Documentation* - Meeting 3 Section, this document presents the details of the 20 August, 2007 LVCAR Study Expert Team Meeting conducted at the offices of Alion Science and Technology, Suffolk, VA. In this meeting, the Architecture Team presented analyses that characterized the "wedge issues" between the architectures, and the requirements collected to date were reviewed.

1.2.6.3.4 17 October 2007 LVCAR Study Expert Team Meeting

Available for review in the *Appendices Volume III: LVCAR Expert Team Meeting Documentation* - Meeting 4 Section, this document presents the details of the 17 October, 2007 LVCAR Study Expert Team Meeting conducted at the offices of John Hopkins University Applied Physics Labs, Laurel, MD. In this meeting, the architectural strategies were introduced and deliberated. Further, pros and cons of these strategies were collected from Expert Team members. Also, the Standards Team worked to collect data characterizing attributes of the standards evolution/management process. Finally, a progress report on requirements collection was delivered.

1.2.6.3.5 6 November 2007 LVCAR Study Expert Team Meeting

Available for review in the *Appendices Volume III: LVCAR Expert Team Meeting Documentation* - Meeting 5 Section, this document presents the details of the 6-7 November, 2007 LVCAR Study Expert Team Meeting conducted at the Institute for Defense Analyses, Alexandria, VA. In this meeting, we discussed potential integration strategies for the strategies across the three dimensions, polled the Expert Team on the most favorable architecture strategies contemplated to date, and introduced initial thoughts leading towards the development of Standards Evolution and Business Model strategies.

1.2.6.3.6 27 November 2007 LVCAR Study Expert Team Meeting

Available for review in the *Appendices Volume III: LVCAR Expert Team Meeting Documentation* - Meeting 6 Section, this document presents the details of the 27 November, 2007 LVCAR Study Expert Team Meeting conducted during the Interservice/Industry Training Simulation and Education Conference (I/ITSEC) and held at the Peabody Hotel in Orlando, FL. In this meeting, we continued discussions on the Standards, Management, and Business Model efforts and debated best methodologies for developing the strategies for each.

1.2.6.3.7 17–18 January 2008 LVCAR Study Business Model Tiger Team Meeting

Available for review in the *Appendices Volume III: LVCAR Expert Team Meeting Documentation* - Meeting 7 Section, this document presents the details of the 27 November, 2007 LVCAR Study Business Model Tiger Team Meeting held at the Institute for Defense Analyses, Alexandria, VA. In this meeting, we reviewed progress made to date, evaluated the study process applied, the constraints on that process, and the requirements of the deliverable. Finally, we started to develop the way ahead to finish the comparative analysis task.

1.2.6.3.8 23-24 January 2008 LVCAR Study Expert Team Meeting

Available for review in the *Appendices Volume III: LVCAR Expert Team Meeting Documentation* - Meeting 8 Section, this document presents the details of the 23 – 24 January, 2008 LVCAR Study Expert Team Meeting held at the Institute for Defense Analyses, Alexandria, VA. At this meeting, the LVCAR Study Team and Expert Team reviewed the Interim Report. Also, the Expert Team provided feedback on a whitepaper focusing on architecture strategies, as well as on progress updates on the development of the business model and standards strategies.

1.2.6.3.9 21 February 2008 LVCAR Study Architecture Tiger Team Meeting

Available for review in the *Appendices Volume III: LVCAR Expert Team Meeting Documentation* - Meeting 9 Section, this document presents the details of the 21 February, 2008 LVCAR Study Architecture Tiger Team Meeting conducted in conjunction with the 3rd LVCAR Workshop (see Section 1.2.5.3) and held at the Alion facility in Suffolk, VA. To begin the definition of the roadmap's architectural strategy, in this meeting, a select team of technical experts reviewed requirements collected to date and the wedge issues identified across the architectures with an eye towards identifying candidate services for convergence.

1.2.6.3.10 5-6 March 2008 LVCAR Study Business Model Tiger Team Meeting

Available for review in the *Appendices Volume III: LVCAR Expert Team Meeting Documentation* - Meeting 10 Section, this document presents the details of the 5-6 March, 2008 LVCAR Study Business Model Tiger Team Meeting held at the Institute for Defense Analyses, Alexandria, VA. In this meeting, the Business Model Tiger Team considered business model implications of the roadmap activities proposed by Architecture Team. Additionally, the most recent work on the comparative analysis document was reviewed, and a number of candidate strategies were developed for further consideration by the Business Model Team.

1.2.6.3.11 27-28 March 2008 LVCAR Study Expert Team Meeting

Available for review in the *Appendices Volume III: LVCAR Expert Team Meeting Documentation* - Meeting 11 Section,, this document presents the details of the 27-28 March, 2008 LVCAR Study Expert Team Meeting held at the Institute for Defense Analyses, Alexandria, VA. In this meeting, the Expert Team reviewed work on the Business Model Comparative Analysis and the candidate strategies developed to date. Further, they reviewed management considerations, architecture activities, and compliance procedures for the various standards being reviewed in the study. Finally, the Expert Team participated in first integration exercise (across architecture, business model, standards, and management) designed to identify potential points of conflict that would require extra attention during the integration phase of the study.

1.2.6.3.12 8-9 May 2008 LVCAR Study Expert Team Meeting

Available for review in the *Appendices Volume III: LVCAR Expert Team Meeting Documentation* - Meeting 12 Section, this document presents the details of the 8-9 May, 2008 LVCAR Study Expert Team Meeting held at the Institute for Defense Analyses, Alexandria, VA. In this meeting, the results of the ROI Survey were reviewed and assumptions used by individual Expert Team members were discussed. Also, much emphasis was placed on generating cost estimates for each of the architecture activities being proposed. Finally, Expert Team recommendations were reviewed and discussed. Those that had strong support of the majority of the Expert Team are included in the LVCAR Final Report as Expert Team Tips and Fundamental Precepts.

1.3 Document Roadmap

Section 1 introduced the LVCAR Final Report document. Subsequent sections will further describe the actual study to include: processes employed, establishment of baseline, points of uncertainty, study observations, establishment of the goal state, and the roadmap intended to achieve that goal state. Specifically, Section 2 “Introduction to the LVCAR Study” describes the LVCAR Study and presents the analytic framework employed. Section 3 “Current State” establishes the as-is condition, or baseline, of LVC in DoD with respect to technical implementations and requirements of the architectures, supporting business models, and standards management processes. Section 4 “Observations” then describes observations made throughout the execution of the Study that are relevant to the proposed goal state and the Roadmap subsequently designed to implement that vision state. Section 5 “Vision and Roadmap Initiatives” presents the LVCAR vision and initiatives for producing interoperability improvements. Finally, the LVCAR Final Report ends with Section 6 “Conclusions and Investment Recommendations”.

Throughout these sections, there are three different types of recommendations offered. These include: fundamental precepts, roadmap activities, and Expert Team tips. These categories of recommendations are distinguished by degree of applicability to the roadmap and by the perceived strength of the underlying rationale by which we endorse the recommendation. Table 1.1 below characterizes these three recommendation types and explains the basis on which these recommendations are formed.

Table 1.1 Categories of Recommendations in LVCAR Final Report

<table>
<tr><th colspan="2">Recommendation Type</th><th>Basis</th></tr>
<tr><td colspan="2">Fundamental Precepts</td><td>Consensus of Study Team and Expert Team</td></tr>
<tr><td colspan="2">Expert Team Tips</td><td>Expert Team agreed, but no cost estimate or value metric</td></tr>
<tr><td rowspan="2">Roadmap Activities</td><td>Architecture Activities</td><td>Focused on DoD-level investments and characterized by ROI analysis based on expert data</td></tr>
<tr><td>Standards and Business Model Activities</td><td>Focused on DoD-level investments, but needing further ROI analysis</td></tr>
</table>

2 Introduction to the LVCAR Study

> "In M&S bigger is not better, better is better."
> Mr. Fred Hartman, IDA
> (formerly Deputy Director, Readiness and Training)

2.1 Introduction and Motivation

The LVCAR Study was designed to consider three important dimensions of simulation interoperability: technical architecture, business models, and the standards evolution and management process, with greatest emphasis (i.e., schedule and resources) placed on the technical architecture. The architectures that were considered in this study include: Aggregate-Level Simulation Protocol (ALSP), Common Training and Instrumentation Architecture (CTIA), Distributed Interactive Simulation (DIS), High-Level Architecture (HLA), and Test and Training Enabling Architecture (TENA).

Many problems have been identified with respect to the procedures and technologies used to develop mixed-architecture LVC environments today. Because of the incompatibilities between these architectures, a considerable amount of resources must be expended to develop point solutions that effectively integrate the various architectures into a single, unified set of supporting simulation services. Gateway solutions to these types of issues have frequently resulted in exercises restricted to using only the limited set of capabilities that are common across all of the architectures, resulting in a "dumbing down" of the more capable architectures. Further, the lack of high-level management oversight of all existing distributed simulation architectures (as a unified resource across the entire Department) has resulted in a situation where continued divergence of architectural capabilities is not only possible but likely, and new (potentially redundant) architectures can emerge at any time. Clearly, such issues must be satisfactorily resolved if long-term interoperability goals are to be achieved.

That said, much can be accomplished with the architectures that are available today and nearly all of the existing architectures[8] are being improved to better serve their communities of use. The various distributed simulation architectures in use within the DoD today have all been designed to meet the needs of one or more user communities. With few exceptions, these architectures have continued to evolve and mature based on changing user requirements. Although the different architectures have different strategies and procedures for managing this evolution (as well as different funding streams, which in turn affects the pace by which the architectures continue to evolve), members of the various user communities seem to be generally satisfied with the features and capabilities provided or planned to be provided by their architecture of choice. The existence of multiple architectures allows users to select the architecture that best meets their needs (O'Connor et al, 1996) and thus provides an incentive for architecture developers and maintainers to competitively keep pace with technology and stay closely engaged with emerging user requirements.

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[8] Notably, the investigation into ALSP revealed that its use is so miniscule that for all practical purposes it didn't need to be considered in this study to any appreciable degree.

While, there are advantages and disadvantages associated with the number of architectures that are available for use, there is no paramount advantage or disadvantage that allows one to immediately recognize the optimal number, given the current user-split across the architectures.

2.2 Analytic Process

Figure 2.1 below illustrates the general process used by each of the dimensions of the LVCAR Study. This process characterizes the current state, characterizes the vision state along with the desired attributes of that state, identifies the differences between the current state and vision state, and develops strategies to move towards that vision state. Once these candidate strategies were developed, the corresponding pros and cons were enumerated and compared with the desired attributes of the vision state. This comparison served as a mechanism to reveal any desirable attributes, benefits, or problem areas ("pros and cons") that may have been missed. Finally, once these independently formed lists were adjudicated, qualitative metrics could be established and applied to prune the strategy space into a more manageable and feasible subset for roadmap consideration. While represented as a linear process for purposes of illustration, the general process was not entirely linear, but included iterations and spirals required for incremental progress.

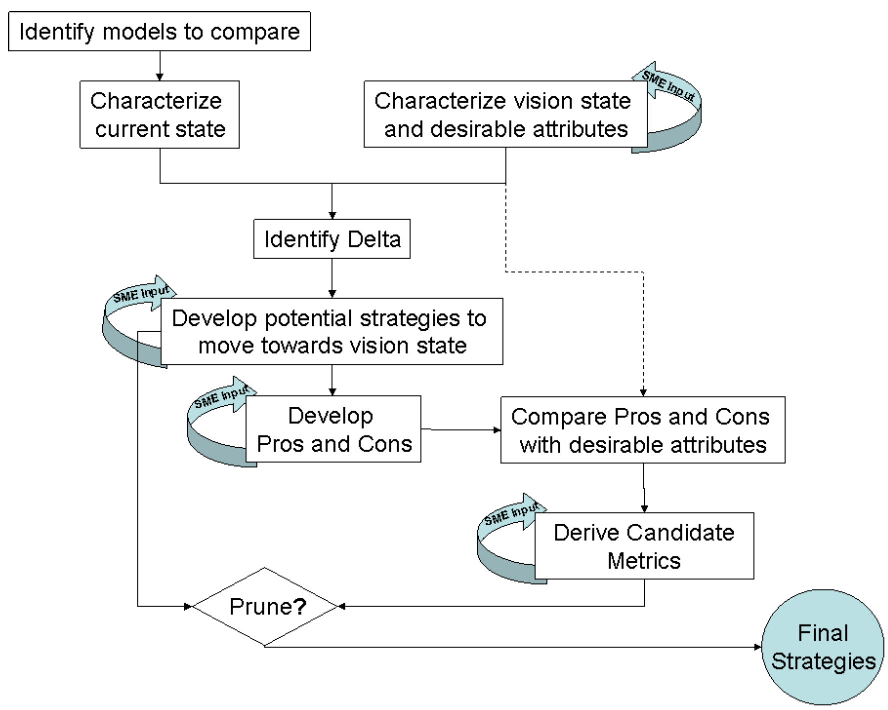

Figure 2.1 Generalized Analytic Framework for Construction of Strategy Space

As a way to make optimal use of resources (e.g., leverage existing expertise and knowledge, avoid cost of implementing large-scale experiments, etc), the M&S SC/IPT encouraged the Study Team to adopt an expert-based approach. Figure 2.1 identifies the opportunities in the analytic process where Expert input and feedback (shown as "SME Input" in the figure) could be inserted into the analysis. Specifically, this feedback was provided in review of the desirable characteristics (precursor to the development of qualitative metrics), development of strategies, development of pros/cons associated with those strategies, and the subsequent adjudication of the desirable characteristics and pros/cons which ultimately formed the qualitative metrics that could be used to prune the strategy space. Once potential strategies for the three dimensions were independently developed, it was necessary to add detail to them and then integrate this detail. Because the Study focused more on architecture than on business model or standards processes, the architecture dimension had the greatest level of detail.

A number of approaches were considered to integrate the resulting strategies across the three dimensions (see the 6 November 2007 meeting documentation in *Appendices Volume III: LVCAR Expert Team Meeting Documentation*). Ultimately, it was the opinion of the Expert Team that the three dimensions (i.e., architecture, business model, and standards) could largely be considered independently. This resulted in an integration strategy that assumed independence a priori, combined the individual strategies, and then tested the assumption post-hoc.

2.3 Data Collection Activities

The LVCAR Study conducted a number of meetings (i.e., Expert Team Meetings), forums and panel discussions (i.e., Working Group Workshops) to promote collection and distribution of information relevant to the study. Thus, a large percentage of the data collected is documented in the form of meeting documentation (see *Appendices Volume III: LVCAR Expert Team Meeting Documentation*) or workshop reports (*LVCAR Study Workshop #1, #2, #3, and #4 Reports*). We have also, however, engaged in a number of data collection activities above and beyond the conduct of these forums. While a more comprehensive review of the processes used to collect these data and the results generated by these additional data collection efforts may be found in documents synopsized in Section 1.2, the sections below serve to provide a summary of the additional data collection efforts conducted to date.

2.3.1 Literature Search

Detailed in Section H of the *Appendices Volume II: Supporting Data to the LVCAR Study* document, the LVCAR Study Team conducted and documented the results of a comprehensive literature search that identified over 800 potential sources of relevant LVC literature. This literature included conference papers, journal papers, technical reports, government reports, and books.

2.3.2 Literature Reviewed as part of LVCAR Study

Detailed in the *LVCAR Study Workshop #1 Report*, over 500 abstracts from the potential LVC literature data base (referenced above in Section 2.3.1) were reviewed by the Study Team and subsequently reduced to into 50 conference papers that were reviewed by the Workshop Focus Groups as source material for LVCAR Study Workshop #1. Other literature reviewed and documented in the *LVCAR Study Functional Requirements and Use Cases* document includes over 19 foundational capabilities and requirements documents that served as basis for the collection of LVCAR functional and operational requirements. Also surveyed were a number of business-related articles and websites supporting the *LVCAR Study Comparative Analysis of Business Models* document, and a number of different papers and websites related to government and commercial standards organizations (see the *LVCAR Study Comparative Analysis of Standards Management and Evolution Processes* document), as well as websites detailing systems engineering processes (see *LVCAR Study Comparative Analysis of the Architectures*).

2.3.3 Formal Data Collection Efforts with Working Group

Above and beyond the group discussion and dialogue at the Working Group Workshops, the LVCAR Study collected data through a formal survey to the Working Group and conducted a number of data collection activities at the Workshops. Details on these efforts are reported in Sections 2.3.3.1 and 2.3.3.2, respectively.

2.3.3.1 Working Group Survey

Documented in Section B of the *Appendices Volume II: Supporting Data to the LVCAR Study* document, the LVCAR Study Team developed a web-based survey that was distributed to LVCAR Working Group (WG) members. The LVCAR Study employed a process by which all WG members were required to complete the survey before being allowed access to the LCVAR Portal, residing at JFCOM. This was an effective strategy that resulted in the capture of data from approximately 135 respondents. While we recognize that this sample is neither large enough nor sufficiently stratified to statistically represent the entire LVC user base, it has been a useful resource. It is apparently one of the most robust data bases on LVC data available, as a number of MSCO-related projects have asked us for access to the source data. Figure 2.2 provides a sense for the demographics of respondents, the details of which are presented in *LVCAR Study Workshop #2 Report*.

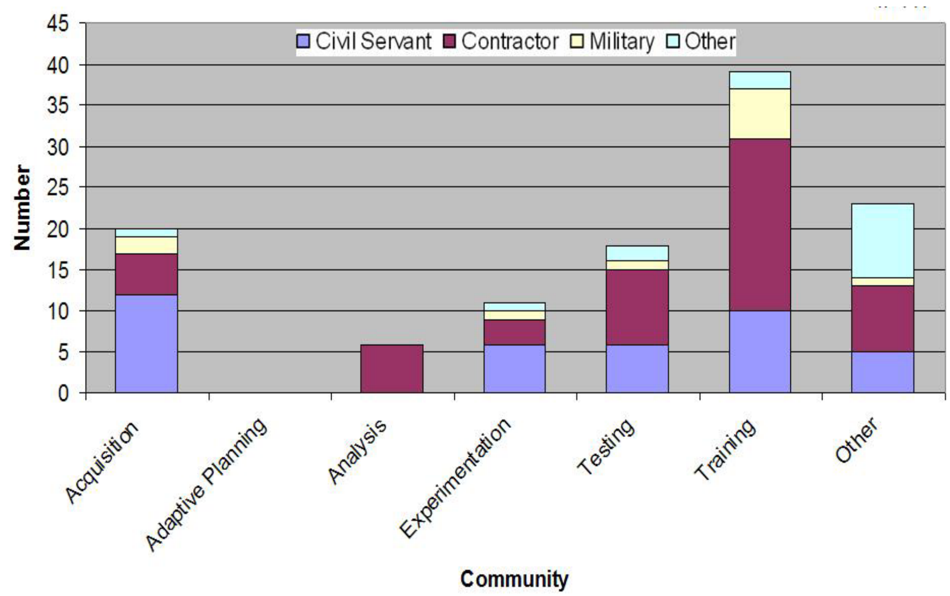

Figure 2.2 Demographics of Working Group Survey Respondents

Other Working Group surveys included a call for information on mixed-architecture events conducted over the last 5 years and/or planned for execution in the next 10 years. This information is referenced in Section A of the *Appendices Volume I: Supporting Analyses to the LVCAR Study* and the working data available in Section J of the *Appendices Volume II: Supporting Data to the LVCAR Study*. (Summaries of the survey results can be found in the reports of results from Workshop #1 and Workshop #2.)

2.3.3.2 Working Group Data Collection Efforts at Workshops

All of the Working Group Workshops conducted formal workshop-wide exit surveys. Additionally, the Business Model Breakout Session at Workshop #2 conducted a formal data collection exercise, and both the Business Model Breakout Session and the Architecture

Breakout Session conducted session-specific exit surveys to gage the Working Group's reaction to their work to date. Lastly, Workshop #4 conducted a thorough survey that asked for detailed feedback on each of the recommendations being considered by the LVCAR Study Team. The results of all of these data collection efforts may be seen in the *LVCAR Study Workshop #1, Workshop #2, Workshop #3 and Workshop #4 Reports*.

2.3.4 Formal Data Collection Efforts with Expert Team

Given that the LVCAR Study is based on an Expert-approach, formal data collection efforts, above and beyond less formal group discussions, have been an important component of the LVCAR Study. To date, all three study dimensions have benefited from some kind of formal data collection effort with the Expert Team. The Architecture Team has used a web-based survey mechanism to get methodically-structured feedback on a whitepaper detailing a number of observations and proposed strategies. This mechanism and the ensuing results are available in Synopsis of Data Collection Activities and RFIs (see *Appendices Volume III: LVCAR Expert Team Meeting Documentation*). The Architecture Team also collected the opinions of the Expert Team on the pros and cons related to the Architecture strategies. This was performed with a computer-based collaboration tool called Groupware at the 17 October 2007 Expert Team Meeting hosted by JHU-APL. More details on the execution and subsequent results of this activity may be found in the corresponding meeting documentation (see 17 October 2007 meeting documentation in *Appendices Volume III: LVCAR Expert Team Meeting Documentation*). Also found in the referenced documentation is a formal data collection activity by the Standards Team using the same software in an exercise designed to rank the importance of various attributes characterizing a number of different standards organizations. The Standards Team amplified this effort in the next Expert Meeting on 6-7 November. The details of this follow-on effort may be seen in the 6 November 2007 meeting documentation in *Appendices Volume III: LVCAR Expert Team Meeting Documentation*). Described in the same document are two exercises conducted by the Business Team to gather Expert opinion on the values and costs of interoperability from the perspective of different stakeholders, as well as the value-drivers from the perspective of different stakeholders. Finally, described in 17-18 January 2008 meeting documentation in *Appendices Volume III: LVCAR Expert Team Meeting Documentation*) and the 5-6 March 2008 meeting documentation in *Appendices Volume III: LVCAR Expert Team Meeting Documentation* are a number of exercises designed to elicit potential business model strategies from the Business Model Tiger Team.

In terms of general cross-dimension information, each member of the Expert Team was asked to provide additional recommendations (to augment the study formal recommendations), each of which was considered by the entire Expert Team for their utility to the LVCAR Study. Out of approximately 24 recommendations considered, 7 were promoted for endorsement in this study. These recommendations have taken the form of Expert Team Tips and Fundamental Precepts.
Finally, to support return-on-investment (ROI) analysis, the Expert Team participated in a number of surveys and data collection activities designed to define the potential savings of various activities, expected savings of various activities, and estimated costs of the activities. These data collection activities are detailed more in Section I of *Appendices Volume II: Supporting Data to the LVCAR Study Final Report.*

2.3.5 Interviews with Community Experts

Used in a variety of documents but reported most thoroughly in the *LVCAR Study Comparative Analysis of Standards Management and Evolution Processes* document, the LVCAR Study Team formally interviewed over 12 people on a variety of topics, to include the history of M&S standards, capabilities of LVC architectures, and related subjects.

2.3.6 More Formal Requests for Information

In an attempt to capture relevant data, the LVCAR Study Team engaged in a number of more formal RFIs. Documented in Section C of the *Appendices Volume II: Supporting Data to the LVCAR Study* document, we distributed an industry-wide RFI to which we received 28 responses. Additionally, based on information collected through the Working Group Survey (discussed in Section 2.3.3) that provided pointers to people who had data and were willing to share it, the LVCAR Study Team distributed 22 requests for middleware performance data to which we received 2 responses and 15 requests for cost data to which we received 4 responses. Finally, in addition to general calls for use cases, we estimate that over 100 people were contacted individually to request support for the development of use cases. This effort resulted in 12 use cases submitted in the form of the LVCAR Study Use Case template.

Other more formal requests were also executed. For example, to develop a measure of the total cost of U.S. DoD expenditures related to LVC integrating architectures, as well as a sense of the ratio of government expenditures on government sponsored middleware vice commercially provided RTI, we distributed a data call on expenditures to government sponsored LVC architecture proponents. These data calls are documented in Section G of the *Appendices Volume II: Supporting Data to the LVCAR Study* document. Worth noting, to develop to develop the estimate of how much the DoD spends on commercially provided RTIs, the LVCAR Study had to request the necessary information from the commercial RTI vendors. Specifically, sales and market-forecast related data were requested.

3 Current State

> "Any time we build a System C with the intent of replacing System A and System B, we end up with Systems A, B, and C."
>
> Mr. Dell Lunceford, Total Immersion Software
> (formerly Director of AMSO)

3.1 Historical Context

Modeling and Simulation (M&S) has made significant progress in enabling M&S users to link critical resources through distributed architectures. Some characterize this advance as the "M&S Success Story" of the last twenty years. The earliest successes came through the SIMNET program (Miller and Thorpe, 1995), which demonstrated that geographically dispersed simulation systems could support distributed training by interacting with each other across network connections. Following on this success, the Aggregate-level Simulation Protocol (ALSP) extended the benefits of distributed simulation to the force-level training community so that different aggregate-level simulations could cooperate to provide theater-level experiences for battle-staff training (Wilson and Weatherly, 1994). At about the same time, the SIMNET protocol evolved and matured into the Distributed Interactive Simulation (DIS) Standard (Hofer and Loper, 1995). DIS allowed an increased number of simulation types to interact in distributed events, but was primarily focused on the platform-level training community.

In the middle 1990s, the Defense Modeling and Simulation Office (DMSO) started the High-Level Architecture (HLA) program to combine the best features of DIS and ALSP into a single architecture that could also support uses in the analysis and acquisition communities while continuing to support training applications (Numrich, 2006). HLA was designed from the start to support a wide set of potential user communities (Kuhl, Weatherly, and Dahmann, 2000). But, as is the case with most broadly applicable tools, some began to perceive HLA as a "jack of all trades, but master of none." In particular, the Test Community started development of alternate architectures based on their perception that HLA yielded unacceptable performance and included reliability limitations. The real-time test range community started development of the Test and Training Enabling Architecture (TENA) to provide low-latency, high-performance service in the hard-real-time application of integrating live assets in the test-range setting (Powell, 2005). Similarly, the Army started development of the Common Training Instrumentation Architecture (CTIA) to link a large number of live assets requiring a relatively narrowly bounded set of data for purposes of providing After Action Reviews (AARs) on Army training ranges in the support of large-scale exercises.

With the exception of SIMNET, all of these architectures remain in service today. Of the remaining architectures: CTIA, DIS, HLA, ALSP and TENA, some are in early and growing use (e.g., CTIA, TENA) while others have seen a user-base reduction (e.g., ALSP). Each of the architectures is providing an acceptable level of capability within the areas where they have been adopted. However, DIS, HLA, TENA, and CTIA-based federations are not inherently interoperable with each other. Thus, when simulation events include applications that rely on the different architectures, additional steps must be taken to allow effective communication between all applications. These additional steps, typically involving interposing gateways or bridges between the various architectures, may introduce increased risk, complexity, cost, level of effort, and preparation time into the event. Additional problems extend beyond the implementation of individual simulation events. As a single example, the ability to reuse supporting models, personnel (expertise), and applications across the different protocols is limited. In short, the limited inherent interoperability between the different protocols introduces a significant and largely unnecessary barrier to the integration of live, virtual, and constructive simulations. This barrier must be greatly reduced or eliminated.

The LVCAR Study is not the first DoD-sponsored effort to consider the plausibility of converging architectures, possibility of eliminating architectural choices, or the implications of significantly enhancing existing architecture implementations. Even in recent years, a number of studies (Davis, 2003; Numrich and Henninger, 2005; JDSETES, 2006; Saunders, Vick, and Conrad; 2006) have paved the way for the LVCAR Study. The LVCAR Study Team has reviewed all of these efforts and developed positions on the recommendations generated. These reviews are available in Section E of the *Appendices Volume I: Supporting Analyses to the LVCAR Study*.

3.2 Current State of Architectures

The current state includes a wide range of user communities, and different architectures and protocols are used across those communities, with no single architecture dominant. There is a range of qualitative factors that must be considered to understand the current state; these also have implications for producing an informed decision for the best way forward. These factors (or assertions) represent practical considerations regarding the application of distributed simulation architectures within the LVC community today, and are considered factual by the communities represented on the LVCAR effort. The list of assertions below (in italics) is explored in more detail in *LVCAR Study Comparative Analysis of Architectures* document.

- *Much can be accomplished with the architectures that are available today and nearly all of the existing architectures are being improved to better serve their communities of use.*
- *The Department of Defense has not always taken and is not currently using a consistent, coherent approach to managing LVC environments.*
- *The number of available architectures has increased since the early 1990's, at least partially, as a result of inadequate management.*
- *Mixed-architecture environments occur as dictated by needs of the using applications, not because of any inherent benefit in mixing architectures.*
- *When mixing architectures is necessary, point solutions to bridging the architectures work in most cases where syntactic interoperability is the main concern, although these kinds of solutions may introduce additional latency and information loss for some applications.*
- *Mixed-architecture approaches may introduce certain limitations on the range of services available to participants within the full simulation environment.*
- *Many legacy, and even some new, simulations will not transition to using a different architecture, unless there are compelling incentives to do so.*

- *GOTS-based and COTS-based business approaches are difficult to reconcile within the scope of a single product.*

- *Cultural and resource issues will be persistent barriers to convincing existing architecture users to switch to a different architecture.*

- *Architectural choices of how to transfer data between applications (syntactic issues, the concern of this study) and application-level choices of how to interpret received and encode transmitted data (semantic issues, beyond the scope of this study) both have impacts on interoperability.*

- *Significant improvements in LVC interoperability can be achieved via supporting data, tool, and process standards.*

In short, the currently available architectures are generally meeting the primary needs of their constituent communities today and are evolving to meet future needs as well. History shows that the number of available architectures tends to increase over time and that once a community of use develops around an architecture, that architecture is very likely to continue to be used. By definition, the inter-architecture communication problem only occurs during mixed-architecture events. While these are currently a small percentage of the number of all DoD simulation exercises, the number of mixed-architecture events is expected to increase over time (see Section C of the *Appendices Volume I: Supporting Analyses to the LVCAR Study*).

There are advantages and disadvantages associated with the number of architectures that are available for use. However, there is no paramount advantage or disadvantage that allows one to immediately recognize the optimal number, given the current user-split across the architectures. To document the similarities and differences across these architectures and to provide a baseline for the "current state", the following four sub-sections review each of these architectures, addressing the technical requirements and capabilities of the architectures; the business models used to develop, distribute and maintain the products supporting the architectures; and the standards evolution and management process used to evolve the architectures.

3.2.1 Current State: DIS

DIS was born out the DARPA SIMNET program of the mid-eighties. Following a successful demonstration of the SIMNET interoperability protocols, the DIS Workshops were started on a semi-annual basis with several smaller working groups meeting throughout the year. The result of this activity produced IEEE 1278 – Distributed Interactive Simulation Protocols (reference DIS Standard). Optimized for human-in-the-loop, platform level simulations, the DIS protocols are still widely employed today, particularly in the Air Force training and operations community.

Human-in-the-loop (HITL) platform-level applications generally are less complicated and more tolerant than other types of applications (e.g., hard real-time or as-fast-as-possible). For example, HITL platform level applications are tolerant to human delays in recognizing and reacting to mismatches in event order. Thus, DIS applications do not require simulation time management. Likewise, HITL applications are tolerant to occasional dropped packets, so DIS can rely on best-effort delivery of messages through use of the User Datagram Protocol (UDP) and does not require reliable transport as provided by Transmission Control Protocol (TCP). As a final example, because scalability is not a primary driver in most soft real-time platform-level simulations, DIS does not need to support some of the more complicated information filtering capabilities that other architectures provide. Because of the simplicity inherent in the requirements of DIS applications, DIS enjoys the luxury of imposing very low overhead. Thus, the DIS protocol has a comparatively low barrier to entry and it is relatively simple to learn and easy to use.

This simplicity is manifested in other ways. Because the DIS data architecture uses an on-the-wire protocol that strictly enforces data structure/encoding rules, it strongly facilitates syntactic interoperability. Moreover, because the allowable content for data exchange is embedded in the standard, people generally understand the semantics of the data in DIS. Another benefit of defining the allowable data exchange content in the standard is that any application that complies with the DIS Standard should be able to interact with other DIS-compliant applications and gateways are not required. That said, it is possible to make changes to the Protocol Data Unit (PDU) content/structure, though it currently happens very infrequently, and defining special-purpose experimental PDUs requires operating outside of the standard. Also, DIS is locally extensible through the use of the generic DATA PDU and current efforts are working to provide further extensibility while maintaining backwards compatibility. In these cases, it is possible that gateways or some other translation mechanism will be required to support communication between applications using different types of PDUs.

Formal DoD management of DIS evolution is now virtually non-existent, though the Air Force tends to be the most actively engaged in proposing enhancements to the DIS Standard. The costs of the actual maintenance and evolution of the DIS Standard are minimal and borne by the participants in Simulation Interoperability Workshops (SIW) – the successor to the DIS Workshops. Required modifications to the standards are generally discovered and solutions tested during development of distributed simulation exercises. The modifications are issue-driven and are therefore seen as an integral part of capability development. As modifications are identified and tested, they are brought into the SIW and vetted in the broader community. The costs for this activity are paid in the form of SIW registration fees.

DIS employs a commercial business model, where a reputable external standards organization maintains the core specifications, and commercial enterprises develop and market tools that support implementations of the specifications. The DIS Standard focused on clearly necessary services to support data exchange in a consistent, effective manner, and left the identification and development of supporting tools to commercial tool vendors.

In summary, DIS serves its user-base well, particularly the HITL platform community. This is evidenced by the fact that so many organizations continue to use DIS. Costs are low and are seen as part of development. Those who use DIS have taken "ownership" of it. Costs for maintenance and evolution are seen as the cost of doing business. Producers in the DIS marketplace have flexibility to introduce features to solve their problems and advocate for broader use of their new features. A well established process, compliant with IEEE standards ground-rules and managed through SISO, provides a venue for this advocacy. Because many voters consider the cost and time to revise their product in deciding which changes to approve, changes with narrow impacts are easily incorporated, whereas changes with broad impact face a much more difficult road to adoption. The result has been an image of DIS as easy to change and yet low cost to use. However, there is no one from the DoD enterprise perspective at the vanguard of DIS development. There is no one looking at "what next". The DoD might benefit from different, perhaps more sweeping, changes to DIS but there is not a mechanism to consider this benefit.

3.2.2 Current State: HLA

The HLA was developed to be a single architecture that could meet the needs of a broad potential set of LVC environment users, including DIS and ALSP users. Under the leadership of the Director, Defense Research and Engineering (DDR&E), it was predetermined that HLA would be the standard to absorb DIS and ALSP. Its charter was to unify simulation across the DoD. To accomplish this, HLA was designed as an architecture with a broad range of services not coupled to the information content of a specific LVC federation, thus providing the flexibility to serve a broadened base of M&S users and exercise requirements. Specifically, whereas the DIS and ALSP communications protocols had respectively emerged from entity-level and constructive Training community requirements, HLA designers recognized that the Acquisition and Analysis communities each had their own unique requirements for simulation applications. Thus, HLA was really the first distributed M&S interoperability paradigm intended from the ground up to support the collective requirements of at least three unique communities (Kuhl, Weatherly, and Dahmann, 2000).

A general-purpose simulation interoperability architecture, HLA can serve a disparate collection of simulation systems, including those that require advanced architectural services, as well as those that have modest requirements. While able to accommodate many different use cases, this one-size-fits-all approach required HLA to incorporate many services that are superfluous to some use cases. For example, motivated by the requirements of constructive federations, HLA has a hard requirement and established mechanism to support non-real-time applications that require strict causal ordering of events and time synchronization mechanisms. Also for the constructive user base, HLA is required to support reliable transport and other mechanisms such that repeatability requirements are supported. In addition, some federation management and ownership management services also require reliable transport. However, since HLA also supports users with low latency requirements, transport can be defined as either best effort or reliable on an individual object attribute and interaction basis. In the early days of the HLA, the overhead required to support all of these different requirements was viewed as an impediment to run-time performance and it paved the path for a number of use case-optimized middleware implementations (i.e., the Run-Time Infrastructure or RTI) such as RTI-S, the RTI developed for Synthetic Theater of War (STOW) that is still used today. Such RTIs are not "HLA compliant", in that compliant RTIs are required to implement all of the services identified in the HLA Interface Specification.

To promote adoption, Dr. Paul Kaminski [USD(A&T)] issued a 1996 policy memorandum designating "*the High Level Architecture as the standard technical architecture for all DoD simulations."* This policy set "No Can Pay" and "No Can Play" dates in an effort to force DoD components to bring their simulation assets into compliance. The policy had a significant impact on the DoD M&S community resulting in many compliant assets. However, the policy memo was never converted to long-term DoD policy and the "No Can" dates were ever enforced. In April 1998, Jacques Gansler [USD(A&T)] issued a policy memo reinforcing the department's move to HLA and encouraging "industry partners to follow suit". This policy memo had similar effect to the first; that is, many simulation assets transitioned but ultimately there was no enforcement of the policy.

The design choices made by the HLA attempted to improve on perceived shortcomings of existing architectures while serving the entire DoD M&S Community. Early in HLA development, the static nature of DIS PDU's was identified as a significant problem; as the real world is always changing, and a flexible object model capable of modeling changing data without having to continuously change the underlying standard was deemed the better approach. Thus, the HLA adopted a template approach whereby data could be separated from the simulation architecture. Allowing the users to define their data exchange based on specific requirements provided improved object model extensibility. While this increased flexibility to the user, it also allowed users to independently develop a plethora of object models that were rarely interoperable. In recognition of the problem associated with specifying a new object model for each new application, users were encouraged to define community-standard object models outside of the architecture. The Real-time Platform Reference (RPR) Federation Object Model (FOM) is one example of this. Also in response to perceived flaws in DIS, HLA adopted an API Standard as opposed to an on-the-wire standard that allowed it to more rapidly adopt technological advancements in how data are transmitted. While this approach provided commercial RTI developers with the freedom to innovate and optimize their RTI implementations, the resulting RTIs were non-interoperable. In practice, when disparate RTI versions are unavoidable in a given event, HLA users generally utilize gateways or other inter-protocol translation mechanisms to bridge the participating federates.

The HLA specifications were developed and evolved by the HLA Architecture Management Group (AMG). This enabled DOD stakeholders to include their requirements and provide technical feedback based on the experiences of their programs. Once they reached a point of maturity, the HLA specifications were formally standardized using SISO processes and procedures and balloted through the IEEE. Some elements of the HLA Standards were also taken to Object Management Group (OMG) to be standardized. Up until 2004, DMSO provided a no-cost version of the DoD-variant (HLA 1.3) of the middleware to US Government offices and US Government contractors. Subsequently, DMSO ended this service and expected all new HLA users to acquire middleware from a commercial provider.

In today's HLA community, the acquisition of HLA middleware is nearly completely decentralized. Proponents are required to either buy a middleware license from one of the many middleware providers or obtain a copy of "black market" RTI[9]. A corollary to the fact that the HLA model is nearly completely decentralized, is the attendant forfeiture of control. The DoD might, in certain circumstances, feel the pain of less control when it requires rapid changes to the specification to meet an emerging demand. Arguably, this is one motivation behind the development of the so-called "black market" RTIs. This forfeiture of control, however, means that there is no one at the vanguard for HLA development. There is no one looking at "what next". DMSO's last serious HLA development effort examined the ability for HLA to operate over the web. Many of those insights have been incorporated in the most recent update of the HLA 1516 specification.

In addition to its large U.S. user base, the HLA is recognized by NATO as the modeling and simulation standard for technical interoperability. Its standing as an international standard has resulted in broad use among the coalition partner countries, facilitating combined simulation events that include multiple nations.

Federate developers are largely responsible for funding their own efforts to bring their simulation assets into compliance. This includes software development labor, middleware licensing fees and the cost of support tools. The existence of middleware license fees, particularly multiple middleware license fees at the federation level, has been a target of criticism and, seemingly contributes to the perception that adopting the HLA results in high and recurring costs. However, the existence of multiple competing middleware vendors presumably promotes

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[9] A black market RTI is an unofficial, unsupported copy of early GOTS RTI.

innovation for market differentiation, controls costs by market forces, and scales with demand. Federate developers are usually focused on the primary application for their simulation. While the DoD enterprise may benefit when their simulation is reused, the benefit to the federate developer would not be sufficient to justify establishing formal compliance testing. The M&S CO currently provides federate compliance testing, to eliminate this roadblock to reuse.

HLA-compliant RTI middleware is subjected to an extensive test suite to verify API and service functionality testing against the HLA Interface Specification. Only RTI developers wishing to have their RTI middleware certified undergo this level of testing. Essentially, certification means that the RTI developer has accurately and successfully implemented all of the defined HLA services. Often, this activity leads to improvements in the specifications, as the discovery of different implementations can lead to the discovery of ambiguities in the specifications. The M&S CO currently provides RTI verification testing (as well as federate compliance testing) as a no-cost service.

Currently, all proponents pay to participate in the development and evolution of the HLA Standard. SISO holds semi-annual meetings and charges a moderate fee for participation; they also collect fees (or more precisely IEEE collects fees) from those participating in the standards balloting process. Additionally, IEEE owns the copyright to the standard and charges a fee to those who obtain copies. The likely place for long-term maintenance of the HLA standard is with SISO – the Standard Proponent for HLA – but SISO is a coalition of the willing. Without significant infusion of funds from some source, the probability that SISO could provide substantive technical leadership is low. Because the HLA Standard, at least the IEEE 1516 variant, is under SISO stewardship, there is an articulated due process for reviewing, changing, and evolving the standard. Changing the IEEE standards process itself requires substantial effort and so the likelihood of major procedural swings is very low.

Finally, given the programming practices that modern day computer science graduates are accustomed to, the HLA might benefit from some of the common (high-level) services found in more contemporary programming languages (e.g., full object orientation/remote methods, parameter marshalling, auto-code generation, etc.). Also, in tune with more modern programming practices, it could benefit from adopting a more composable approach where sub-sets of the infrastructure could be implemented and tailored towards the requirements of a particular user community. That said, there is no known technical reason why user-groups of other architectures could not have used the HLA, as it is a general-purpose architecture that accommodates most of their technical requirements. Minimally, it could have served as a foundation for specializations.

3.2.3 Current State: TENA

TENA is a very capable architecture, offering much of the same capability as HLA, but using object-oriented technology more extensively (e.g., polymorphism, local methods, RMI, etc.). The architecture was originally designed to link the test facilities at various range locations, and where applicable, link the test ranges to high performance computational assets. The communication between ranges in TENA involves passing test information, potentially a large set of data, the nature of which can change with each new test.

When the issues of Training Transformation led to the current partnerships between training and testing, TENA began to extend its original focus to include live, virtual and constructive (LVC) capabilities in the training domain. Thus TENA's new thrust is to provide communications and data exchange to facilitate the execution of interoperable Joint exercises conducted at test and training ranges throughout the DoD. This expanded role and use is, in some part, the impetus for the LVCAR study.

TENA appears to be growing in use. We attribute this in part to the partnerships in training and testing referenced above, but also to the fact that the TENA middleware is freely available to approved government users as GOTS, unlike the HLA middleware that must be purchased. The GOTS model serves to support one of the architecture's fundamental requirements. Specifically, the TENA JORD states: "SW-6: the software must minimize the purchase of run-time licenses." This appears to be the only example where a purchase requirement has been expressed as an architectural requirement.

As HLA implemented a design in response to a number of perceived shortcomings in the DIS Standard, TENA implemented a design in response to a number of perceived shortcomings in the HLA Standard. For example, to facilitate interoperability among ranges, a set of TENA standard object models were developed. Thus, if all participants use the standard TENA object model, a high degree of interoperability could be achieved. However, the TENA architecture also allows users to define alternative object models that better fit their needs. This provides a highly flexible "middle ground" between the options of having the data being part of the simulation architecture or not. Also, TENA defines a "product line" of supporting tools and utilities to assist users creating and managing logical ranges and for working with the TENA common infrastructure. Since using TENA would be very difficult without these tools and utilities, the product line was made a core component of the overall architecture. Again applying the principles of GOTS, these supporting tools and other resources (e.g., user support, training, etc.) are freely available to approved users.

Interestingly, TENA was originally conceived as an application riding on top of the HLA middleware. In May 2001 (Zimmerman and Rumford, 2001), a brief – co-presented by the HLA and TENA program managers included the following bumper sticker on the summary slide:

> *"HLA & TENA are complementary in Purpose, Design, Development, and Implementation"*

In the ensuing years, senior DoD leadership turned to other issues and top-level support for DoD-wide adoption of the HLA waned. HLA and TENA subsequently diverged and became competitors rather than complementary. That said, TENA does have an explicit requirement to "interoperate with HLA federations", and that requirement is typically met using a TENA – HLA gateway, one of the tools in the TENA product line.

Centralized funding aligns TENA costs with the organizations that derive value from it. TENA is championed by the Test Resource Management Center (TRMC) with additional funding coming from the Joint National Training Capability (JNTC). The Central Test and Evaluation Investment Program (CTEIP), managed by the TRMC, has been the primary sponsor of TENA. Funding for TENA also comes from the Joint Mission Environment Test Capability (JMETC) – a TRMC-sponsored activity – for addressing their requirements and JFCOM's JNTC to meet joint training requirements. Much of TENA's success can be attributed to the alignment of mission, policy and funding at TRMC. TRMC has significant knowledge of the costs of TENA, as well as the user-base and compliant TENA components.

TENA enforces a higher level of model compliance through the use of a compiled object model which enables compile time type checking and improves the reliability of the system. TENA has three levels of compliance, none of which are associated with formal compliance tests, but use checklist-like constructs. As federates are brought into compliance in support of test and evaluation, it's likely that some funding for federate owners would come from test and evaluation sources. As a minimum, some of the Federate Proponent technical labor (particularly maintenance and operations) would be subsidized by the Major Range and Test Facility Base.

Apart from Federation Development, the Architecture Proponent (e.g., CTEIP and JNTC) bears the vast majority of costs associated with TENA requirements, development, and integration. Federation Development costs are borne by the Federation Proponent primarily. Costs borne by the Federate Developers includes costs to participate, as desired, in deliberations of the government sponsored forum guiding TENA's development (the Architecture Management Team [AMT]) and costs to develop federate interoperability requirements and prepare federate software for middleware integration.

In summary, TENA offers a community-optimized specialization of many HLA capabilities. It offers more progressive programming constructs than the HLA, with reduction in scope (i.e., subset of the technical requirements). Thus, there is no technical reason why TENA users cannot migrate to the HLA, but there are programmatic/risk issues (e.g., reliability concerns due to run-time binding). And, the cost of obtaining the HLA middleware it is a barrier to some TENA users; there is a TENA business requirement to "minimize the purchase of license fees".

3.2.4 Current State: CTIA

CTIA provides a common training architecture for the Army's Live Training Transformation (LT2) Product Line (Dumanoir and Rivera, 2005). The CTIA architecture enables distributed training by linking live, constructive and virtual (LVC) assets with visualization, data collection and after action review capability on a training range. Its functionality centers on the receipt, correlation and processing of data related to the live ground maneuver domain (i.e., collects and processes live training data to meet exercise objectives). This is collection of data includes live vehicles and personnel in the field at training ranges. It is designed to access a very large number of assets to collect a relatively narrowly bounded set of data over relatively unreliable wireless data links. It supports rapid training system development and fielding based on "plug & play" components and provides logically centralized services with persistent data. The scalability of the system to support Squad to Brigade echelon live training warfighters hinges on data processing and computation (e.g., the interaction of databases, workstations, players/entity state).

With a documented requirement to provide a persistent, common database of all objects that is reused by the LT2-FTS programs, CTIA is required to support persistence of component identities across restarts. Thus, all information is continually recorded in an SQL-type database to support exercise execution and anytime, anywhere Army live training After Action Reviews. This requirement is different than that imposed on a data logger which records interactions sent across the simulation network. CTIA is the only architecture that supports such a requirement (although TENA has a requirement to "support the local collection of data to a persistent store"). It is this tight coupling to and emphasis on a persistent database that makes CTIA an installation specific system that is not competitive with any of the existing architectures (i.e., ALSP, DIS, HLA, and TENA). Further, CTIA has the requirement to support communication over a wireless network. This has two impacts on the development of the CTIA architecture. First, it must carefully manage bandwidth over wireless links. This was accomplished by using centralized services to better manage the bandwidth communication between the wireless nodes of a CTIA-based system. Second, it needs to make provisions in the architecture for unreliable wireless data links, and one of the most difficult entities to collect on over a wireless network is a soldier trying not to be seen. Thus, while CTIA might have embraced M&S standards to a greater degree in its development, the requirements to handle unreliable wireless data links drove CTIA in other architectural directions. Also, CTIA does provide gateways to non-CTIA compliant protocols (such as DIS and HLA) and the middleware is based on an open-standard version of CORBA that it adopts without customizations. Thus, CTIA-based applications may use any adequate Object Request Broker (ORB) the way any CORBA application would, and as a result, CTIA-compliant components may be developed without using any CTIA developed code; compliance is at the interface level.

CTIA uses the service-oriented architecture (SOA) paradigm and is unique in that respect, as most current distributed simulation architectures (i.e., ALSP, DIS, HLA, and TENA) are designed to use peer-to-peer network architectures, versus client-server architectures. Of note, there is a need to recognize and account for longer-term trends such as the perceived benefits of SOA in the LVC Architecture Roadmap. Also, CTIA has been designed to continue providing some level of service even in the face of unreliable communication networks and appears to have the most robust capability in this area. The provision of reliable transport and other advanced Quality of Service (QoS) mechanisms when required by user applications will likely be a requirement for all architectures in the future. Finally, CTIA also provides advanced service capabilities while providing a single "on-the-wire" implementation (instead of an API-level standard), thus offering potentially improved support for multiple hardware platforms, operating systems, and software development languages. This also allows CTIA to optimize the interfaces to maximize performance over limited bandwidth networks (i.e. wireless).

The CTIA business model is very similar to the TENA model. CTIA evolution/maintenance belongs with the architecture organization for the development of a specific set of Army Live Ground Maneuver training products that is configuration managed as a product line by PEO STRI / PM TRADE organization. PM TRADE has identified this product line as the Live Training Transformation (LT2) Family of Training Systems (LT2-FTS) responsible for deploying common live training solutions to the Combat Training Centers, Homestation, and Deployed locations. A version of the middleware has been developed by the architecture organization and is being maintained. Development of middleware by other producers is allowed as is development of tools. All CTIA/LT2 components are available to all consumers belonging to the PM Trade LT2-FTS programs.

One major difference between CTIA and TENA is that CTIA provides source code with unlimited Government rights available to their LT2-FTS consumers in support for development of Live Ground Maneuver Training Systems. The goal of the LT2-FTS product line is to maximize reuse of code across PM TRADE training products and provide common interoperability solutions for LT2-FTS with external training systems used on Army ranges or with other Joint ranges. For example, CTIA Services include common services that allow interaction with TENA. The LT2-FTS requirements used to develop the architecture and middleware development were derived from multiple PM Trade program Operational Requirements Documents (e.g., CTC-OIS, HITS, Instrumented Ranges, MOUT, OneTESS, etc.).

CTIA funding comes from PEO STRI and Department of the Army. The Army Training Support Center (ATSC) is the user proponent for the architecture. Participating programs include:

Combat Training Centers Objective Instrumentation System (CTC OIS), Instrumented Ranges, One Tactical Engagement Simulation System (OneTESS), and Homestation Instrumentation Training System (HITS). Participating programs built CTIA-compliant LT2 components. They may create CTIA components that are rolled back into the repository and become available for use by other consumers. CTIA product developers are associated with a product line scope identified as the LT2-FTS managed within PM Trade organization to achieve reduction in total ownership costs for the live training systems deployed and maintained throughout the life cycle of the training products.

In summary, CTIA is the orange in a basket of apples. While it might have embraced M&S standards to a greater degree in its development, the requirements to handle unreliable wireless data links drove CTIA in other architectural directions; and, as an installation specific system, CTIA does not compete with any of the existing architectures (i.e., ALSP, DIS, HLA, and TENA). Its scope is focused on supporting product line development associated with PM TRADE's LT2-FTS programs responsible for deploying ground maneuver live training systems to Combat Training Centers, Homestation, and deployed locations; reducing total ownership and life cycle costs for all PM TRADE LT2-FTS programs; and supporting all of the training capabilities derived from the approved LT2-FTS ORDs, ICDs, and CPDs.

3.3 Current State: Summary

Each of the architectures supports a variety of requirements tailored to the needs of the community (communities) that they serve. A number of these capabilities were reviewed in the preceding text. A comprehensive analysis of these capabilities (detailed in the *LVCAR Study Comparative Analysis of the Architectures* document) illustrates that there is a high degree of technical requirement commonality between the architectures and protocols. This is particularly true concerning HLA and TENA. While there are a few key differences that have been indicated in the specifications of requirement for these architectures, a considerable amount of capability overlap (considering only major characteristics) is evident (see the *LVCAR Study Comparative Analysis of Architectures* document). At the implementation level, however, there are substantive differences among the architectures. Such differences are characterized as "wedge issues", potentially becoming barriers to achieving cross-architecture interoperability. The study finds that none of the wedge issues introduce irreconcilable incompatibilities that prevent the integration of the different architectures into mixed-architecture events. However, achieving such integration is not without cost and the potential for undesirable limitations in capability.

The standards and/or requirements for these architectures are evolved by one of two major types of forums: those sponsored by government organizations and those sponsored by commercial standards organizations. The former includes groups like the TENA AMT and the CTIA ACB. As government-sponsored forums, these types of standards organizations are typically composed of systems engineers and technical leads of major DOD stakeholders of the architecture. They discuss requirements, design trade-offs and issues associated with the architecture. Alternatively, the standards forums sponsored by commercial organizations outside of government control include: the IEEE, the SISO, and the OMG. These types of organizations are composed of users, vendors, academics, government representatives, and developers of the architecture. Like government forums, they discuss requirements, trade-offs, and other issues associated with the architecture. However, they do not have contractor support for architecture design and prototyping. Instead, these forums rely on members to develop prototypes and provide technical feedback on the architecture specifications. Table 3.3 in the *LVCAR Study Comparative Analysis of Standards Management and Evolution Processes* document delineates some of the important differences between these types of standards creating bodies.

Finally, all of these architectures have different models for policy and funding support. These models are discussed in detail in Section 3 of the *LVCAR Study Comparative Analysis of Business Models* document. At present, there appears to be a correlation between the business processes and the standards processes. Specifically, the middleware for architectures whose standards are led by government organizations is typically developed through funding from government organizations, and the middleware for architectures whose standards are led by commercial organizations is typically developed through funding from the commercial sector.

Figure 3.1 characterizes the high-level trade-space in two axes (Control and Marketplace) from the perspective of the enterprise. In this model, Control represents the degree of influence the DoD corporate level has over an architecture and its related business and standards practices and Marketplace represents the degree to which the architecture, including its corresponding business and standards processes, promotes cross-stakeholder and cross-user participation.

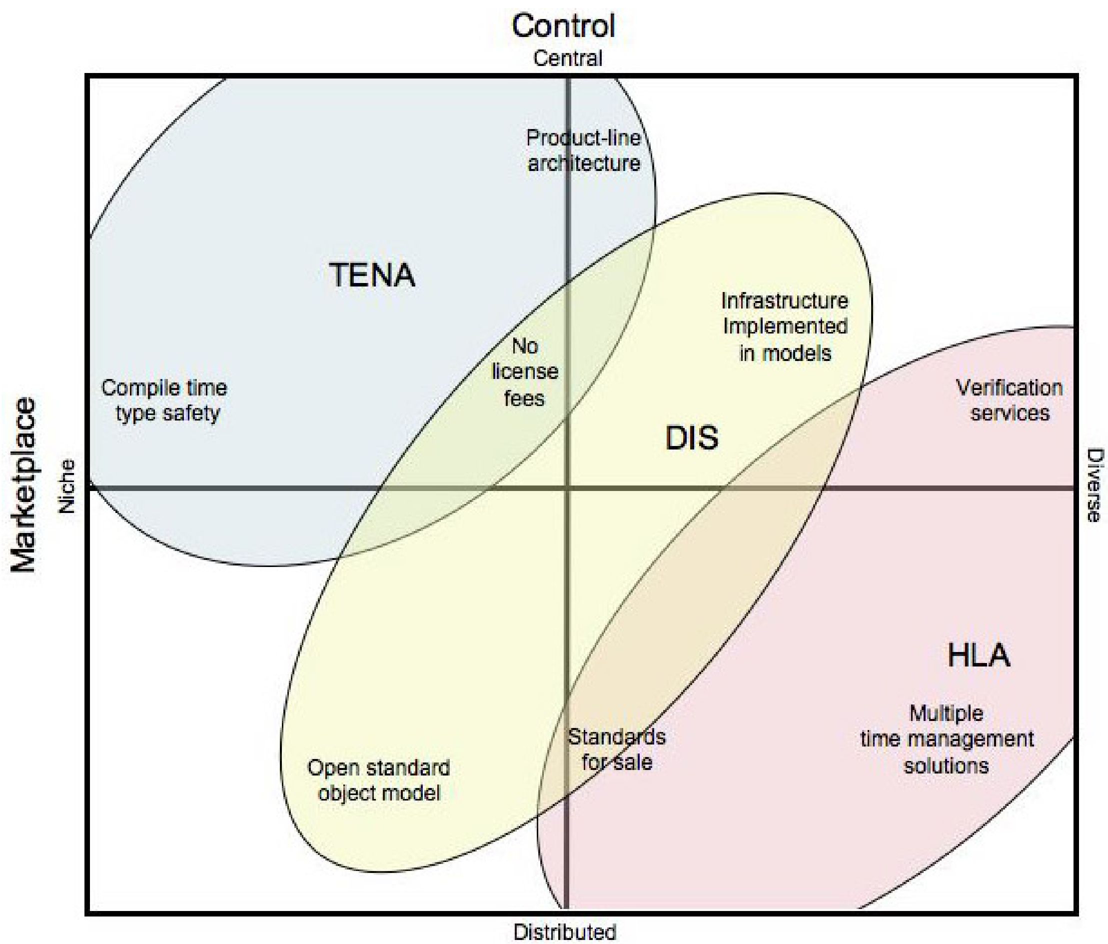

Figure 3.1 Conceptual Similarities, Contrasts and Progressions of LVC

By plotting the three major competing architectures on these axes, similarities, contrasts and progressions are visible. For example, characteristics such as "compile time type safety" and "Product-line architecture" are clearly present in the TENA model, but nowhere else. Characteristics such as "infrastructure implemented in models" and "open standard object model" are clearly present in the DIS model, but nowhere else. And, characteristics such as "multiple solutions for time management" and "verification services" are present in the HLA model, but nowhere else. In contrast, some characteristics are common. For example, the characteristic "no license fee (for middleware)" exists in both the TENA model and the DIS model. And, characteristics like "standards for sale" are shared by both the DIS and the HLA model.

This diagram also communicates trends in historical progressions. Namely, whereas DIS seemed to provide a good middle ground, HLA adjusted to improve diversity but ultimately at the expense of control, and then TENA adjusted in the opposite direction to improve control and chose to limit diversity. A significant problem for the LVCAR roadmap effort is to navigate this trade space to arrive at an achievable solution that maximizes the benefit for all concerned while not exceeding the resources that will be necessary to realize that solution.

3.4 Current State: Community at a Crossroads

A thorough requirements-capture effort (see *LVCAR Study Requirements and Use Cases Document*), led to the determination that most of the current requirements for LVC environments have an implementation in at least one of the current LVC architectures (i.e., most of the requirements are satisfied by the set of currently existing architectures). Several unsupported requirements, however, also exist; and while it is believed that some of these capabilities could be incorporated in existing architectures without major redesigns, many of these concepts warrant further exploration and improved definition so that the precise requirement can be adequately articulated. For example, instead of the stand-alone systems paradigm characterizing LVC capabilities today, the future of LVC will focus on a tighter coupling of operational capabilities (weapon systems, C4I, etc) and LVC capabilities. With this tighter coupling, presumably, will come more policy and standards constraints from other communities (acquisition, C4I, etc.). In light of this, until these constraints are better understood and defined, it is premature for the DoD to make broad, sweeping changes (e.g., a brand new architecture) without having a better sense for the requirements that will emerge from these other communities.

As the technologies that drive the warfighting systems employed by the U.S. military continue to advance and mature, corresponding advances in supporting LVC environments are also necessary. In some cases, these advancements only affect the individual simulations that participate in LVC events, such as the capability extensions needed to accurately represent new individual systems (e.g., longer-range radars or stealthier platforms). However, many of the same system interoperability needs that underlie modern "system-of-systems" approaches result in corresponding interoperability requirements for the LVC environments that simulate those approaches. While all modern LVC simulation architectures were designed to support syntactic interoperability among cooperating simulations, none provide the full range of capabilities required to support these types of emerging warfighting requirements. For instance, while most current simulation architectures generally provide some support for integrating live systems, none provide default support for the wide range of message formats used within the C4I community, and few are designed to operate in a manner consistent with the Service Oriented Architecture (SOA) paradigm that underlies the Global Information Grid (GIG) enterprise services. Another example is the potential for inconsistent representations of the various components of complex system-of-systems warfighting solutions (along with the environments in which they operate), which implies the need for greater support of semantic-level LVC interoperability issues.

Section F of the *Appendices Volume I: Supporting Analyses to the LVCAR Study* identifies several known deficiencies of existing LVC capabilities, along with new requirements related to these deficiencies. First, this is explored from the C4I perspective, including GIG/SOA implications for M&S and additional LVC considerations associated with embedded training. Then, several subtopics related to semantic interoperability are discussed; these transcend the purely syntactic issues typically associated with architecture interoperability. Finally, the topics of human behavior representation and Multi-Level Security (MLS) are discussed in terms of capabilities envisioned for future LVC applications. Any and all future work on implementing this roadmap should heed these topics closely.

4 Observations

> "Maybe we're standardizing at the wrong level…if we have to rebuild standards as often as we are rebuilding them [now], you have to stand back and ask: Are we doing it right? Are we doing it too soon? Are we doing it at the wrong level?… We're developing architectures because we can, yet we don't have good C4I models, we don't have a good model of the GIG, we don't have good models of human behavior and performance…We're lacking whole sets of model types because we don't know how to do them and we're spending our focus on the thing that we can do."
>
> Dr. S. K. Numrich, IDA
> (formerly DMSO Deputy Director, Technology)

4.1 Introduction

This section describes major themes evolving from work performed over the course of the Study. These factors represent practical considerations regarding the application of distributed simulation architectures within the LVC community today. The list below is accompanied by a discussion of supporting rationale and potential future impact to the LVC community. The observations in this section are developed from a variety of sources including: invited expert opinion, survey results, workshop reports, expert discussions, and community input. These observations provide foundation to the goal state characterized in the next section, Section 5.

4.2 On Interoperability: Defining the Architectural Boundaries

As identified in Section 1.4 of the *LVCAR Study Comparative Analysis of the Architectures* document, interoperability researchers have worked to define a theory of conceptual interoperability and have identified several potential levels of interoperability. The stated purpose of the LVCAR is "to develop the way forward for efficient, effective interoperability" where interoperability was interpreted at the technical level, the least ambitious form of interoperability. A more robust interpretation of the words "efficient and effective interoperability" however, could well result in at least Level 3 (Semantic Interoperability) and most likely Level 4 (Pragmatic Interoperability)[10]. At the present time, none of our infrastructures assure this to any meaningful degree. We spend significant resources doing work, above and beyond the work needed to be "compatible" with an infrastructure, which is necessary to have pragmatic interoperability. Much of that work occurs as part of VV&A.

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[10] which is characterized by Tolk and Muguira (2003) as follows: "Pragmatic Interoperability implies the use of the data – or the context of its application – is understood by the participating systems; the context in which the information is exchanged is unambiguously defined." Definitions for these constructs are also reviewed in the *LVCAR Study Comparative Analysis of the Architectures* document.

After a decade, three major HLA standards (i.e., DoD HLA 1.3, IEEE 1516-2000, and the current 1516 update, IEEE 1516-2009), and lots of other usage, we do not yet have an architectural boundary where we can truly provide “efficient, effective interoperability”. This boundary is not at the TCP/IP stack level, where the DIS protocol was defined. While DIS is useful, it is insufficient. HLA, and subsequently TENA, defined a boundary farther out, which included both data networking capabilities like those provided in DIS and new “object” manipulation capabilities. Additional capabilities, arguably outside the architectural boundary, have been offered as efficiency improvements, from data logging and playback to visualization.

The LVCAR took a broad definition of the architectural boundary to consider the pressing issues of semantic interoperability. We reviewed a number of large programs (e.g., MATREX, DDG1000, etc.) that have achieved some improved measure of “efficient, effective interoperability” by expanding their architectural boundary. These programs started with an HLA communications infrastructure, and built extensions on top of it. Their federates must be more than just HLA compliant, federates must also be compatible with their program-based extensions. Any federation with federation agreements requires more of federates than the narrow HLA architectural boundary would require.

For example, the MATREX ProtoCore makes it clear how they have expanded their architectural boundary in terms of application programming interfaces. *Appendices Volume III: LVCAR Expert Team Meeting Documentation* (see Meeting 11 sub-appendix G, LVCAR MATREX Brief) shows MATREX models programmed to a ProtoCore Based Architecture. Having studied both HLA and TENA, MATREX found a project specific convergence like that espoused in our architectural convergence strategy (see explanation of Strategy #3 in the *LVCAR Study Comparative Analysis of the Architectures* document). MATREX is more than ProtoCore, they also have capability extensions beyond the architecture such as C3Grid for representation of communication and ATC for regression testing.

The DDG 1000 Total Ship Simulation System (illustrated in Figure 1 of the DDG 1000 Use Case appended to the *LVCAR Study Functional Requirements and Use Cases* document) found a very similar need to go beyond HLA or TENA to define an architecture for “efficient, effective interoperability”. Their Simulation Middleware Architecture (SMART) expands HLA not only in terms of interfaces, which are based on the COTS VR-Link tool, but also in terms of additional services. The SMART services include data conversion, analogous to the TENA capability, initialization, common environment, and access to a database of model parameters used to automatically execute a run matrix (Raytheon, 2006).

Neither of these federations could be satisfied with simply “HLA compatible”. That is, an HLA compatible piece of software may or may not be able to perform in the federation. HLA compatibility represents a necessary, but not sufficient, precondition to “efficient, effective interoperability”. None of the LVCAR studied architectures provide these capabilities, and the extensions used to provide them are incompatible between these two examples.

If LVCAR addresses only commonality within the architectural boundaries defined in HLA, or even TENA, even complete convergence of these architectures would not achieve “efficient, effective interoperability” among these two federations. Truly, a much larger architectural boundary is needed to address the larger problems.

Expert Team Tip

The DoD should provide additional resources to address LVC issues that are not directly architecture-related. While the emphasis of the LVCAR study has been on architecture convergence and interoperability, many LVC users have reported that these types of issues are only part of the larger problem. For many users, their immediate requirements do not even require the use of mixed-architectures, and thus more vexing issues such as multi-level security and representation of the natural environment are considered of higher importance. Many such issues are semantic in nature, and also include such activities as conceptual modeling and verification of algorithmic consistency. Although investments related to improved architecture interoperability are certainly needed, it should not be forgotten that these other types of issues also need investment if the associated LVC environment deficiencies are ever to be effectively addressed.

4.3 On Interoperability: LVC Cost Drivers

Related to the notion of a larger architectural boundary presented in the previous section, this section provides a notional relationship of LVC event costs. Fundamentally, "effective, efficient" interoperability is about the exchange of data and consistent implementation of algorithms and the data that goes with them. The LVCAR is focused on the exchange of data, which is the least ambitious form of interoperability. As expressed by Dr. Ed Powell at first Expert Team Meeting (may be seen in 9 May 2007 meeting documentation in *Appendices Volume III: LVCAR Expert Team Meeting Documentation*), "Getting data from one application to another is not even in the top ten issues confronting successful LVC integration". We represent the large dimensions of this space in Table 4.1 below.

Table 4.1 The Costs of an LVC Event

A	Cost of the work that surrounds simulation infrastructure development (e.g., Planning conferences, Establishing objectives, Planning scenario, Personnel, Sites, Sims involved, Evaluate results, Budget negotiations, Establishing schedule, Subjects rehearse for and take part in the exercise, Data analysis and report writing, etc.)	Single Architecture Event (rows A–D)	Mixed-Architecture Event (rows A–E)
B	Cost of extending and integrating simulations semantically, including data and terrain		
C	Cost of integrating with C4I		
D	Cost of integrating simulation communications and control within each architecture		
E	Cost of integrating simulation communications and control across architectures		

In Table 4.1, Row A represents all of the work that is not directly M&S related. Rows B – E, alternatively, represent all of the M&S related costs in 4 bins, generally categorized according to what kinds of systems they make interoperable. Noteworthy is that Row E is the primary focus of this study and the costs most targeted for reduction.

It was observed (A. Ceranowicz, personal communication, May, 2008) that usually,

$$A >> B > (C \text{ or } D) > E.$$

In generalizing that observation, experienced LVC practitioners were surveyed on the concept, and the notional representation of the cost relationships was developed (see Figure 4.1).

Noteworthy is that “A” is part of the “billions” that can be indirectly influenced by the M&S SC. “D” enjoys some cost reduction through implementation of LVCAR activities designed to reduce “E”. But, we assert that “B” is the area where M&S SC efforts can have biggest direct impact on the cost of LVC events.

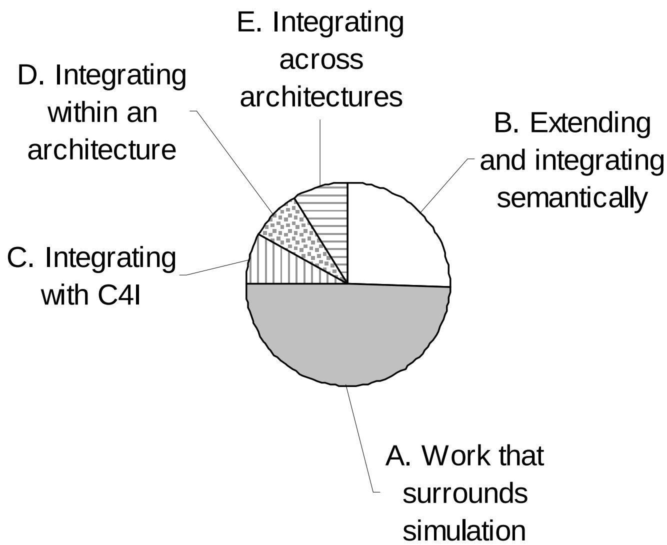

Figure 4.1 Notional Relationship of Costs Expressed in Table 4.1

Expert Team Tip

The DoD should lead efforts to standardize or automate translations of data/scenario inputs to simulations and data capture formats. This makes it easier to prepare common data for use in different simulations. It will also help to limit errors due to data mismatches. It makes it easier to test and compare results of different federations. It also makes it easier and cheaper to build new simulations since there will be ready data sources available.

4.4 Bridges and Gateways: A Growth Industry

Gateways are currently the most widely used method to link disparate simulations together. Gateways have demonstrated an impressive range of capabilities across the simulation communities that employ them, such as the ability to translate between different protocols/object model representations and to address disparities in the services typically encountered in mixed-architecture environments (e.g., time management, filtering, etc.). However, most gateways are designed as point solutions to specific problems, and are rarely shared across user organizations. Thus, the same basic capabilities tend to get developed multiple times, and programs may not even know about more advanced features developed by external organizations.

Federation proponents have identified up to 43 different bridges/translators that exist in the LVC user-community that are actively being used on the different ranges/test facilities (W. Bizub, personal communication, May, 2008). In a short exercise designed to document some of these gateways, the LVCAR Study quickly identified eleven different gateways used by major programs, and this list does not include the numerous event-specific gateways built for single use applications. As indicated in Table 4.2, there appears to be some degree of redundancy in

Table 4.2 Architectural Space Covered by Subset of Known Gateways

Name	*Sponsor*	*HLA*	*TENA*	*DIS*	*C2*	*Usage*

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integrating architectures supported by the various gateways, as well as a dispersion of non-traditional gateway functions. Simply put, there are more than we need and there are unique capabilities in some that are not available to others. The large number of gateway implementations is supported by a workforce characterized by small teams of developers each with experience only in the gateway application chosen or developed for use within their immediate domain. As multiple organizations come together to build a distributed LVC environment, success depends heavily on the availability and expertise of these few individuals to properly configure, test, and operate the chosen gateway application(s). However, by providing a free highly-customizable and well-documented set of gateway products to the LVC user community, the pool of technical talent knowledgeable in the use of this limited set of standardized products can be significantly increased, the intellectual power of the M&S workforce can be better focused, and both technical and schedule risk can be reduced.

4.5 Open Source is Here: e.g., the Portico Project

Open source software (OSS) is computer code that is licensed to users allowing them to 1) run the code, 2) analyze and modify the code and 3) redistribute copies of the code, either the original or modified, without royalty payments or other restrictions on who can receive them (Wheeler, 2007).

From this perspective, most OSS can be considered commercial off-the-shelf (COTS) software since it fits the descriptions given in U.S. Code and Federal Acquisition Regulations (FAR) as a commercial item being one that is "customarily used by the general public or by non-governmental entities" (i.e., they have uses not unique to a government) and has been "sold, leased or licensed to the general public". (U.S. Code Title 41, Chapter 7, Section 403; Federal Acquisition Regulations).

In DoD memos, policy and guidance for the acquisition, use and development of OSS has been issued. In May 2003, a DoD Chief Information Officer (CIO) memo contained guidance requiring DoD components to ensure that OSS complies with DoD policies that govern COTS and GOTS software (Stenbit, 2003). In June 2007, the Dept. of the Navy CIO issued similar guidance for Navy use of OSS (Carey, 2007). Both of these memos were intended to allow equal consideration of OSS when choosing software.

There are current efforts to implement the RTI of the HLA as OSS to support distributed simulation environments. One of the leading efforts, supported by the Australian Defence Simulation Office, is the Portico Project. The Portico Project is focused on the development and distribution of a cross-platform RTI implementation (Pokorny, 2007). While it's still in development, experts in RTI compliance estimate that the Portico Project will complete development of a fully compliant RTI in approximately three years. Given that the cost of licensing fees is one of the most cited dislikes of adopting HLA through the use of a compliant RTI, we expect that the availability of the OSS version will serve to energize the HLA-RTI's continued use by lowering the related costs. Further, if history serves as a predictor, we would also expect the OSS mechanism to increase functionality and quality due to increased and varied users, faster progress to setting standards for interoperability among applications and platforms and faster understanding of best practices among the OSS communities (Pearce and Bailetti, 2004).

4.6 Change is Always Coming: Other Architectures

For the past two decades, the simulation community has focused on a single mechanism for achieving interoperability, that of defining an architecture with a single middleware or protocol, and trying to make this protocol the single standard for all simulation applications. Thus the simulation community first developed SIMNET then DIS and ALSP, then HLA, then TENA and CTIA. The HLA RTI comes in a variety of versions, including black-market versions. If anything, we must recognize that inspired people want to create what they believe to be "better, faster, cheaper".

During the 2008 Small Business Innovation Research (SBIR) solicitation cycle, the Navy issued a topic seeking small business proposals to "provide an open architecture solution to interprocess communications between real-time simulation applications and services." (DoD 2008.2 SBIR Solicitation, 2008). This solicitation has the potential to create yet another competing architecture. Other efforts that make the LVC architecture space more complex include universal interoperability software packages such as OSAMS (Steinman, 2007), CONDOR (Hannibal and Wallace, n.d.), NGENS (McGraw, 2007) developed and distributed by commercial vendors.

Clearly, the enterprise is currently not in a position to maintain situational awareness over the entire Department in all LVC matters; and clearly, change is always on the horizon. We can try to squelch or delay it; or, we can try to shape and embrace it.

4.7 Implications of Open Standards: A Case Study on RTI Subsets

This case study, based on the "HLA Evolved" Product Development Group (PDG) as sponsored by the SISO[11] is designed to highlight the potentially competing interests of the various stakeholders within an open, commercial standards process, and share the various lessons learned from this experience. Specifically, it showcases how membership and voting policies of SISO influence the standardization process. For the interested reader, the case study is presented, in its entirety in Section B of the *Appendices Volume I: Supporting Analyses to the LVCAR Study* to this report. Also, detailed information on membership and voting policies of standards organizations may be seen in the *LVCAR Study Comparative Analysis of Standards Management and Evolution Processes* document. What follows is a small excerpt from the case study.

The notion of "subset" RTIs originated as part of a technical paper (Saunders, 2004) written by interoperability researchers at JHU/APL. Essentially, the notion of a subset was to define fundamental RTI capabilities (e.g., Save/Restore, Ownership Management, Time Management, etc) that could be optionally implemented such that the RTI was more finely tailored to the community the RTI subset would serve. The intent was to enable vendors to better serve the different user groups rather than provide a "one size fits all" approach. Additionally, it would lower barriers to entry for new vendors, as they would be able to implement subsets of RTI features, while still remaining compliant with the HLA standard.

During the reflector discussion period, the PDG Chair emphasized the fact that under the rules set forth by IEEE, discussion of product pricing, territorial restrictions, or market share as part of standards development are prohibited. Since the HLA specifications fall underneath the IEEE, the PDG was bound by these rules. Thus, both the reflector discussions and face-to-face discussions of this technical issue at the PDG meetings did not include many of the related business issues. Still, as was stated at the beginning of the reflector discussion, it was clear (mainly based on undocumented communications including personal discussions and other documented but informal exchanges) that current RTI developers had reasons beyond the purely technical considerations for not wanting the concept of RTI subset to be introduced into the HLA specifications. The main objection appeared to be the fact that existing RTI developers had to make a significant upfront investment to implement all of the HLA services in order to be certified as compliant. If the RTI subset change was made, new RTI developer organizations could then make much smaller upfront investments to only implement a certain subset of the HLA services, and their RTIs could still be certified as compliant. This could potentially give these organizations some competitive advantage over the existing RTI developers, as they could charge less for their products and still achieve a viable return on their smaller investment. This perceived "unfairness" is considered to be a significant factor in the eventual defeat of the RTI subset proposal.

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[11] SISO operated as a standards sponsor for the IEEE, who actually owns the HLA standard

The open standards processes used by the HLA Evolved PDG allow all interested parties to have representatives at the meetings, and each representative has one vote. Mechanisms exist to prevent a single organization from bringing enough representatives to take unilateral action. However, the mechanisms are ineffective when diverse organizations share a position, in this example for economic reasons. The primary beneficiaries of RTI subsetting would be small federations and the overall DoD enterprise. In general, small organizations do not participate in open standards processes, as they generally achieve as much benefit by "following the majority". In this era, the DoD enterprise view was not widely represented in the HLA Evolved PDG. In fairness, there was no collusion among the developers to defeat this proposal; they voted the same way because they shared a common business model. Also, there were technical opinions for defeating this proposal offered by both developers and some users. Still, this case study illustrates the potential for several contractor organizations, with a common business interest, to create a formidable voting block that can significantly influence the technical direction of an emerging standard in ways contrary to the DoD enterprise interest.

4.8 Cross Community M&S: The Landscape of M&S Forums

Many of the communities enabled by M&S attend, participate, or support forums (e.g., conferences, workshops, symposium, etc.) that are sponsored by non-profit corporations. Some of these forums include: Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC); Military Operations Research Society events (MORS), and International Testing and Evaluation Association Live-Virtual-Constructive Conference. These conferences promote a sense of community, advance the knowledge of the collective, and further the education of the attendees. However, while these forums are generally open to any interested attendee[12], none of these forums are decisively "cross-community", rarely do these forums present M&S interoperability related research, and if they do, few of the technical M&S interoperability papers are written from a cross-community perspective.

All of these organizations benefit from some form of direct or indirect government support that improves the organizations' health and, in turn, increases the likelihood that they will better serve the DoD. These forms of government support vary. Some forums such as I/ITSEC receive persistent and predetermined government participation over the course of a year's planning cycle for the conference[13]. Some forums such as MORS are directly funded by the DoD in exchange for contracted deliverables[14] including special meetings, reports, and educational colloquium, while also enjoying much in-kind participation to promulgate the Society's stature.

Currently, SISO receives some limited funding support from the DoD[15]. This is allocated to support some basic infrastructure (e.g., web site, part time admin, etc.) to develop M&S standards. It is not used to produce SISO's bi-annual conference(s), the Simulation Interoperability Workshop (SIW). Presumably, for government employees who are involved in the planning of such activities, there is additionally some amount of in-kind support. This participation, however, is transitory, and not comparable in magnitude to the in kind participation supplied to the other organizations and/or forums mentioned previously. Moreover, in addition

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[12] MORS often requires advanced formal government clearance to attend
[13] The cost for this support (independent of the cost of attending the conference) is estimated as labor and travel.
[14] Estimates for in-kind funding for planning functions not provided here.
[15] SISO receives support from DoD annually.

to providing a forum for intellectual exchange, SISO produces a number of products central to the successful employment of LVC in the Department.

As a rule of thumb, it is reasonable to suggest that the degree to which an organization serves the needs of the DoD is correlated to the degree of support the organization receives from the DoD. This heuristic coupled with the fact that SISO is the only organization dedicated to the "*promotion of modeling and simulation interoperability and reuse…"* and that it embraces this challenge in the context of fully recognizing a cross-community environment, implies that the M&S SC could find a strong partner in SISO given more vigorous support and active engagement.

4.9 Supporting Data for Decision Making

The LVCAR Study has made a number of data requests, formal and informal. These are documented in the *Appendices Volume II: Supporting Data to the LVCAR Study* document.

The less formal, point-to-point requests included an appeal for data on performance analyses, use cases, and integration costs. These requests yielded some, but few responses, with the most success coming in the form of use cases. However, even the submitted use cases did not provide the full amount of data requested, which was admittedly ambitious. Thus, above and beyond their use in definition of functional requirements, even the use case data, particularly cost data, have really not added a great deal to the analysis, as they do not provide for an apples-to-apples comparison. They either represent a unique data point that does not generalize across the population of LVC users or they are conflicted with other data (e.g., particularly financial data) and cannot be uniquely identified.

As one example of data collection efforts, we offer Figure 4.2 below. This graphic, formed from survey data generated by members of the LVCAR Working Group (documented in the *LVCAR Study Workshop #2 Report*), illustrates the lack of data that exists, as well as the unwillingness or inability to share data that do exist, and it does so by Community-type.

Noteworthy is that few of these respondents even had data, and of all those who did have data, including those who were willing to share data, few actually delivered it to the LVCAR Study. These requests for data and the subsequent results of the requests are documented in Section B of the *Appendices Volume II: Supporting Data to the LVCAR Study* document.

Also, more formal data requests were executed. For example, the LVCAR Study worked to develop a measure of the total cost of U.S. DoD expenditures related to LVC integrating architectures, as well as a sense of the ratio of government expenditures on government sponsored middleware vice commercially provided RTIs. To this end, we distributed a data call on expenditures to government sponsored LVC architecture proponents. Turn around time for these requests ranged from two weeks to two months. Even more noteworthy though, is that to develop an estimate of how much the DoD spends on commercially provided RTIs, the LVCAR Study had to request the information from the major RTI vendors. Specifically, we requested their sales and market-forecast related data. Clearly, if the DoD is going to manage LVC environments from an enterprise perspective, some better method for acquiring decision-support data is required.

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Figure 4.2 Community-aggregated responses to requests to share information for comparative assessments of middleware performance (blue), LVC requirements (red), and LVC integration cost data (yellow). Individual columns represent "Yes. Am willing to share.", "Yes. Will NOT share.", "No.", and "I don't know." which are then expressed across each of the six communities.

4.10 Fundamental Precepts

On contemplating the recommendations resulting from LVCAR Study, the Expert Team converged on a core set of beliefs, sort of 'meta-recommendations' that seemed to provide guiding principles to implementation and execution of the roadmap. These principles are presented below as the fundamental precepts to the LVCAR Study Final Report.

Fundamental Precept #1: Do No Harm. The DoD should not take any immediate action to discontinue any of the existing simulation architectures, as such an action would place undue hardship and costs on one or more communities of users. There is a considerable degree of consensus within the LVC user community that a long-term strategy based on architecture convergence would benefit the DoD. However, it is also understood that there are many design issues that must be resolved prior to implementing such a strategy, and that the actual implementation needs to be a well-planned, deliberate, evolutionary process to avoid adversely impacting participating user communities. Because of these considerations, it would be unwise to eliminate support for any of the existing simulation architectures in the near-term. Rather, as the differences among the architectures are gradually reduced, it should be the users themselves that decide if and when it is appropriate to merge their architectures into some smaller set based on both technical and business concerns. Any attempt by the DoD to mandate a convergence solution on an unwilling user base is certain to meet strong resistence and likely to fail.

Fundamental Precept #2: Interoperability is not Free. The DoD must make the necessary investments to enable implementation of the activities described in the LVC Roadmap. LVC interoperability is not free. It is not reasonable to expect that LVC interoperability goals can be met with little or no investment. Since the return on LVC investments is nearly impossible to accurately quantify in the near-term, it is understood that major new up-front investments are difficult to justify. In recognition of this fact, the Roadmap has taken a long-run approach which requires only limited investment early in its implementation, with subsequent investments dependent on demonstrable progress. Without the necessary investments, the LVC Roadmap is nothing more than a blueprint of what is possible to accomplish, with no mechanism to realize the associated benefits.

Fundamental Precept #3: Start with Small Steps. The DoD should take immediate action to improve interoperability among existing simulation architectures. The vast range of technical problems currently associated with the development and execution of mixed-architecture LVC environments is well recognized. Such problems increase the technical risk associated with the use of these mixed-architecture environments, and require considerable resources to address. While architecture convergence would lessen (and even eliminate) several of these problems, it is not practical to expect any significant degree of convergence to occur for many years. Instead, LVC users need near-term solutions that reduce both cost and technical risk until such time as architecture convergence can occur. These solutions include actions such as improved gateways/bridges, common object models, and common development/execution processes. Many of these solutions can be implemented at low cost, and provide significant near- and mid-term value to the LVC community.

Fundamental Precept #4: Provide Central Management[16]. The DoD must establish a centralized management structure that can perform Department-wide oversight of M&S resources and activities across developer and user organizations. A strong centralized management team is necessary to prevent further divergence and to effectively enable the architecture convergence strategy. This team needs to have considerable influence on the organizations that own the existing architectures, and must also have influence on funding decisions related to future LVC architecture development activities. Without centralized DoD management, existing architecture communities will continue to operate in line with their own self-interests, and the broader corporate needs of the DoD will be treated as secondary issues that are likely to continue to be ignored as concerns that are not germane to the local problems.

! Expert Team Tip

The enterprise perspective should be represented from a technical position. Current Enterprise steering committees and IPTs are representing a functionary position. This is needed, but not sufficient. The current functionaries need to set policy so that technocrats assess technical decisions before they are funded.

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[16] The Government Management Team has supplied a separate report on management issues (see *LVCAR Study Execution Management*).

4.11 Architectural Recurrence

The LVCAR Study Team and Expert Team shared many interesting "war stories". Over time it became clear that the architecture issues posed in the study were not new. The same issues motivated participants in the first DIS workshop of 1989. Some of the same people are still working the issues. Examination of these technical issues led to DIS, ALSP, HLA, TENA, and CTIA in turn. The team asked itself "Is this just another iteration of the same thing? What are we doing differently this time?"

Ultimately, the team members found one key difference. All the prior efforts had excluded the business model dimension of the problem. The DIS and HLA efforts used a technical approach to produce an increasingly generalized specification and a standardization approach to promulgate it. TENA and CTIA sought to better serve narrower interests by promulgating a single implementation instead of standardization.

In this study, a third leg has been added to the stool. By explicitly considering the business implications of the decisions we hope to break the cycle of "new architecture" solutions fracturing the user community into more and more non-interoperable pieces. Having seen five working technical solutions developed over the years, we have confidence that the technical issues can be solved by the people involved. To break the cycle, our excellent technicians and architects must be further constrained by the business interests of the DoD enterprise. In a balanced marketplace the alignment forces must foster convergence and inject long-term decision criteria into the current locally-optimized decision making that has caused our past divergences. Including business actions in this study was the first step towards fixing the root cause of the problem.

4.12 Summary

The intent of Section 4 was to introduce a succinct set of issues that are relevant to both current and future LVC applications. These issues span the architecture, business model, and standards space. Though generally and initially presented as independent elements, the next section (Section 5) builds on the effects of these observations in the development of a comprehensive vision statement for the LVCAR Roadmap.

5 The Vision and Roadmap Initiatives

> "There needs to be a mediating body….that looks at programs from one standard to the next NOT with an eye towards dismissing or dropping the old standard, but toward integrating them."
>
> Ms. Philomena Zimmerman,
> FCS SI Associate Director, Modeling, Simulation and Analysis
> (formerly HLA PM)

5.1 The Vision

We envision an environment in which the M&S SC can leverage its millions to influence the billions spent on distributed M&S and LVC across the Department. We believe this is possible. Microsoft, for example, has profound influence over the information technology (IT) marketplace; yet in "both its revenue and number of employees represent about 0.05% of the total figures for the ecosystem." (Iansiti and Levien, 2004). We assert that it is possible for a central M&S oversight organization with a budget of merely $35M to have a substantial influence on the estimated $10B (Cuda and Frieders, 2005) spent annually on M&S in the DoD.

M&S leadership in DoD saw growing expenditures on M&S as far back as the late 80s. Growing expenditures attracted contractors looking to "stake out a claim" and provide needed goods and services. Perhaps too literally, model developers saw non-interoperability as a business benefit, and built M&S that was incompatible with that of their competitors. To try and receive a fair benefit for dollars spent, initiatives were launched to encourage "interoperability". For the past two decades, the M&S community has focused on a single mechanism for achieving interoperability, that of defining an architecture with a single middleware or protocol, and trying to make this protocol the single standard for all simulation applications. Thus the simulation community first developed DIS, then HLA, then TENA. Each of these interoperability architectures is only fully successful when adopted by most, if not all, simulations that have a need to interoperate. Some people call this the Network Effect.[17,18]

As discussed in Section 4.2, however, the definition of a system's architecture is largely a matter of where one draws the boundary. Thus, a single physical architecture (e.g., DIS, HLA, TENA) that can be universally applied is not necessarily the only or the best outcome for this effort. Of chief importance is that we reach a state that promotes simple adoption of the same interoperability paradigm, independent of whether that paradigm is a physically and programmatically single architecture (e.g., DIS, HLA, TENA) or a conceptually single architecture, where the existing architectures are so easily integrated that they can be viewed

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[17] There is some disagreement as to the actual network-effect value function (Briscoe, 2006; Metcalf, 2007). Regardless, it is considered by the Business Model Team to be an important principle that drives the motivation to increase the number of interoperable LVC assets.

[18] M&S has not seen the consolidation that might be expected from the Network Effect. The "interoperability initiatives" and two decades of spending on network-level interoperability have not produced M&S community that is as cohesive as the much older telephone community or the much younger instant message community. Clearly interoperability technology alone is not the solution to Balkanization in M&S. Other technical and management activities must be coordinated to achieve the desired effects.

as a single "architecture of architectures". Thus, the desired end state is agnostic on the number of different architectures or protocols that exist, but does express a requirement that they are, at a minimum, conceptually a single resource.

Section 4.3 additionally provides information on the true cost drivers in an LVC integration. More specifically, it suggests that potential for reducing costs related to technical interoperability is far outweighed by the potential for reducing costs related to semantic interoperability. We assert that the combination of these two observations implies a need to revisit the prevailing view[19]. Achieving technical interoperability will not solve all interoperability problems.

Expanding Our Vision for Interoperability. *The vision for LVC interoperability has to be bigger than merely the scope of the LVCAR Study. We must move beyond the debate of technical interoperability and start focusing on the semantics of these systems. This more elegant focus will direct us to a path towards improving both the effectiveness[20] of LVC applications, as well as the costs of LVC applications. Technical interoperability has been a problem, but it is clearly tractable; solutions to the technical interoperability problems exist and they should no longer consume all of our attention. From this point forward, our technical vision for the next phase of LVC in the Department must raise the bar.*

Getting to the point where we can raise this bar, however, would seemingly be better served by a shift in our business practices. As demonstrated in Section 4.4, M&S development and use is spread across a large number of program elements and authority for executing those funds is spread across an equally large number of organizations. There is no single organization that controls both policy and funding under a single mission umbrella, and the differences in institutional investment and cost of entry for the users have resulted in a marketplace where the array of possible key products cannot compete on technical merit alone; the marketplace displays some degree of unnecessary redundancy. Further, we see in Sections 4.5 that open source RTI efforts exist and they are expected to change the landscape of the market; and, in Section 4.6 that new architectures are consistently trying to break into the market. We assert that the combination of these observations implies a need to revisit the current business environment where sometimes redundant resources are competing with one another.

Harnessing the Power of M&S Intellectual Capital and Focusing Diverse Fiscal Resources. *We envision a common workspace to share architecture and tool advancements serving as a unifying enabler of change. This opens the core capability to innovation by other organizations, governments, commercial entities, and academia. Investment in development is pushed out to the community, and the potential for innovation is improved by spreading access and risk to a greater constituency.*

For innovation to propagate, however, we must, as discussed in Section 4.7, develop adequate spheres of influence in standards organizations and related communities (e.g., C4I, DISA, etc.) to ensure that DoD interests are well served. Further, as discussed in Section 4.8, we must build an M&S workforce proficient in these innovations by providing them adequate opportunities to engage in intellectual discourse and debate with others in the community.

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[19] Prevailing view is that interoperability is a binary construct and that this Roadmap will solve it.
[20] It will improve the validity of analyses and reduce the possibility of negative training.

Building a Sense of Community and an Intellectual Forum for the M&S Workforce. *We envision the existence of a cross-community forum to foster intellectual exchange such that the M&S workforce has a place to learn from one another, identify future requirements, discuss expected impacts of other programs in DoD, and grow as individuals and as a community.*

Finally, as demonstrated in Section 4.9 and repeated in a number of the supporting documents, we must develop processes that support solid, performance-based decision-making such that management can evaluate the efficacy of roadmap, make mid-course corrections, and develop the next-generation of goals.

Fostering Adequate Data Support for Decision Making. *To facilitate good decision making, the Roadmap must account for the need to provide decision makers with adequate data to assess community trends and make informed technical, business, policy, management and standards-related decisions.*

5.2 Roadmap Initiatives

The strategy for transitioning from the current state of simulation interoperability for LVC environments to the goal state described in the previous section involves many complex technical, business, and cultural factors. The initiatives illustrated in the schedule in Figure 5.1 and described in the sections below represent a LVCAR-participant consensus of the recommended approaches to addressing LVC interoperability issues from which the Roadmap is derived. All of these initiatives are detailed in Section A of the *Appendices Volume I: Supporting Analyses to the LVCAR Study* document.

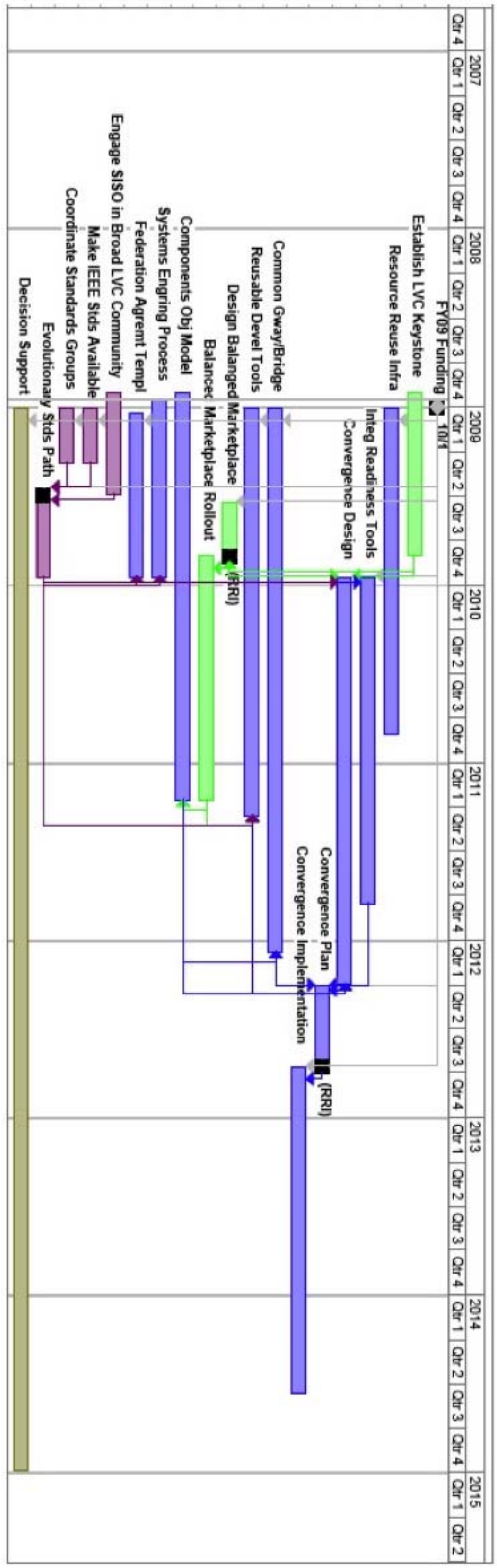

Figure 5.1 Potential Schedule for Roadmap Initiatives

5.2.1 Architecture Initiatives

Promoted from the *LVCAR Study Comparative Analysis of the Architectures* document and illustrated in Figure 5.1, the Roadmap contains ten architecture activities designed to foster the environment described in the vision state. Details on all of these activities may be found in Section A of the *Appendices Volume I: Supporting Analyses to the LVCAR Study* document and the details of the ROI analysis leading to their incorporation into the roadmap may be found in Section C of that same document.

These activities are based on the notion that having multiple architectures available for use is desirable and that the best way forward is to take actions that can reduce or eliminate the barriers to interoperability between the existing architectures and protocols. More specifically, this strategy acknowledges that the existing architectures have been created, have evolved, and are being maintained to meet the specific needs of their constituent communities. Elimination of any architecture should only occur as a natural result of disuse. Modification of the existing architectures is left to the owning communities as the best option to ensure meeting the needs of the various user communities, both throughout the DoD and among the Department's coalition partners. To resolve the interoperability problems, efforts should be directed towards creating and providing standard resources, such as common gateways, common componentized object models, and common federation agreements, which can render integration of the multiple architectures an efficient and nearly transparent process. In effect, these actions will create the perception of a single architecture that supports all the diverse simulation systems, even though the systems will actually be serviced by an "architecture of architectures", comprised of as many different architectures and protocols as are required to interconnect the participating simulation systems.

The potential activities have been discussed and refined with both LVCAR Expert Team members and participants in the LVCAR Workshops (starting at Workshop #3). The Expert Team members have individually assessed the potential value of each activity in two different ways. Most simply, each Expert Team member provided a rank-order of the potential activities in descending order of value (with the most valuable activity listed first). Expert team members also provided an estimate of potential cost savings and cost to implement for each activity (described in detail in Appendix Volume 1), forming the basis for the ROI analyses. Each of the potential activities was also rank-ordered by each of the LVCAR Workshop #3 participant (using the same decreasing value ranking as above). As evidenced in Table 5.2, there is considerable agreement in these three distinct evaluations of potential benefit; the most valuable activities (top 4) and the least valuable activities (bottom 2) are nearly identical. In fact, the two lowest-value potential activities are not recommended investment areas (as described later in Table 6.1) because of their potentially high cost and low estimates of value

Table 5.2 Value-Rank of Potential Investment Activities

Activity Title	Expert Rank	Workshop Rank	ROI Rank
Common components of architecture-independent object models	1	1	1
Create common, reusable federation agreement template	2	2	2
Produce reusable, common gateways and bridges	3	3	4
Describe and document a common, architecture-independent systems engineering process	4	4	3
Produce and / or enable reusable development tools	5	7	5
Specify a resource or capability to facilitate pre-integration systems readiness	6	5	7
Analyze, plan and implement improvements to the processes and infrastructure supporting M&S asset reuse	7	6	6
Conduct a study to generate future requirements for simulations	8	8	8
Produce a standard for on-the-wire representation of data	9	9	9

We consider achieving the most valuable of these activities a viable step, and an intermediate step, towards the desired end state. And, as acknowledged in the introduction, the desired end state is agnostic on the number of different architectures or protocols that exist, but does express a requirement that they are, at a minimum, conceptually a single resource. The next logical progression after this state would include and be bounded by: complete plug-and-play or complete middleware convergence. In the former, a variety of individual interoperability architectures would exist but the interfacing technologies and surrounding processes would be so well defined that they innately become a part of the system. In the latter, the interoperability architectures and corresponding middlewares would converge completely such that there would be only one single common software engineering baseline. In this instance, it would be likely to ultimately adopt a composable infrastructure that allowed for optimization to the requirements of a given community. The decision for which of these paths to pursue or not to pursue should happen in the “Risk Reduction Investigation (RRI) convergence technical feasibility” activity. At this point, the completion of earlier activities (e.g., Common Components Object Model, Systems Engineering Process, etc.) will have yielded a sense for how big of an impact they actually had on the costs to integrate mixed-architecture events. Also, by this point, other business model and standards activities that might influence this decision will be completed.

Regardless of which path is pursued, the proposed architecture activities provide: 1) an interim solution during the period of evaluation and evolutionary convergence and; 2) mechanisms to meet the needs of external systems, which do not use simulation architectures, and legacy systems, which will probably not be revised to take advantage of the converged services, and interface to external systems.

5.2.2 Business Model Initiatives

Two large-scale business activities were promoted from the *LVCAR Study Comparative Analysis of the Business Models* document to foster the environment described in the vision state. First, the DoD must clearly identify and establish an LVC Keystone, to gather and disseminate information across the M&S community, representing a unified consensus of opinion in place of the partial perspectives provided today by the DoD services and agencies individually. Second, the marketplace must be balanced across architectural approaches so that investments are made in terms of their overall benefit to the DoD enterprise, rather than program-by-program sub-optimization.

Establishment of an LVC Keystone is conceptually simple. The appropriate office or agent must be identified, or stood up if this responsibility is not assigned to an existing office. The role of the LVC Keystone must be documented and communicated throughout the DoD through an appropriate plan or instruction. The LVC Keystone must then begin to gather information about DoD M&S usage, architectures, schedules, funding, and producers. The staff of the LVC Keystone must analyze this information and consolidate it into a unified operational picture. The picture would be circulated to understand where it represents a consensus and published, perhaps as an annual report, for the benefit of the communities using M&S/LVC. Continuing efforts would take in additional information and revise the operational picture as time and situations proceed.

Balancing the marketplace will require the establishment of a clear LVC Keystone. Beyond that, several alternative approaches need to be considered to set an optimal course of action. This study had limited resources for business model assessment, and as a result a thorough ROI evaluation for this dimension was not possible.

The goal of a balanced marketplace means that all decision makers are working from the same, relatively complete, information. The current state, outlined previously, is significantly unbalanced because most decision makers know only about the expenditures they are asked to make. Architecture advocates control some of the available information to influence decisions in favor of their architecture. Other information, such as the total amount spent on an architecture by DoD, is simply unknown. Decision makers are influenced by contractor opinion and other sub-optimal factors, inevitably leading to the redundant funding observed today.

Table 5.3 illustrates two alternatives that were discussed during the study, but a thorough RRI of alternatives for balancing the marketplace should be open to other alternatives.

Table 5.3 Possible Mechanisms to Balance the Marketplace

Mechanism	***PROs***	***CONs***
Centrally Coordinated GOTS: DoD resources are spent through a central office (like telecom under the DISA Networks construct)	• Logical extension of the current TENA mechanism • Vendors sell to a single, expert buyer	• Distance between user and buyer can result in low satisfaction (ex NMCI) • Cost savings through constraint will lead to avoidance (ex black market RTIs) • Past experiences have been subjected to legal challenge (ex HLA Training)
Open Technology Development (OTD): DoD participates in limited open-source development of products that are free-to-use (like the Linux operating system often used for M&S)	• Established mechanism proven in other IT areas • Already started in the HLA community (ex Portico, Carlton Univ, …)	• Disruptive to current technology providers • Access limitations reduce the free labor available (ex: grad student thesis researchers)

The establishment of a single DoD investment agent for M&S architecture would significantly expand the role of the LVC Keystone. Centralization of acquisitions, such as RTI license purchases, will provide better terms and more insight into costs and usage. When commercial providers do not meet the desired costs, directed development would be an alternative. The TENA architecture has used the directed development of GOTS throughout its history.

The adoption of an Open Technology Development (OTD) paradigm has many examples in the DoD. In April 2006, the Deputy Undersecretary of Defense for Advanced Systems and Concepts published a roadmap for OTD (Hertz, 2006) which embraces government's calculated use of Open Source alternatives. The government has already undertaken or completed Open Technology initiatives under similar circumstances [21] that seem to provide ample precedent and experience. A recent report (Bollinger, 2002) on the use of Open Source within the government context highlighted the vital role that Open Source plays within DoD's operational and security environments. There are strong technical motivations that drive the selection of an OTD solution (Raymond, 2001). Section 4.5 referenced an Australian effort on the development of an open source RTI. Other countries have other open source RTI efforts. The DoD needs to understand the potential impacts of these on-going efforts on the interoperability of M&S systems across the DoD as an enterprise. Further, the DoD should explore the adoption of such a model as a means of balancing the marketplace, where "adoption" could be supporting one of these ongoing open source efforts or sponsoring a new open source effort. Open source M&S efforts in the DoD, such as the OneSAF Program (Parsons, 2007), can serve as a data point in this evaluation.

All of the efforts mentioned here are presented in detail in the *LVCAR Study Comparative Analysis of the Business Models* document. The RRI should continue to examine these concepts, in addition to others proposed, to develop the best approach for balancing the marketplace. By focusing resources on key players and leveraging them with existing resources, greater effects are achievable. In an effort to foster expedient migration of federates and federations into the LVCAR, the M&S Leadership should identify important Federation Proponents (JNTC, NCTE, JMETC, large PEOs, etc.) and work with them to integrate emerging development by using the LVC OTD as a basis for their future architectural solution.

Figure 5.2 shows the historical spending on the LVC architectures[22]. Each architecture shows an initial cost surge, when the technology is being developed. The sustaining cost is significantly lower, usually less than 1/3 of the development peak. The sustaining cost is shared between the users and the government in DIS and HLA, but all this cost is borne by the DoD enterprise. Some HLA sustaining cost is absorbed by international parties, but it has been excluded from this chart. TENA has had an extended development phase, choosing to add more functionality over time. It may enter a sustainment phase in the future.

Consolidation still represents the most likely long term means to reduce the sustainment costs. A balanced marketplace can minimize spending within an architecture, but those low hanging fruits will be harvested within a couple of years.

5.2.3 Standards Initiatives

Promoted from the *LVCAR Study Comparative Analysis of Standards Management and Evolution Processes* document and illustrated in Figure 5.1, the Roadmap contains five standards activities designed to foster the environment described in the vision state.

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[21] Examples include NSA's SELinux (Ballard, 2008; Security Enhanced Linux, n.d.) effort which could be construed as competing with Sun's Solaris Operating System and DOE's VisIT (Software that Delivers Parallel Interactive Visualization, 2008) which could be seen as competing with any number of commercially-developed data visualization packages.

[22] Data available in Appndices Volume II: Supporting Data to the LVCAR Study

In these activities, the SISO is the primary target for LVC standards development. Their existing infrastructure and established presence as an M&S standards development organization uniquely position them to take the lead in future LVC standards evolution and management. While SISO is the primary target for LVC standards development, the spectrum of standards needed by the LVC community is much broader than SISO. Emerging work on the Service

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Figure 5.2 Historical and Projected Annual LVC Architecture Spending by DoD[23]

Oriented Architecture, Global Information Grid, Information Security, Web Services, and Modeling, are but a few of the standards poised to heavily impact LVC systems yet none are developed by the LVC community.

The cost of acquiring IEEE standards (DIS and HLA)[24] is an issue that concerns many people in the LVC community. The requirement to purchase the standards is a barrier to entry for many individuals, including small companies and academic researchers. There is a considerable degree of consensus in the LVC community that these standards should be available to anyone in the LVC community without charge.

Execution of the activity "RRI sphere of influence adequate" is designed to provide the M&S SC with an increased sphere of influence at SISO. Section 4.7 illustrated the potential for SISO to pass efforts that are not in the best interest of the DoD or defeat efforts that are in the best

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[23] These estimates are not comparable across architectures. There are differences in the fundamental assumptions of each, differences in the architectural boundaries, and differences in the user base size supported by each. The figure is best used to represent the lower bounds, projections and trends of LVC architecture expenditures at a gross level.
[24] A set of DIS standards (IEEE 1278.x) is $607 and a set of HLA standards (IEEE 1516.x) is $366.

interest of the DoD. This general phenomenon has also been documented by standards experts who suggest that representation by individuals makes it "possible to bias voting by sending multiple committee members to meetings from the same firm" (Weiss, 1988). Thus, before proceeding with the standardization of any of the LVCAR products, it would be prudent to ensure that DoD's sphere of influence is sufficient. If it is not, we must pursue other ways of increasing the sphere of influence in that organization, possibly through methods that could include evaluating membership and voting policies (Hofer and Loper, 1995; OMG Membership Matrix, 2007; The Open Group Become a Member, 2008; W3C Membership, 2008) as well as other techniques.

The fifth standards activity recognizes that the types of standards needed by the LVC community are varied including integration standards, data exchange standards, best practices, and threshold standards (National Training and Simulation Association, 2008). As a result, a standards evolution process that supports the flexibility and stability required by the government is needed. The benefits of stable standards to protect investments must be weighed against the need for flexible standards that can be modified to meet emerging user needs. Approaches such as trial standards might support both flexibility and stability. These allow the government to work well in a commercial standards process.

5.2.4 Management Decision Support Initiatives

Obvious across all three dimensions and discussed in Section 4.9 is the need for improved decision support. To measure the effects of these changes and plan for the future, the M&S SC must have improved decision-making data. While this report does not focus on management or leadership issues, it does address the need to produce better decision support for management use.

5.3 Summary

Roughly 20 activities have been developed for consideration in the LVC Architecture Roadmap. The execution of a handful of these activities is dependent on results of earlier activities. All of the architecture activities, except for the few that are dependent on earlier efforts, have been considered in light of their potential return, given an estimated cost. The analyses supporting the development of any activity's ROI may be seen in Section C of the *Appendices Volume I: Supporting Analyses to the LVCAR Study* document. And the results of the ROI analysis may be found in the activity description found in Section A of the *Appendices Volume I: Supporting Analyses to the LVCAR Study* document.

6 Recommendations and Conclusions

> "It's denying the nature of reality to believe that the solution is to impose a standard on all simulation communities rather than first asking: How can we get better at bridging communities together?"
>
> Dr. Richard Weatherly, MITRE
> (formerly Chief Architect of the HLA)

6.1 Conclusions

Figure 6.1 provides a useful tool in visualizing where we have been, where we are now, and where we want to be. Although only notional and schematic, with no firm basis in empirical work, the picture appears to accurately capture the key meta-concepts. Combining this

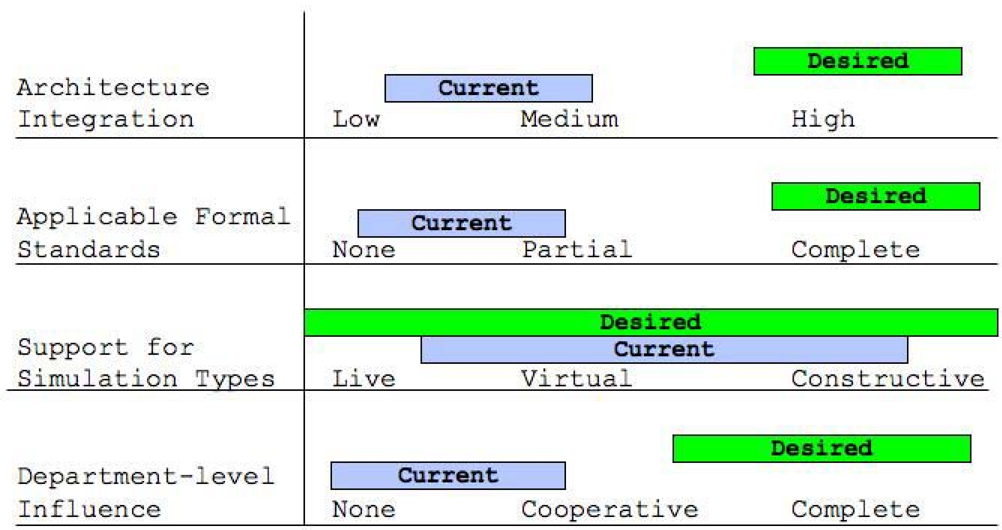

Figure 6.1 Where we want to be (in green)

schematic with architecture use indicators (see the *LVCAR Study Comparative Analysis of Architectures* document), In the current state, the effort required to integrate the various architectures in preparation for conducting a mixed-architecture simulation event is high because of the individual differences between the architectures; none of them can communicate with each other "right out of the box" and, in the case of HLA, different implementations of the same architecture require add-on bridges to communicate effectively. However, some assets (e.g., gateways, bridges, object model reconciliations, etc.) that are prepared to support a mixed architecture event can be reused to support repetitions of the same event or those that are highly similar. Further, they can often be modified for reuse at lower effort than creating new integration resources. The desired state is one where there is only a single architecture, either due convergence, the creation of reusable intercommunication resources that will make different architecture implementations appear as a single resource, or a combination of these two developments.

Currently, the availability of formal standards is mixed. Formal IEEE standards exist for HLA and DIS. Less formal standards exist for TENA. CTIA is not described by a standard. The most desirable state is one where all architectures are associated with widely available standards. Currently, we can achieve partial support for combining live, virtual, and constructive simulations. We can support intercommunication at the technical (syntactic) level, but ensuring semantic level interoperability is difficult, at best. The desired state is one where full interoperability can be achieved across all simulation types.

Department-level influence over architecture evolution is currently poor to moderate. Command-level decisions guide TENA and CTIA evolution while "those willing to participate" can often influence the evolutionary course of both DIS and HLA (through participation in the SISO, and thus IEEE, standards modification processes). The desired situation is one where the Department has significant influence over the architecture evolution, in cooperation with coalition partners as well as the supporting industrial base.

The second point is that the DoD, from the enterprise view, should be able to accommodate a host of different requirements, whether they're technical, business, or programmatic. Each of the existing architectures is providing useful service to a dedicated user community. While there are many similarities between the architectures, there are also differences so that each architecture has an appropriate role within the community overall.

6.2 Summary Recommendations on Investment

Many of the earlier recommendations (e.g., fundamental precepts, Expert Team Tips) relate more to emphasis and management than to DoD-level investment. Table 6.1 instead focuses exclusively on DoD-level investments. These are seen as common goods particularly worthy of DoD-level attention. Each of the listed activities has been discussed with Expert Team members, presented and discussed at the LVCAR Workshops, and subjected to return-on-investment (ROI) analyses. Table 6.1's recommendations fall into three categories, consistent with the dimensions of the study discussed earlier. Within each category, the table indicates desirable investment and their priority (1, 2, or 3); and suggestions as to whom the executor might be and whether or not the estimate of investment, immediate and recurring over 10 years, is RRI dependent (note that the investment unit of measure should be man-years (MY), except where direct current-year dollar costs are known) .

The Architecture activities are designed to enhance the interoperability of mixed-architecture events, while preserving options and positioning the community for some degree of architecture convergence in the future. The activities are founded on the idea that having multiple architectures available for use is desirable and that the best way forward is to take actions that can reduce or eliminate the barriers to interoperability (including the specific problems described above) between the existing architectures and protocols. More specifically, this strategy acknowledges that the existing architectures have been created, have evolved, and are being maintained to meet the specific needs of their constituent communities. Elimination of any architecture should only occur as a natural result of disuse. Modification and management of the existing architectures is left to the owning communities as the best option to ensure meeting the needs of the various user communities, both throughout the DoD and among the Department's coalition partners. To resolve the interoperability problems, efforts should be directed towards creating and providing standard resources, such as common gateways, common componentized object models, and common federation agreements. These can resolve the problems identified in the preceding section and render integration of the multiple architectures an efficient and nearly transparent process by creating the perception of a single architecture that supports all of the diverse simulation systems. Thus, the systems will actually be serviced by an “architecture of architectures”, comprised of as many different architectures and protocols as are required to interconnect the participating simulation systems.

The Business Model activities are designed to move the costs and control of the architectures and related tools to a common environment where access and risk are spread across a greater constituency. We believe this also improves the potential for innovation and reduces barriers to entry. Thus, the Business Model work makes a case for harnessing the power of M&S intellectual capital and focusing diverse fiscal resources through the instantiation of a common workspace to share architecture and tool advancements and to serve as a unifying place for change to happen.

For change to propagate, however, we must develop adequate spheres of influence in relevant standards organizations and related communities (e.g., C4I, DISA, etc.) to ensure that DoD interests are well served. Also, standards processes must be coordinated such that they can provide required stability, yet be flexible and responsive to users. The Standards activities are designed to develop this organizational influence, promote flexible standards evolution processes, and to build a more cohesive sense of community.

To measure the effects of these changes and plan for the future, management[25] must have access to improved decision support data and supporting analyses. This includes data from the technical domain, business domain, and standards domain. The Decision Support activity is designed to provide a mechanism to capture and analyze these data to facilitate the decision-making processes of the M&S SC.

[25] There is a companion document supplied by the Government Management Team that addresses more management issues. More information is available in the *LVCAR Study Execution Management* document.

Table 6.1 Summary of Investment Recommendations

		Investments	*Initial Investment*	*Bounds of 10-year Investment*	*Coordinated by*
Architecture Activities	1	Common components of architecture-independent object models	TDB	TDB	Roadmap Execution Team (RET)
	1	Describe and document a common, architecture-independent systems engineering process	TBD	TBD	RET
	1	Create common, reusable federation agreement template	TBD	TBD	RET
	2	Analyze, plan and implement improvements to the processes and infrastructure supporting M&S asset reuse	TBD	TBD	MSSC and RET
	2	Produce and/or enable reusable development tools	TBD	TBD	RET
	1	RRI – Convergence feasibility determination and design	TBD	N/A	Trusted Agent Team (TAT)
	3	Convergence plan	TBD	TBD	RET
	3	Convergence implementation	RRI dependent	RRI dependent	RET
	1	Produce common gateways and bridges	TBD	TBD	RET
	2	Specify a resource or capability to facilitate pre-integration systems readiness	TBD	TBD	RET
Standards Activities	2	Make IEEE standards more accessible to LVC community.	TBD	N/A	MSSC
	1	Engage SISO and the broader LVC community	TBD	TBD	MSSC
	2	Coordinate activities and fund participation in commercial standards development groups	TBD	TBD	MSSC
	1	RRI - Increase sphere of influence in SISO	TBD	N/A	MSSC
	1	Develop evolutionary growth path for LVC standards	TBD	N/A	MSSC
Business Activities	1	Identify and establish an LVC Keystone[26]	TBD	TBD	MSSC
	1	RRI – Balance the marketplace	TBD	N/A	TAT
	3	Balance the marketplace	RRI dependent	RRI dependent	MSSC
Mgmt Activities	1	Decision Support Data	TDB	TDB	MSSC

[26] See the *LVCAR Study Comparative Analysis of the Business Models* document for a full explanation of the term. The central player in a healthy ecosystem is the keystone organism, which serves as the leader of the ecosystem.

The activities in this Roadmap represent a LVCAR-participant consensus of the recommended approaches to addressing LVC interoperability issues. Feedback received on products has been favorable, as has the overwhelming majority of the feedback received at community outreach forums such as the Working Group Workshops. We believe that the effort generally has the support of the community, and is perceived to be an inclusive approach, largely based on historical lessons learned, that presents a pragmatic low-risk opportunity to improve some of the current impediments to interoperability and the employment of mixed-architecture events.

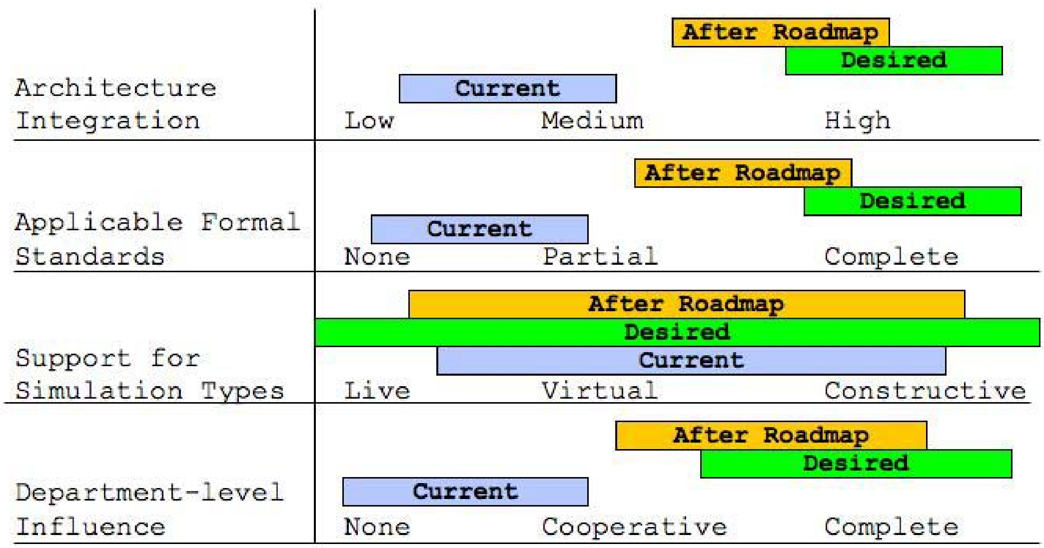

Figure 6.2 Approaching the desired state (in gold)

Figure 6.2 provides a graphical estimate of progress towards the desired state, given that the road map activities are accomplished. As illustrated, it should not be anticipated that completing all of the actions described in Table 6.1 will fully transform the current state into the most desirable state. Limitations stem from at least two areas. First, the LVCAR scope is limited to addressing syntactic-level interoperability problems. As noted several times in the report, significant interoperability limitations exist at higher levels, such as the semantic level. Second, each area described in Table 6.1 includes some topics that require additional study before selecting a preferred course of action. Future actions, based on the results of the completed studies will allow further progress towards the desired state.

Most of the architecture activities (as in Table 6.1) are designed to improve the degree of architecture integration and are expected to substantially decrease the effort required to integrate multiple architectures in a single event. This could be achieved through convergence of some architectures (subsequent to favorable RRI results) and / or by making reuse of integration assets a reality. The standards activities are designed to make existing and future standards more widely accessible as well as broaden direct and indirect Department-level participation in standards formation (and thus, evolution of the architectures). Assuming a favorable outcome of the standards-area RRI, the Department should enjoy alliance with a responsive and widely-recognized standards organization.

Support for the complete integration of live, virtual, and constructive simulations will only be slightly improved after execution of the roadmap activities. There is no effort to improve at higher levels (e.g. semantic) interoperability. However, having common components of common object models, consistent systems engineering processes, and common federation agreement templates will improve the object model reconciliation process and thus ease the semantic interoperability problems somewhat. Finally, Department-level influence that can help guide architecture evolution will improve subsequent to completing the roadmap activities. There are business, standards, and management recommended investments that will enable the progress in this area.

In closing, on 16 July 2007, the United States Congress passed House Resolution 487, “recognizing the contribution of modeling and simulation technology to the security and prosperity of the United States, recognizing modeling and simulation as a National Critical Technology” and commending members of the modeling and simulation community in government, industry, and academia who have contributed. We believe that Congress has a vision for M&S in the United States and we believe that the DoD, as a corporate entity, can either be a driving force in shaping that vision or can go along for the ride. The vision for this Roadmap is for the DoD, as a corporate entity, to be a driving force in the way forward for distributed M&S/LVC as a technology supporting the security and prosperity of the United States.

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