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Strategic Implications of Cloud Computing for Modeling and Simulation (Briefing)

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Strategic Implications of Cloud Computing for Modeling and Simulation

NDIA SE Division M&S Committee
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NOTES:
- This brief was designed for presentation to a technical working group of the National Defense Industry Association Systems Engineering Division. The brief assumes audience familiarity with M&S/LVC architectures, federation development processes, and basic principles of distributed computing.
- This brief reports the results of a relatively small effort, something on the order of a thought piece intended to lay out a top level research agenda.

This brief is excerpted from a report that considers the potential benefits and barriers to using cloud computing infrastructures to host and deliver M&S capabilities. The report serves as the initial step in thinking about the problem strategically, by establishing scope and bounding the problem space, anticipating benefits and barriers, and laying out a research agenda to understand the issues more comprehensively.

The question is timely. In 2008, ASD(RE) sponsored a large $2M+ study to develop a Live, Virtual, Constructive Architecture Roadmap (LVCAR; Henninger et al, 2008) necessitating the assessment of a number of LVC interoperability architectures which were not interoperable with each other. The LVCAR study included a thorough requirements-capture effort which eventually led to the determination that at that time, most of the current requirements for LVC environments were satisfied by the existing architectures. It went on to assert that the (then) unsupported requirements could either

be incorporated into those existing architectures or were so ill-defined and so abstract that no meaningful technical requirement could be adequately articulated.

Seven years later, in 2015, we have a better sense for the requirements emerging from these other communities, and there are Federal mandates requiring compliance with these architectures to the extent it is possible. For reasons such as these, it is important that DoD M&S leadership and oversight understand the benefits and barriers of using cloud computing infrastructures to host and deliver M&S capabilities, both from the perspective of potential efficiencies, but also from the perspective of being able to respond intelligently to potential mandates.
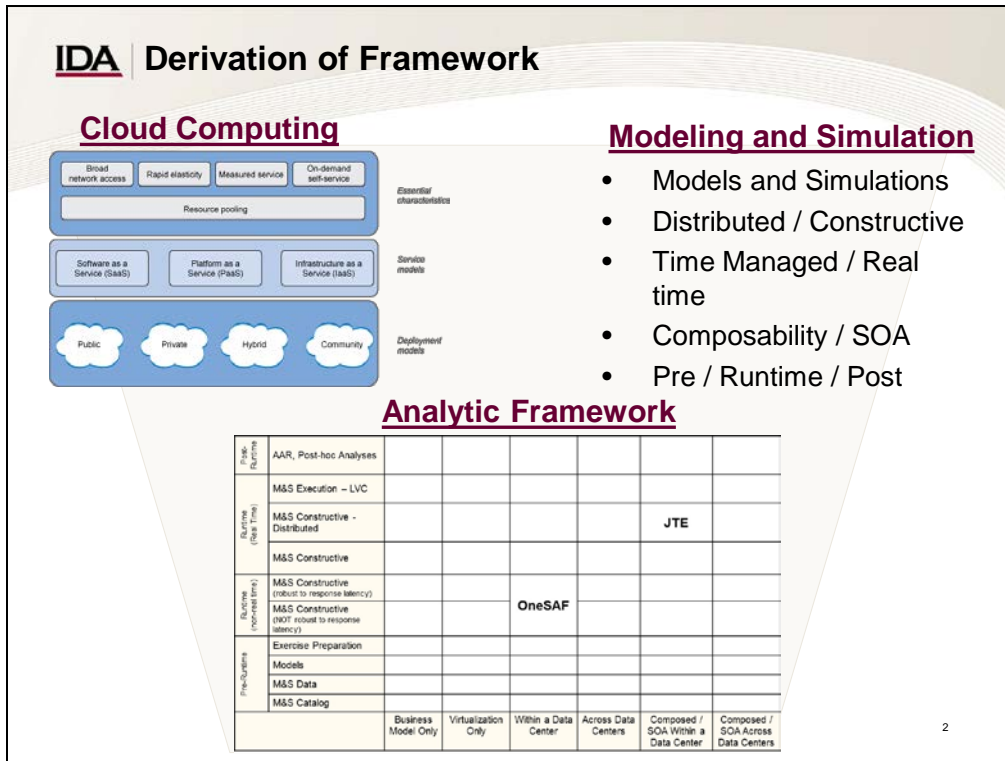
IDA | Presentation Outline

- Framework
- Benefits and Challenges
- Insights and Observations
- Recommendations

Sponsor's Question: What are strategic implications (pros/cons) of Cloud Computing for Modeling and Simulation in the Defense enterprise?

1

More specificity in the sponsor's research question was imperative to developing a meaningful response. "M&S" is a conceptual label assigned to a host of different, albeit related technologies. Likewise, cloud-computing can be instantiated in a number of different forms, and the instantiation of M&S in a cloud-based computing paradigm could take on a number of different forms. Thus, without adding more precision to the broad labels, "M&S" and "Cloud Computing", the resultant cross-product of the two is represented at such a high level of abstraction that any derived benefit or barrier may not be universally true. To address this and to facilitate a meaningful discussion among practitioners with different use cases, we created a framework in the form of a taxonomy.

IDA | Derivation of Framework

Cloud Computing

Broad network access	Rapid elasticity	Measured service	On-demand self-service	*Essential characteristics*
Resource pooling	
Software as a Service (SaaS)	Platform as a Service (PaaS)	Infrastructure as a Service (IaaS)	*Service models*
Public	Private	Hybrid	Community	*Deployment models*

Modeling and Simulation

- Models and Simulations
- Distributed / Constructive
- Time Managed / Real time
- Composability / SOA
- Pre / Runtime / Post

Analytic Framework

		Business Model Only	Virtualization Only	Within a Data Center	Across Data Centers	Composed / SOA Within a Data Center	Composed / SOA Across Data Centers
Post-Runtime	AAR, Post-hoc Analyses						
Runtime (Real Time)	M&S Execution – LVC						
	M&S Constructive - Distributed					JTE	
	M&S Constructive						
Runtime (non-real time)	M&S Constructive (robust to response latency)						
	M&S Constructive (NOT robust to response latency)			OneSAF			
Pre-Runtime	Exercise Preparation						
	Models						
	M&S Data						
	M&S Catalog						

2

The vertical axis distinguishes important M&S features, including:

- Parsing the umbrella label "M&S" into two distinct constructs: "Models" and "Simulations"
- Distinguishing distributed simulation environments from single-processor/single-machine applications
- Distinguishing time-managed simulations from real-time simulations
- Acknowledging the potential of service composition often associated with cloud computing (Davis and Anderson, 2004)
- Identifying the pre-runtime, runtime, and post-runtime processes that could independently be candidates for migration

The horizontal axis represents (some) important cloud-computing features, including:

- Within a data center or across/between data centers
- With / without service composition

NOTE: the other two columns (Business Model Only and Virtualization Only) are not pure but are partial cloud concepts. They are included in the framework to cover breadth of use cases being investigated in the practitioner community.

While more granularity is always possible, this framework provides complete coverage of the space of interest. It also provides a common reference model for practitioners to exchange and compare information gleaned from their research. In the example above, for instance, one would not expect the OneSAF as a Service application to yield all of the

exact same benefits or experience all of the exact same challenges as the JTE as a Service application. This is because the form of the M&S is different and the instantiation of that M&S in a cloud computing paradigm is different.

IDA | Benefits and Challenges

Lots of Promises with Cloud
- Cost efficiency
- Unlimited storage
- Backup and recovery
- Automatic software integration
- Easy access to information
- Quick deployment
- Easier scale of services
- Scalability
- Rapid development, deployments, and change management
- Agility
- Efficiency
- High reliability / availability
- Flexibility
- Better performance
- Greater mobility
- Green IT data center
- Improved security
- Improved automation, support and management
- …

Study Classification Scheme

Potential Benefits
- On Demand Self Service
- Broad Network Access
- Rapid Elasticity
- Resource Pooling
- Business Model / Measured Service
- Exercises (heavy interactions)

Potential Challenges
- Performance
- Architecting for Cloud
- Service Composition
- Trust/Risk/Accountability
- Security and Privacy

Cloud is one of most cringe-worthy IT buzz terms of the 21st century. With just a quick review of literature, both business and academic, it is easy to develop a list describing the theoretical or anticipated benefits of Cloud Computing. Other than a few focused investigations, what these papers generally lack, however, is any kind of systematically derived evidence to support their assertions or an assessment of how well those assertions might generalize. Generalization is especially important because even the claims that do have at least some empirical evidence to support them tend to be gleaned from classic IT applications not from scientific applications. M&S falls more into the latter category than the former. In contrast to classic IT applications, M&S applications tend to use central processing unit (CPU) more intensely, have multiple distributed nodes, higher memory requirements and different communications requirements (demanding the delivery of many small messages quickly rather than fewer larger lag-tolerant messages).

To develop the potential benefits and barriers documented in this report, the Study Team pulled data from a number of different sources: reports describing M&S research conducted in related computing paradigms (e.g., SOA-based [Drake et al, 2011]; Web-based [Brutzman et al, 2002]; HPC-based [Bouwens et al, 2012]), Grid-based [Pan et al, 2007]), technical exchanges with community practitioners, and consideration of concepts derived from business/academic literature in cloud computing. Because the organic data was presented at different levels of abstraction, the study team created categorization schemes to represent a strategic view. This required decomposing all of the data at the

lowest level of abstraction possible, assigning relevant metadata, and then categorizing the potential benefits and barriers at the meta-level. We were able to reuse the Federal Government's definition of Cloud Computing, developed by NIST (Mell and Grance, 2011), which offers a simple characterization of cloud that inherently provides a way of classifying potential benefits: on-demand service, broad network access, rapid elasticity, resource pooling, and measured service.

The metal-level categories for barriers include: Performance, Architecting, Service Composition, Trust/Risk/Accountability, and Security/Privacy. While these categories are not perfectly orthogonal, the study team knows of no other existing representation and considers this first attempt to create such a model a reasonably effective approach.

Heavy Hitters - Benefits

- On Demand: Potential of "anytime, anywhere", on-demand simulation capabilities.
- Broad Network Access: Support the use of handheld mobile devices.
- Resource Pooling: Outsources computing infrastructure, reducing or eliminating the need for organizations to offer extensive IT services.
- Measured Service: Pay per use / new business models
- Exercise Specific:
  - Set up costs
  - Ramping up time

On-Demand Self-Service: M&S resources could be generated anytime, anywhere and distributed throughout the force structure. Training and planning material and C4I updates can be pushed to commanders in transit and in theater, while they can use M&S as needed. Cloud multi-tenancy properties ensure availability of the simulation.

Broad Network Access: Because complex simulations or distributed simulations are sophisticated pieces of software requiring high-end computing infrastructures, they are not easily accessible to users who are not experts in the software or hardware technologies. By providing an environment that is device and location independent, broad network access expands accessibility to these resources and offers the potential to make simulation capabilities much more widely available.

Rapid Elasticity: Particularly for larger exercises or events, the computational requirements of users can vary significantly over time. This typically results in the need to overprovision the infrastructure to meet the peak expected workload. Overprovisioning, however, leaves the facility underutilized during periods of less intense usage. Rapid elasticity, the ability to allocate and release resources dynamically (or statically), mitigates that gap.

Resource Pooling: This lowers barrier to entry because it eliminates the need to purchase and operate expensive equipment for a local site. And even if organizations do offer computing hardware, it is a form-factor less expensive, usually taking on characteristics of hand-held device or dumb terminal. In addition, this paradigm

decreases cost of ownership by reducing licensing requirements, as well as the need for specific hardware, hardware and software maintenance/upgrades, and facility resources.

Measured Service (Business Model):   Today, the norm is for organizations to (potentially) incur large capital expenditure costs to build and operate their own computing infrastructure and IT. Measured service gives rise to a pay-per-use model, which provides many more business model options than consumers have had in the past.

Exercise Specific: The majority of costs incurred in a simulation-based exercise come from the activities that wrap the actual exercise itself (e.g., travel for exercise support, data collection, integration, etc.). Cloud-based simulation would theoretically reduce these kinds of setup costs for exercises, as well as reduce staff requirements and staff idle times. This would result in a quicker "ramp up" of exercise environments, resulting in faster implementation times.

Performance: M&S paradigms tend to require low-latency/high-bandwidth networks, accustomed to sending many small messages requiring quick delivery rather than fewer large messages requiring high bandwidth. Cloud environments tend to be better at providing high-bandwidth communications among applications than in providing low latency. Fujimoto (2010) reports on tests of parallel scientific code (HPC) executed over Amazon Elastic Compute Cloud (Amazon EC2) ran significantly slower compared with being executed on dedicated cluster nodes.

Architecting: Simulations need to be architected for virtualization. Not all M&S applications can reside in the cloud. The integration of LVC and C2 and other operational equipment (e.g., unmanned air vehicles) will require M&S cloud implementations to allow for a mix of cloud- and non-cloud-resident applications. Inter-cloud will require even further standardization (syntactic, semantic, and pragmatic) and standardized definitions of functionality to support service composition (Cayrici, 2011).

Service Composition: In current distributed M&S paradigms, the attribute of an entity is normally owned by a single federate. However, in an SOA-based inter-data center configuration, the attribute of an entity could be updated based on the computations of many federates, so current paradigms would not suffice for integrating federates in this type of federation (Macedonia et al. 2014). Moreover, some researchers (Cayrici, 2013) assert that the new challenge of determining federates interoperable with each other and selecting the set that fits best to the constraints and performance expectations (i.e., inter-

data center federation configuration) is an NP-complete problem. Finally, improved processes for verification, validation, and accreditation (VV&A), particularly regression-based VV&A, will need to be invented to fully harness the potential of cloud-based M&S, particularly in an SOA-based paradigm.

Trust/Risk/Accountability: Cloud Service Providers (CSPs) usually keep the locations of their server farms and data centers abstracted away from users. Also, risks get higher and more difficult to analyze in nested cloud architectures (i.e., inter-cloud, service mashups, and partner clouds). Since M&S/LVC federations are basically cloud service mashups, the complexity of accountability, risk, and trust is exacerbated. There is also a concern with making the use of M&S "too easy" for users, potentially resulting in the misuse of M&S by unskilled users.

Security and Privacy: Many classic security and privacy issues with clouds in standard IT settings continue to exist. Risks with specific dynamics related to M&S include the exploitation of bugs in the implementation of services. In particular, with high numbers of clients and very large databases with high number of clients, there are increased opportunities for denial-of-service attacks. Also, unauthorized users may perform analysis of network traffic to derive information about the results of a simulation-based study or exercise.

IDA | Observations / Insights

- The biggest new M&S capability that will be enabled by the Cloud is real-time course of action analysis (COAA) supporting Mission Command.
- M&S Community Myth Busters
  - It is possible to leverage a cloud without employing SOA, and to leverage SOA without employing cloud computing. Some M&S Community literature discusses them as though they must co-exist.
  - It is possible to leverage cloud without employing Virtualization. Some M&S Community literature discusses them as though virtualization is a necessary but not sufficient pre-condition for Cloud.
- We have not discovered, at an abstract level, any advantage or disadvantage to M&S employed in a cloud infrastructure, that would not be true of any typical IT Application or System employed in a cloud infrastructure.
- In support of Data Center Consolidation and Cloud Migration, many Services' CIOs are embarking on Application Rationalization efforts.
- Cloudy Crystal Ball (no pun intended): It will be important in future to determine whether M&S is an IT function or an S&T function.

6

The potential of "anytime, anywhere on-demand" simulation capabilities coupled with the potential of broad network access (particularly the use of handheld mobile devices) positions cloud-based M&S to be an enabling technology in the realization of using M&S to support battle command Course of Action Analysis (COAA). This is significant. It broadens the impact of M&S to warfighting applications beyond institutional applications, and beyond training and mission rehearsal.

We have not discovered, at an abstract level, any advantage or disadvantage to M&S employed in a cloud infrastructure that would not be true of any typical IT application employed in a cloud infrastructure. And, we have concluded that there is great potential for both cost savings as well as for the development of new warfighting capabilities. We have also, however, identified a number of barriers resulting from the fact that M&S applications tend to be more complicated than IT applications. These barriers have been documented.

The remainder of this presentation reviews the potential cost savings and lays out a research agenda to more fully explore potential barriers and mitigation strategies.

IDA | **Potential Cost Savings in Pictures**

leveraging SOA to modernize M&S has great potential to reduce overall M&S costs
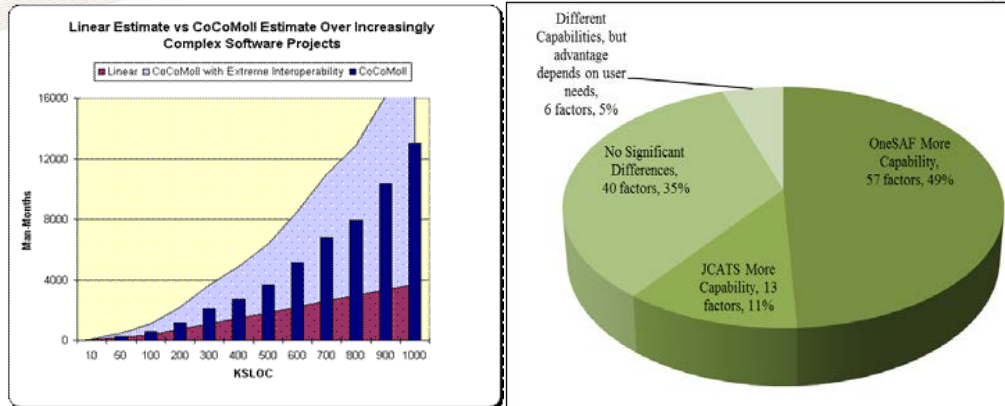
savings by defining common simulation architecture infrastructure

savings by reducing the development of redundant functionality in models

Pratt and Henninger (2002) demonstrate a strong, general business case for working at the component level, using general-purpose software or simulation software. They developed a series of Constructive Cost Model (CoCoMo) II models for software cost estimation for a series of hypothetical software projects, where lines of code ranged from 10,000 to 1,000,000 for projects of increasing complexity. The results demonstrate the tradeoff between size and complexity of program and cost of the development effort. This tradeoff is even more evident when comparing the bar graph representing a CoCoMo II estimate with the lower area plot representing an estimate based on linear extrapolation of the 10,000 lines of code estimate. This suggests that instead of one large monolithic simulation, a more prudent approach would be to develop a general architecture that could serve as a platform for a variety of modular models. More specifically, this approach lends itself to savings by defining common simulation architecture infrastructure that can run many models, thus reducing costs of redundant simulation infrastructures and lowering the barrier to entry for model developers who cannot afford to build whole simulation infrastructures.

Another implication of a services-based cloud approach could be the reduction of redundant functionality across models. For example, Henninger et al, (2016) demonstrate the amount of redundant functionality in two popular entity-based brigade and below simulations. A service-based approach to composable simulations facilitated by cloud computing, would reduce costs by making one model available to many composed

13

simulations, instead of having to duplicate models in independent and incompatible simulation architectures. More specifically, this approach lends itself to saving by reducing the development of redundant functionality across models (instantiated in simulations).

Type of Enabler	Policy Action	Investment	Sponsor/ROM
Business	Establish managerial baseline.	Follow lead of the CIO community by applying application rationalization-like methods to the DoD's M&S portfolio to facilitate the introduction of new solutions and retire old solutions and to provide the strategic management data required for making sound decisions and investments.	
Business	Investigate business model implications.	A number of new constructs (e.g., measured service, composability, outsourcing computing infrastructure, etc.) have implications for new and powerful business models for M&S users, sponsors and industry developers. Define the business model implications across all of the M&S stakeholders, government, industry and academia.	
Cultural	Lead by example.	Move DMSCO enterprise capabilities to a cloud-based infrastructure. In particular, moving assets like the M&S catalog to a public cloud theoretically improves the accessibility and availability of the capability (i.e., catalog) to other agencies and coalition partners.	
Cultural	Take steps to promote trust.	Develop primer expanding on the differences between requirements for the successful operation of IT versus M&S in cloud-based infrastructures. Use primer to inform Defense Information Systems Agency (DISA) and eventually broker the development of service-level agreements between cloud providers (i.e., DISA's Mil Cloud) and potential M&S customers.	
Technical & Cultural	Establish experimental framework, to include cloud resources.	Broker deals (see Appendix A) on behalf of the M&S community with cloud providers (i.e., Mil Cloud, EC2, etc.) for free time and resources to test cloud capabilities. Develop a campaign plan for series of experiments per the framework offered in Figure 5 and barriers presented in Section 5.B. What questions need to be addressed, in what order, and by whom? Offer these free resources to M&S users in return for performance data and lessons learned in accordance with the campaign plan.	
Technical & Cultural	Educate community on potential cyber threats.	Develop a primer for community on potential cyber vulnerabilities of M&S in a cloud-based infrastructure (e.g., exploitation of bugs in the implementation of M&S; degradation of services through processes related to self-configuring, self-optimizing, self-monitoring, and self-healing; potential for denial of service due to the interactions of very high numbers of users with very large databases; reverse engineering the simulation study results through analysis of network traffic; etc.). Include preventive measures in the form of best practices.	

This table enumerates DoD-level activities and investments seen as common goods, particularly worthy of DoD-level attention, whereas the vast bulk of M&S work is and should be conducted by the various Services and Defense agencies.

This work represents an initial step in formalizing the pursuit of adopting cloud-based infrastructures for M&S applications. As presented in earlier list of barriers, there is much work to do. By identifying the known unknowns, and in some cases turning the unknown unknowns into known unknowns, this report, at least, provides a framework and the start of a roadmap for the questions to be investigated.

Technical	Advance state of M&S to best enable these cloud processes.	Continue research in composability and SOA, but especially in the context of cloud processes including but not limited to self-configuration, -optimization, and -healing mechanisms. Examine new mechanisms required for efficient load-balancing across distributed exercise in a cloud based infrastructure.
	Advance research bridging current methods with future computing paradigms.	Examine research in federation creation and initiation; joining and retiring federates to and from federations; migrating federates from one cloud to another; platform migration from one cloud to another; management of entity ownership among federates in different clouds; registration and subscription for the entities simulated by federates; and perception management.
	Issue new VV&A guidelines to support requirements for SOA and composability.	Commission report drawing upon community knowledge to recommend new VV&A methodologies and guidelines focused on regression-based methods suitable for requirements of SOA-based implementations.
	Establish new architecture(s) for cloud-based M&S.	Commission the competitive design, development, test and transition of a framework for SOA and mobile M&S. DoD M&S efforts focused on mobile computing should be tightly coupled with DISA's and the Services' approaches and infrastructure for cloud computing and mobility. A concerted effort, as opposed to a series of small exploratory projects, is necessary to establish a robust infrastructure that enables greater accessibility to models and simulations via cloud computing, SOA, and mobility.

9

This research reinforces the view that the use of cloud computing is both possible and beneficial in some instances of M&S applications. Whether these successes can be or should be scaled up to the full breadth of the DoD's M&S portfolio is yet a researchable question. This document provides a roadmap toward answering that question, informs the broader research agenda for those instances of M&S applications that have not yet weighed the benefits and costs of migration, and provides some degree of confidence that the potential payoff is worthy of continued research investment at the institutional level.

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14. ABSTRACT

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