Next Generation Modeling and Simulation Architecture 11F-SIW-068

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ABSTRACT

With the increasing use of Joint Live Virtual Constructive (JLVC) simulations, tightly-coupled simulations in JLVC environments continue to require considerable effort and resources to integrate federates into new versions of a Runtime Infrastructure (RTI) or High Level Architecture (HLA). The JCWC Team created an innovative "way ahead" for a Next Generation M&S Architecture paradigm to meet this challenge. This paradigm shift leverages benefits from Service Oriented Architectures (SOAs), cloud computing, intelligent agents, composable services and other forward-thinking next generation technologies. Combined, these technologies create acceptable and usable hybrid architectures to reduce JLVC resource requirements while increasing efficiency. A next generation M&S architecture standard is designed to resolve problems associated with tightly-coupled simulations within a federation, i.e. inflexibilities associated with change. Achieving a more efficient, loosely-coupled platform for future JLVC simulations will provide significant cost savings, increased capabilities and greater efficiency, particularly with legacy HLA and RTI upgrades.

This paper presents a three-phased plan to support implementation for a planned JLVC environment evolution. The cornerstone of Phase 1 is a cloud-based SOA web service. In this phase, a hybrid SOA infrastructure will leverage and extend an HLA-evolved framework. The hybrid SOA infrastructure will decouple the RTI functionality into common services available to all federates. Phase 2 will deliver decomposed models resulting in composable operational M&S services. Phase 3 will use next generation technology to employ intelligent agents, metadata and model bases to allow "on-the-fly" M&S solution development. Phase 3 will integrate technologies and capabilities not yet used by the DOD, but necessary to continually develop joint adaptive training environment-centric state-of-the-art solutions. A hybrid SOA M&S solution is the fundamental building block of the Next Generation M&S Architecture and is a key to transforming the JLVC and synthetic environment.

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INTRODUCTION

The growth and demand of new federates is taxing and spurs the need for an orchestrated, well-researched way ahead. The current JLVC environment is strained by significant upgrade costs to convert simulations to newer versions of a Runtime Infrastructure (RTI) or High Level Architecture (HLA), resource-intensive integration, existing federate upgrades and increasing interoperability needs.

To optimize future resources, an innovative way ahead is essential. The newly-crafted Next Generation (NextGen) M&S Architecture will support independent services collaboration within a common framework. A suite of innovative technologies will reduce the resource demand currently required to support the JLVC's tightly-coupled simulations. Innovative technologies including cloud computing, intelligent agents, composable services and other forward-thinking technologies will be leveraged within Service Oriented Architectures (SOAs). The SOA framework provides a standard means of interoperating between different software applications and running a variety of platforms and/or frameworks. The services framework is intended to support interoperable machine-to-machine interaction over a network. These critical elements create acceptable and usable hybrid architectures to reduce JLVC resource requirements and increase efficiency. A NextGen M&S Architecture standard will resolve problems associated with tightly-coupled simulations within a federation including the lack of flexible change and composability. Achieving a more efficient, loosely-coupled platform for future JLVC simulations will result in significant cost savings, increased capabilities and greater efficiency particularly with legacy HLA and RTI upgrades.

The NextGen M&S architecture approach will catapult current M&S applications into the future by changing current M&S paradigms, infrastructures, modularity components, enterprise management and technical specifications. Designed in three phases, the strategy gently transitions the existing architectures to become more proficient.

THE PROBLEM STATEMENT

JLVC environments are comprised of tightly-coupled simulations that increasingly demand resources to integrate new and upgrade existing federates. These demands are cost-intensive and compound as federates must upgrade each simulation to newer versions of RTI or HLA. By establishing a more efficient, loosely-coupled platform for future JLVC simulations, significant cost savings, increased capabilities and greater efficiency will be realized particularly with legacy HLA and RTI upgrades. Figure 1 shows an example of the current JLVC federation infrastructure.

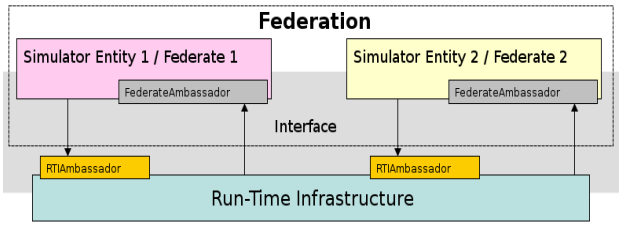

Figure 1. Tightly-coupled federates & RTI

BACKGROUND & RELATED WORK

In support of the Joint and Coalition Warfighting Center (JCWC), a Next Generation Architecture Team (NGAT) was formed to provide research and recommendations for Next Generation Modeling & Simulation Architecture. The NGAT approach was based upon analysis of the current state of M&S architecture. This analysis was foundational to developing a three-phased strategic vision to empower JCWC using M&S capabilities to effectively, efficiently support Department of Defense (DOD) activities and operations with a new, efficient architecture. The NGAT analyzed the state of current M&S architectures to build upon current approaches to move the JLVC community toward a forward-thinking NextGen M&S architecture construct and standard. Figure 2 illustrates the complexity of the current JLVC federation. The NextGen M&S architecture is detailed by phase and identifies the developing characteristics new infrastructure, real modularity, new paradigms, enterprise management and technical standards within each phase.

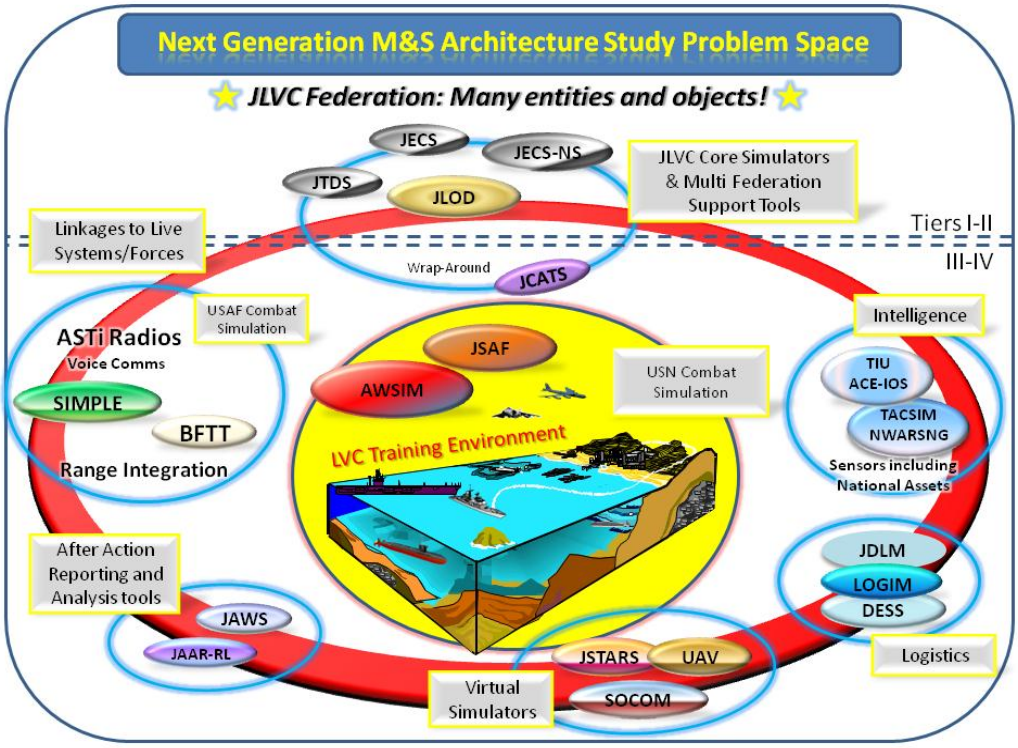

Figure 2. The current, complex state of the JLVC federation

NEXTGEN M&S ARCHITECTURE

The Next Generation M&S Architecture technical approach consists of three phases. Each phase builds on the research, prototypes, implementation, technical standards, and configuration management approaches developed in the previous phase. Phase 1 builds on existing infrastructure, standards and communities of interest by establishing a hybrid SOA framework that combines RTI and other simulation services to gain an advantage that neither of the two services could not achieve alone to lay a foundation for cloud computing [1] of simulation services.

Phase 2 further develops the Phase 1's established hybrid SOA framework and implement the cloud computing infrastructure. Also in Phase 2, intelligent agents and composable services are instantiated and model base foundations and standards prepared for Phase 3 integration.

Phase 3 leverages SOA, cloud computing, intelligent agents and composable services to support the development and implementation of autonomous intelligent services facilitated by model bases and Model Query Language (MQL).

Architecture Characteristics

The NextGen M&S Architecture is defined by three characteristics: new infrastructure, real modularity and new paradigms. A new infrastructure does not depend on proprietary RTIs and architecture-specific solutions, but integrates new technologies. The backbone of new execution methods is open source adaptations of cloud computing and SOA capabilities.

Real modularity refers to how JLVC environments no longer support simulation federations that overlap supported entities and functionality. Instead, real modularity describes how JLVC environments will use composable RTI and simulation services to integrate required functionality based on operational requirements. New semantic web technologies support the identification, selection, composition and orchestration of such services.

The final NextGen M&S Architecture characteristic is new paradigms that shift from using simulation as a computational activity with pre-designed, hard-coded solutions to executing procedurally-encoded knowledge towards new forms of knowledge transfer (education and training), knowledge processing (experimentation and analysis) and knowledge production. [2]

COST-BENEFIT CONSIDERATIONS

As the NextGen M&S Architecture is comprised of many new technologies, DoD-specific cost data documentation is practically non-existent. To develop a reasonable assumption for costs and benefits associated with the implementation of the NextGen M&S Architecture, current commercial best practices, cost savings and Return on Investment (ROI) data for SOA implementations were reviewed.

In the "Real Evidence from 100 SOA Implementation Examples," commercial SOA infrastructure applications produced numerous cost savings and benefits:

- 100% ROI within nine months
- 54% revenue growth within one year
- $3 million savings in back office support
- 5-10% logistics cost reduction
- 25% cycle time reduction
- $2 million licensing cost reduction to $50,000

While these results were found in commercial SOA applications, the DOD faces parallel issues. It is likely that similar results will be realized through the adoption of the NextGen M&S architecture. A literature review unveiled many case studies with similar characteristics to the NextGen M&S architecture. The cost-benefit considerations are summarized in the following examples:

- U.S. Department of Defense, Acquisition, Technology & Logistics (AT&L) used SOA to provide efficient delivery of warfighter capabilities through data and information sharing activities. [10]
- SunGard Financial Systems used SOA to develop their Common Services Architecture (CSA) to make their business components and processes discoverable and easier to consume. [10]
- Canada Health Info Way used SOA to develop architecture and standards to realize annual benefits of $6.1B and $82.4B over a 20 year period. [10]

To set the stage for a broader application for the DOD M&S community in the future, the NGAT proposes that a follow-on prototype effort for this study should include a database to collect metrics and final data to build a cost-benefit model. An initial listing of metrics includes:

- Time investment to stand up a SOA broken down by specific tasks
- Financial investment to stand up a SOA based upon various incremental tasks
- Manpower required to stand up a SOA
- Necessary project roles and duration of each
- Tasks required to stand up a SOA
- Time required to develop various services
- Time required to integrate/achieve correct functionality of service for a given federate
- Integration testing time required
- ROI milestones
- Redundancy reduction for federates using the new service
- Maintenance cost savings for federates using the new service

Architecture Management and Standards

In addition to the three characteristics described above, the NextGen M&S Architecture can be described with technical standards and enterprise management. Technical standards are the guidelines and rules used for implementation, data management, application and technology use. Enterprise management describes the overarching structure for administration and oversight for a system.

Phase 1

Phase 1 is the foundation of the NextGen M&S Architecture and initiates web service integration and commence service decomposition to build the framework for the future phases. It steers current efforts toward interoperability, reuse and enhanced capability. To accomplish this, Phase 1 combines management, standards and infrastructure.

Phase 1 marks the gradual JLVC transition from the existing HLA 1.3 implementation to a hybrid SOA implementation. This allows existing legacy federates to continue using the HLA RTI application programming interface (API), while new services develop using a SOA web service interface. Despite the varied interfaces, legacy federates and new services are integrated through gateways. The hybrid SOA implementation use the open source Portico Project RTI to allow customized implementations of HLA Evolved using either the traditional RTI API or the new SOA WS API. The Portico project serves as a fully supported, open source, cross-platform HLA RTI implementation that is both modular and flexible. It provides a production-grade RTI implementation and an environment for continued research and development.

The hybrid SOA implementation is the baseline capability for decomposition and services creation. The hybrid SOA allows newly developed RTI and M&S services to provide reusable capabilities to all members involved in a scenario. A combination of hybrid SOA framework and web services provides a method to present and access these services. Web services allow the NextGen M&S Architecture to leverage already-created commercial standards to support it.

All Phase I efforts contribute to developing a more loosely-coupled simulation environment. To achieve this, existing components are decoupled to realize several significant benefits. Decomposition decouples services from each other and allows them to recompose as needed.

To evolve this phase, web services decouple from the underlying hardware. With web services, a federate can be located anywhere in a network. Web standards also support the definition and maintenance of associated services metadata. Lessons learned from the Joint Composable Object Model (JCOM) [5] project enhance knowledge needed to decouple the data model from the architecture. Decoupling addresses current JLVC problems and set the stage for Phases 2 and 3.

Phase 1 Management

The Phase 1 management process governs the JLVC, facilitate change and ensure adherence to developed standards. The current JLVC communities of interest and practice ensure smooth operations, promote unity of service simulation efforts and encourage development of needed technologies for the way forward. At the conclusion of Phase 1, management will have adapted to guarantee the oversight, development, and maintenance of the NextGen M&S Architecture standards for The JLVC environments.

Phase 1 Standards

Initially, the current standards [5, 6 and 7] are used in this transition. Evolution of these standards is influenced by organizations such as SISO, IEEE and the newly-formed Government Cloud NextGen Governance Board. Throughout Phase 1, policies are created and communicated to the M&S community. These policies establish standard change procedures through a formal Request for Architecture Change which will be managed by the appointed Configuration Control Board (CCB). The standards in Phase 1 are established by the following processes:

- Leverage existing standards
- Identify and appoint board members
- Ensure members stay current on standards and identify areas of best practices
- Ensure the standards promote modularity, reuse and growth
- Continue standards for discovery and structural metadata

Phase 1 Infrastructure

Phase 1 transitions the current methods of the LVC environment as the phased approach is established to integrate federates. The hybrid SOA infrastructure, web services and service level agreements (SLAs) are also initiated. At the close of Phase 1 as shown in [3], [4] the infrastructure provides services robust enough to support a grid and cloud computing environment while fully utilizing the hybrid SOA infrastructure and web services.

Phase 1 Conclusion

Phase 1 transitions to Phase 2 by investing in development and research in future technologies and concepts. Architecture and Development Flexibility is also \important, as problems are typically discovered in hindsight. Reducing development cycles and promoting interoperability, along with consistent oversight, ensures that the long term goals are met.

Figure 3 illustrates the Phase 1 process flow. In the end, Phase 1 steers management, standards and infrastructure to a state of greater interoperability and reuse. The new hybrid SOA paradigm is introduced into the JLVC and support existing systems during the transition into decoupled and decomposed environments. At the close of Phase 1, the following implementation steps will have occurred:

- Establish governance board
- Decompose functionality for “web service” candidates
- Develop services
- Migrate select federates using services

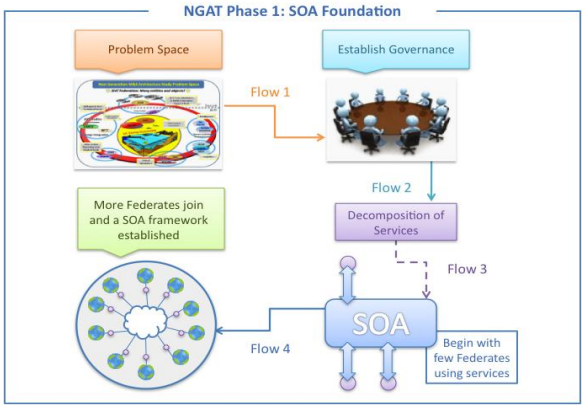

Figure 3. Phase 1 Process (OV-5)

Phase 2

The objective of Phase 2 is to provide composable M&S services. The current DOD M&S paradigm cannot confirm that federates use battle space entity models that are similar in nature and can be composed into each other. Different federates may use different focus points yet contain common main attributes. When describing a tank, a combat-oriented simulation focuses on the weapon systems, calibers, kill probabilities and other combat relevant attributes, while logistics-oriented simulations consider maintenance data, mean time between failure and other characteristics. Both describe the same simulated tank on the virtual battlefield. If two systems use different attribute categories to describe the same entity, this is considered multi-scope modeling. If two systems group the same attribute into different concepts, this is multi-structure modeling. In all cases, two such systems can be federated together by applying standards to align their overlap as shown in Figure 4.

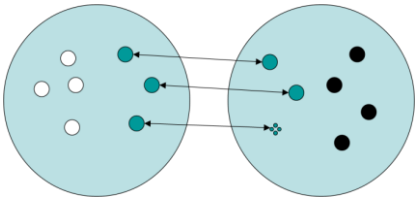

Figure 4. Multi-structure modeling

When moving towards services, the individual entity groups with unique capabilities need to be identified; functions that work on these entity groups need to be provided as services. In Phase 1, each federate provides all its capabilities as a federation service, but the challenges described above remain the same. In a gradual refinement, the federates need to be developed to provide partitioned services. When two systems are federated, the logical partitions are the intersection and the two compliments, as shown in Figure 5.

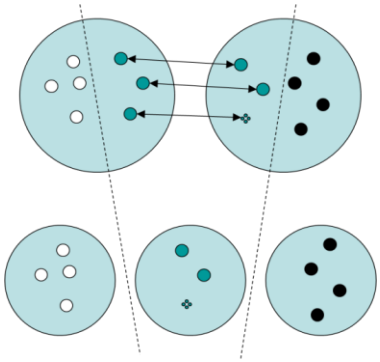

Figure 5. Logical Partitions

When more systems are federated, this number increases. The motivation to decompose federations in individual entities and composable services working on these entities is twofold. First, current research [8, 9] shows that interoperability between independently-developed federates is limited to the intersection of identical entities connected via identical functions. Everything else requires individual engineering efforts that cannot be reused as a rule. Composable M&S services will avoid this challenge.

Secondly, it is practical to have entities represented in all federates. Following individual federate conceptualizations result in high maintenance costs for all associated federations. Each change in one federate affects all others and results in inconsistency.

Phase 2 will lay the groundwork and standards for a Model Based Data Engineering (MBDE) [8, 9] framework. The MBDE framework is a foundational element in Phase 3 that further remedies some of the current architectural issues found in HLA 1.3. At the conclusion of Phase 2, the NextGen M&S architecture corrects present JLVC simulation problems including tightly-coupled data and applications, non-standardized object agreement/representation, code maintenance and reuse and a lack of interoperability among the various architectures (HLA, TENA, and DIS).

Phase 2 Management

In Phase 2, management facilitates change, ensure adherence to developed standards, manages cloud computing resources development and administration and manages SLAs that must exist among the federates to ensure a properly functioning environment. Phase 2 addresses any management issues that arise during the execution of Phase 1. At the end of Phase 2, management oversees, develops, and maintains the NextGen M&S Architecture standards, secure cloud and grid computing resources and secure intelligent agents. Communities of interest (COIs) and working groups facilitates the development of the NextGen M&S Architecture.

Phase 2 Standards

Phase 2 standards and policies are established by the Governance Board and a Configuration Control Board (CCB) that represents all stakeholders. Phase 2 standards are established with the following process:

- Identify and appoint CCB members
- Ensure CCB members stay current on standards through attendance at various formal standards organizations activities (i.e. SISO and IEEE)

- Look to current de facto standards to develop official standards
- Constantly review industry to determine any best practices that should be made into standards
- Ensure the standards continue to promote modularity, reuse and growth
- Continue standards for discovery and structural metadata
- Leverage government cloud computing entities such as DISA Rapid Access Computing Environment (RACE), a quick-turn computing solution that uses cloud computing to develop a necessary platform quickly, inexpensively and securely

Phase 2 Infrastructure

Phase 2 further develops the NextGen M&S Architecture by expanding the cloud and grid computing environments which are characterized by intelligent agents that are autonomous entity which observes and acts upon an environment and a MBDE framework. SLAs are established and govern data exchange, common objects and data lexicon and taxonomy. The RACE environment is leveraged to utilize the DOD's existing cloud computing environment. Upon completion of Phase 2, the infrastructure includes a secure cloud computing environment, a grid computing plan and resource usage, intelligent agent services and agents, an MDBE framework and Model Query Language (MQL).

Phase 2 Conclusion

Figure 6 maps the Phase 2 process flow. Phase 2 builds upon the standards and hybrid SOA infrastructure developed during Phase 1. Moreover, the cloud computing framework laid in Phase 1 is also a primary building block in Phase 2. With the services developed and cloud computing environment established, the technology is extended to develop intelligent services that understand and monitor the environment. The services and information is decomposed through an MBDE process. This MBDE framework lays the foundation for Phase 3. This services decomposition and data allows any platform (HLA, TENA, and DIS) to use the developed services. The services become composable and can be stored using an MBDE for reuse. At the close of Phase 2, the following actions will have occurred:

- Continue governance board
- Establish cloud computing environment
- Develop common reference model
- Create composable services/agents
- Migrate various architecture models using intelligent agents and composable services

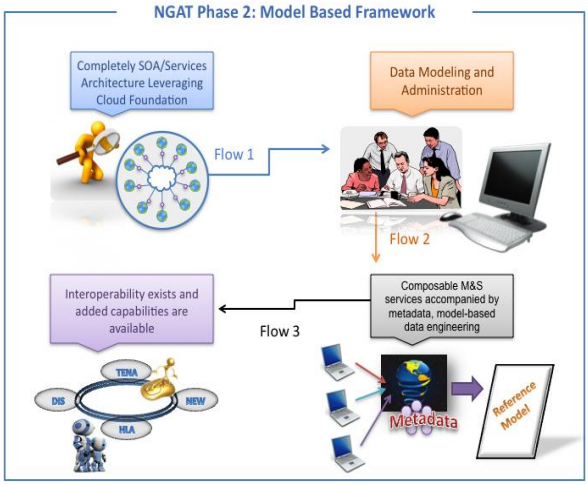

Figure 6. Phase 2 Process (OV-5)

Phase 3

Phase 3 realizes the full application of the NextGen M&S Architecture through autonomous intelligent services development and implementation. These services monitor and learn environment information and are intelligent enough to intuitively determine, select, compose and run simulations from an existing simulations model base. At completion, Phase 3 leverages, extends and builds upon the governance, standards, SOA infrastructure, cloud computing environment and intelligent agent concepts and technologies achieved during Phase 1 and Phase 2. Current-state JLVC simulation problems such as simulation reusability, and dynamic simulation composition are improved.

Model base implementation and autonomous intelligent services evolves the data-driven architecture to self-aware intelligent architecture able to self-correct and execute itself with high efficiency and low latency. In addition, incorrect simulation states that required human-in-the-loop intervention to force a move indicates that a simulation is not running optimally. This forced move, commonly referred to a "magic move," creates bottlenecks and skews the data, and thus the outcome of the simulation. Each of these undesired characteristics is eliminated through autonomous intelligent services capable of running the simulations unassisted.

Phase 3 Management

Management facilitates change, ensures smooth operations, manages development and administers the model. Phase 3 establishes standardized, government-owned and populated repositories that house scenarios

and simulations; maintains and administers model bases; develops autonomous services; and maintains and develops autonomous services. Management encourages the joint development of a single solution, funds research and development of model bases, pushes for automated integration solutions, generates a developer community and facilitates communication.

Phase 3 Standards

To support model bases, standards are formed to define the models. Model classes are defined in a standardized way using property inheritance derivation, attribute and keyword definitions and standardized semantic relationship definitions. These models are classified into domain ontologies and utilize DARPA Agent Markup Language DAML and Resource Definition Framework (RDF) to express these ontologies. This collection of ontologies supports matchmaking agents to perform dynamic selection and assembly. An MQL standard creates a structured language to query the model base and use agent-supported matchmaking to provide potential scenario solutions. By the conclusion of Phase 3, the formal NextGen M&S Architecture standards and a formal CCB will be established with a standardized request and change NextGen M&S Architecture process.

Phase 3 Infrastructure

The Phase 3 infrastructure extends Phase 2 accomplishments including the secured cloud computing environment, intelligent agents and the MBDE framework. Phase 3's proposed infrastructure involves autonomous services, model bases, MQL and the proliferation of SOA. Phase 3 completes the desired infrastructure by:

- Building services that can learn from the environment
- Storing information learned by the services as scenarios in a repository, thus creating a model base
- Continually developing model bases
  - SLAs will develop, enforce and standardize the common reference model
  - XML will develop a mediation service to provide semantic mapping between XML, the service and the user by providing knowledge of data location, data meaning and context the data format required
- Developing new MQL using SQL as a guide or standard to develop a language to extract, add, delete and update simulations in the model bases

By the close of Phase 3, the cost-efficient, standardized, fully functioning, reusable NextGen M&S Architecture has functioning, fully-autonomous intelligent services, model bases and MQL.

Phase 3 Conclusion

Phase 3 corrects existing JLVC simulation drawbacks such as simulation reusability, replay and dynamically composition. The areas of governance, standards, and infrastructure are advanced to ensure management oversees, develops and maintains NextGen M&S Architecture standards, model bases, services and simulations. Formal NextGen M&S Architecture standards and a CCB are established with a standardized change process.

The process flow for Phase 3 is illustrated in Figure 7. At the close of Phase 3, the following implementation steps are completed:

- Continue governance board
- Design model bases
- Develop MQL
- Migrate composable services and agents to autonomous intelligent agents

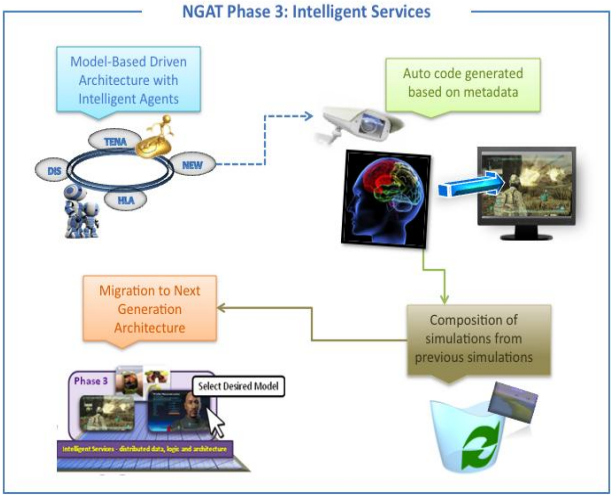

Figure 7. Phase 3 Process (OV-5)

CONCLUSION

As evidenced by the SOA implementations presented in the cost-benefit considerations, shifting toward a paradigm that leverages SOA and related technologies provides a definite ROI for an organization, regardless if it is a commercial or DoD entity. The research conducted in this study indicates numerous benefits to a SOA implementation.

By examining lessons learned in similar efforts, it is evident that establishing governance, a community of

practice and the right technical staff is important to a successful implementation. The NextGen M&S Architecture approach has similar tasks, ideals and technologies to all of the successful SOA case studies presented. Therefore, NextGen M&S Architecture is expected to achieve the same success and ROIs achieved by these SOA case studies.

ACKNOWLEDGEMENTS

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