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FROM THE EXECUTIVE EDITOR

INTEROPERABILITY IN M&S A fine-tuned simulation is like a well-written and performed symphony – music to my ears. But, like great music, a great simulation is difficult to develop and execute. Seventeen years ago, the DoD noted that simulations are narrowly focused, stove-piped developments designed to support specific user communities. As a result, they did not fully meet modern, joint force needs; they were expensive to build and costly to operate; once built, they were not easily maintained or extended; and they were not interoperable with other M&S assets that could be useful. To mitigate these concerns, the parts of a simulation need to *interoperate*, just as orchestra members' individual parts need to work together to create the great sound of a symphony. Interoperability was a timely topic seventeen years ago, and it remains so now. Consequently, I'm pleased to offer this interoperability issue of the M&S Journal.

The DoD M&S Glossary defines interoperability as the ability of a model or simulation to provide services to, and accept services from, other models and simulations, and to use the services so exchanged to enable them to *operate effectively together.* To explain this, I will continue using music as an analogy, since most people understand it takes skill, training, and practice to produce Beethoven's Ninth Symphony and not noise. Similarly, skill, training, practice, and technology are needed to coax a group of models and simulations into producing meaningful results for the end user.

The similarities to music are many, but here are just a few. A musical ensemble plays from a common score; a simulation federation needs a common technical framework. Musicians have a sense of pitch, tone, and rhythm; simulations need authoritative representations of systems, human behavior, and the environment in which they operate. Musicians understand tempo and have the ability to play in multiple time signatures, often within the same song; simulations also share a common definition of time and how to use it. Musicians intuitively know which instrument is leading at any given time and who is supporting; simulations have agreements on simulation initialization and federate control.

These and other musical examples indicate the difficulties with getting a group of musicians to interoperate. The papers presented herein indicate the similar difficulty of getting a group of simulations to interoperate. We are just beginning to understand the effects that music has on the human brain. I hope that these papers will be music to your ears and stimulate you in a positive way. And let's hope there won't be a need to discuss the continuing need for the "same sheet of M&S music" seventeen years from now.

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Interoperability

GUEST EDITOR:

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ARLES, FRANCE, SOME GUEST EDITORS TAKE A FEW QUIET MOMENTS OUT OF THE WORKDAY TO COMPOSE THEIR THOUGHTS. SOME PROBABLY PARTITION A FEW HOURS ON A WEEKEND TO MULL OVER THE LESSONS FROM THEIR PROFESSIONAL ENVIRONMENT AND DISTILL THEIR THOUGHTS. THEN THERE'S THE *BON VIVANT* WHO EXCUSES HIMSELF FROM THE PENTAGON TO EXAMINE A TOPIC FROM A DISCRETE DISTANCE. ARLES, FRANCE IS ABOUT AS DISCRETE AS I GET.

All of the elements for a discussion of interoperability are *present ici*. A souvenir trip into the old city with my wife reminded me of every challenge faced by the Defense modeling and simulation community. I should have taken a lesson from Vincent Van Gogh and recognized risks from indulging in the beauty of Provence.

As we tour the shopping district, my wife spoke with remarkable fluidity – as did the shop keepers. She came equipped with the respected universal resource translator, a carte de credit. She was on a specific mission in search of the vaunted linens of Provence, a resource resident in a stunning choice of designs and offered by a veritable ensemble of proprietors. With ample expectation for rewarding exchanges of money for cloth, she encountered impediments of language that changed a peaceful early morning stroll into a lesson on the pitfalls of mismatched language. Despite mutual intent, despite coincidence of consumer cash and products, despite obvious mutual benefit for successful commerce, the interactions foundered on execution. Her English and the shopkeeper's French fell short of the minimal data exchange required for mission success. The data mediation expedient of repeating words with flailing hands and louder voices failed to surmount the language barriers.

Mr. Mike Knollmann

On the edge of the conversations, my wife had a husband with translation skills acquired on assignment in Belgium and honed in the bars of Mons. Why did I hesitate to intervene and provide translation services so clearly needed for interoperability? Husbands of the world know better. Interoperability risks uncontrolled bills and imposed costs.

The Modeling & Simulation community espouses interoperability as a common goal, but actual product design to achieve interoperability remains the exception. Compilation and implementation of common data standards, interface protocols, data mediation services, high level architectures, even fundamental functional definitions proves difficult in an often fractious Defense community of practice.

Interoperability suffers from the same conceptual duality encountered by the term, "joint". They are at once everyone's responsibility and no one's responsibility. Joint doctrine is vague, often representing a high water mark of Service consensus at a point substantially short of the threshold for profound operational integration. A legacy of historical precedent, Service-oriented Title 10 authorities to "organize, train and equip" have served the nation well in generating capable military forces. But with the

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exception of Major Force Program authority delegated to US Special Operations Command for special operations peculiar equipment, there are no binding legal prescriptions for organizing, training and equipping a joint force. "Joint" remains a thin veneer binding Service-aligned components forces as they perform deployed missions.

There is no Service-neutral joint force construct to represent a meaningful baseline for Department-wide affordability assessment – nor for ascertainment of interoperability requirements before Service force development investments. Interoperability of forces, and interoperability of functional elements contributing to generation of those forces, is generally relegated to remedial actions addressing conflicts arising from inter-component friction between Service-generated capabilities.

There is an adage in the Department that Services retreat to core responsibilities when budgets constrict. In these times of budgetary constraint, the Services will likely view both "interoperability" and "joint" as expensive luxuries, not core functional design elements. The Modeling & Simulation community extols savings from joint ventures and common solutions, but the record reflects few significant strides in vertical integration between communities of practice or in attainment of enduring integration of Service M&S capabilities. There will be many examples held high in rebuttal, but band-aids outnumber functional mergers.

In execution, interoperability and joint features suffer the reputation of uncontrolled lifecycle costs. Evolving standards and third-party configuration management rapidly erode the functionality delivered with initial capabilities. Cross-Service commitments based on original functionality become recurrent bills to maintain compatibility with counterpart systems.

Economics again stymie interoperability when it comes to striking bargains with commercial providers for near term features at the hidden expense of accepting proprietary solutions. The analytics community is no stranger to such practices. In retrospect, the cascading cost of dependency on sole-source products seems to include daunting bills discouraging lifecycle interoperability.

This insular dependency also tends to align with long-term relationships between Service M&S communities and Federally Funded Research & Development Centers (FFRDCs). Service-FFRDC partnerships. Over time, these consortia and favored M&S tools amass a body of studies that represent the "conventional wisdom" underpinning force construct decisions. It is only human to avoid external influences that could call into question key tenets of that conventional wisdom, and threaten the equilibrium of resource allocations within the Service or community budget. It is only economics to understand that there is a more mature market for interoperable remedies than for interoperability features for products ranging from analytic tools to cockpit simulations and remote piloting systems.

Why does the Department pursue perceived benefits from interoperability in the face of structural factors that discourage wide-ranging interactivity? Because there is unrequited end-user demand for such interoperability. Warfighters express the need for Command and Control (C2) and intelligence products capability of seamless interfaces. Senior budget and acquisition officials (and their congressional overseers) flinch at the iterative and supplementary costs to bind dissociated systems into coherent capabilities. And lately, there is a fresh demand for interactive analytic tools for mission- and portfolio-based assessment of affordability. The expanding demand for joint and interoperable products could drive a new market equilibrium that might impose M&S costs on Service-centric members of the community. More likely, joint advocates, joint customers, and Department-level decision makers will need to ante up additional funding to obtain micro-level interoperability features and macro-level joint analyses.

And what about Arles, France? In the end, I succumbed to demand and became the joint owner of fully interoperable napkins, table runners and tea cloths. I'm still not sure why the patterned *coq de France* yields improved performance in our dining room, but having invested in the trip to Europe the incremental cost of linens seemed somehow an economical investment. Still, I did better in Arles than Vincent Van Gogh. *C'est la vie.*

GUEST EDITOR'S BIOGRAPHY

Michael G. Knollmann

Mike Knollmann serves in the Office of the Deputy Under Secretary of Defense (Advanced Systems & Concepts). This office formulates and executes policy, programs and initiatives to promote rapid transition of technologies and enabling operational concepts from applied engineering to fielded and sustained military capabilities to support joint missions. Programs directed by this office include Advanced Concept Technology Demonstrations, Foreign Comparative Testing, Defense Challenge Program, Technology Transition Initiative, Joint Warfare (Experimentation) Program and programs to enhance the Defense industrial base.

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As ADUSD (Joint & Coalition Operations Support), Mr. Knollmann provides leadership, management oversight, policy guidance and coordination of all Advanced Systems & Capabilities activities directly associated with the Joint Warfighting Combatant Commanders (CoComs) and our coalition partners. ADUSD (JCOS) also formulates strategic goals and develops architecture for technology demonstration and transition in achieving the transformational goals of the DoD. He develops the AS&C roadmap for introduction of maturing domestic and foreign technologies (both commercial and defense) through the demonstration and testing process. Mr. Knollmann also monitors emerging technologies and coordinates with research authorities to encourage employment of demonstrations to confirm military application of advanced technologies.

How is M&S Interoperability different from other Interoperability Domains?

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Abstract

During every standard workshop or event, the examples of working interoperability solutions are used to motivate for 'plug and play' standards for M&S as well, like standardized batteries for electronics, or the use of XML to exchange data between heterogeneous systems. While these are successful applications of standards, they are off the mark regarding M&S interoperability. The challenge of M&S is that the product that needs to be made interoperable is not the service or the system alone, but the model behind it as well. The paper shows that the alignment of conceptualizations is the real problem that is not yet dealt with in current interoperability standards.

1 Introduction

To answer the questions of how and why modeling and simulation (M&S) interoperability are different from other interoperability domains, we have to gain a better understanding of what makes M&S special first. In other words, we need to understand the epistemology of M&S and answer the question if and how it is different from other related interoperability domains. To answer this question, we furthermore limit our discourse and focus on M&S supporting computer simulations and information technology (IT) interoperability domains.

2 Current Interoperability Standards

One of the most often used examples for solved interoperability challenges are batteries. There is hardly a workshop on interoperability in which it is not used: based on the standard that defines measurements like size, electronic data, voltage, and ampere, the same battery can power a radio, flashlight, night vision goggles, or the proverbial toy bunny.

Another example closer to software is the use of the Extensible Markup Language (XML) to exchange data between heterogeneous systems. The XML standard uses basic standard foundations, so that many heterogeneous systems can support them easily (like being fully Unicode compliant), but is extensible to support complex information exchange needs.

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The final examples of working interoperability solutions are web services and cloud computing. Although different in their implementation, the underlying conceptual ideas are comparable: a service is well defined by its interface (input and output parameters) and, if necessary, by additional constraints, such as timing, synchronization points, and more. The semantic markup for services OWL-S [1] defines three categories needed to describe services (as shown in figure 1):

- With the *ServiceProfile*, the service presents "what the service does." As specified in OWL-S, [1] this includes the description of what is accomplished by the service, limitations on service applicability and quality of service, and requirements that the service requester must satisfy to use the service successfully.
- Within the *ServiceGrounding* definition, the service supports different ways "how to access it." In this part, communication protocols, message formats, and other service-specific details such as port numbers are specified.
- Finally, a service is described by a *ServiceModel* that defines "how the service works." This description fulfills the tasks of detailing the semantic content of requests, the conditions under which particular outcomes will occur, and, where necessary, the step by step processes leading to those outcomes.

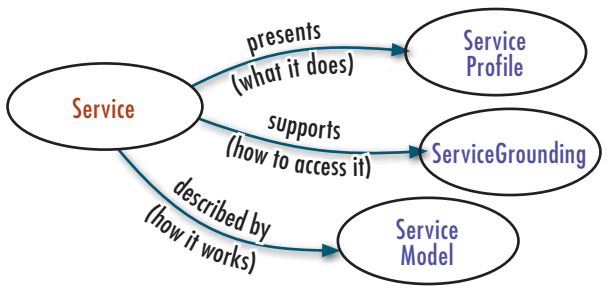

Figure 1: OWL-S

The authors showed in "Ontology Driven Interoperability – M&S Applications," [2] that OWL-S is one of the most advanced available standards supporting interoperability for M&S applications. These findings were based on research conducted in support of the Extensible Modeling and Simulation Framework (XMSF) initiative that evaluated the applicability of web-based standards to drive interoperability for M&S [3, 4]. All these standards are applied successfully, including in the M&S domain.

In addition, we have M&S specific solutions that successfully have been standardized via SISO and IEEE, namely the Distributed Interactive Simulation (DIS) protocol [5], standardized in IEEE1278, and the Modeling and Simulation High Level Architecture (HLA) [6], standardized in IEEE1516. Despite significant success stories, M&S interoperability standards seem to have "hit the wall." In recent years, no break-through has been accomplished. Instead, we look at gradual improvements, but the promised "plug and play" functionality, as suggested by the battery example, is still a dream. What is this wall? In the next section, we will have a look at where we are and how we got there, and this may help to better understand where the current challenge lies.

3 A Brief Historical Overview

In order to better understand the current view on M&S interoperability standards it is necessary to review the history of distributed simulation.

The use of simulators and simulations in the armed forces has a long history, including the use of strategic games, life exercises, and board games. However, with the advance of computers, a new era of computer simulation and simulators began. The birth of simulation standards can be seen with the creation of the Simulator Network SIMNET, which was a project of the Defense Advanced Research Project Agency (DARPA). Developed between 1980 and 1990 in collaboration with DARPA and the U.S. Army, SIMNET showed how to combine individual tank simulators of the Combined Arms Tactical Training System (CATT) to enable tank crews to operate side by side in a common synthetic battle space. The individual simulators represented weapon systems on this common virtual battlefield that had a well defined set of actions and interactions: tanks could move, observe, shoot at each other, exchange radio communication, etc. Individual activities led to status changes that were communicated via status reports. Interactions were communicated via messages.

If two tanks engaged in a duel, the order of activities and the data to be exchanged between these entities were well defined. The shooter decided to engage the victim. He moved his weapon system, and potentially platform components like a turret and a cannon into the best direc-

tion, always updating his status, so that other simulators could update their visualization showing that the tank/turret/cannon is moving. He shot at the victim. This data was sent to everyone as well. All observing systems could visualize the shooting (smoke, flash, etc.). The victim also received information on the ammunition shot at him such as velocity, angle, etc. The victim computed the result of this engagement – like catastrophic kill, movement kill, firepower kill, etc. – and communicated the result. All observers, including the shooter, updated their visualization of the victim (like being on fire, smoking, or no effect beside the impact explosion). Based on his assessment of the effect, the shooter could reengage, or continue with a new task. The tasks of who is doing what based on what data was well understood by those simulators embedded as individual independent entities in the common battle space.

As the set of information exchange specifications could be well defined, this resulted in the idea to standardize these messages, which led to the IEEE1278 Distributed Interactive Simulation (DIS) standard: the Protocol Data Units (PDUs) captured syntactically and semantically all possible actions and interactions based on the idea that individual simulators represent individual weapon platforms. Only later, instead of individual platforms also groups and aggregates (like platoons or companies) were accepted as receivers and producers of such PDUs, but these groups were understood as individual entities in the battle space as well. DIS is still successfully used and supported by a large user community.

In parallel to the simulator community that serviced the tactical level training needs, higher commands started to use computer assisted exercises (CAX) to support their command post exercises as well. Ever since Baron von Reisswitz introduced the "Kriegsspiel" during his tenure as war counselor in Prussia in 1811, [see figure 2] combat models were used to train command post officers. These exercise support games had well defined units with well defined interactions, all ruled by very detailed tables enumerating in detail the effects of each possible interaction.

Figure 2: Kriegsspiel (War Game)

The computer based successors also required a distributed capability, in particular to support higher command training of distributed facilities. As the earlier war games, these computer simulations represented aggregates on the operational level, like battalions and brigades. Again, they were interpreted as individual entities on the battlefield. MITRE developed the Aggregate Level Simulation Protocol (ALSP) to exchange information between these simulation systems.

However, unlike the simulator solution, in ALSP several units were represented in each system. When these systems were connected, the protocol ensured that each simulated aggregate had exactly one simulation system that was responsible for updates. In all other simulation systems, the respective aggregate was "ghosted," which means that a simulation object was instantiated in the simulation system, but it was tagged to be controlled by another system and was only used to make decisions for the aggregates controlled by the system, e.g., where to place surveillance radars in the surveillance simulation systems based on the distribution of tanks in the combat simulation system.

As the diversity of aggregates were higher than that of platforms and in addition differed from exercise to exercise, ALSP did not standardize the messages to be exchanged. Instead, ALSP standardized the syntax to be used, but allowed to specify the semantics (meaning of information exchange) in special formats that today would be described as metadata allowing the interpretation of the exchanged data. While during the time of "das Kriegsspiel" the possible units were limited to a set of categories supported by all armies, such as infantry, cavalry, artillery, scouts, etc.), ALSP provided a frame to communicate the participating entities (or better aggregates), possible interactions, and the effects of such interactions.

The High Level Architecture (HLA) was developed to replace both approaches – DIS and ALSP – with a new and merging approach. Originally developed within the U.S. DoD, the final version HLA 1.3 NG was handed to IEEE for international standardization,

resulting in the IEEE 1516-2000 and was only recently updated to the HLA evolved standard IEEE 1516-2010. Significantly influenced by recent new methods developed in computer science in general and software engineering in particular, a very flexible protocol was developed providing more flexibility and configurability than both of its predecessors.

The HLA interoperability standard was focused to maximize the flexibility for all kinds of M&S application domains and supported M&S paradigms. The information exchange requirements of a federation are captured in the Federation Object Model (FOM). This model defines all persistent objects and their attributes and transient objects and their parameters that can be exchanged between participating simulations. While persistent objects have to be created and then are updated (and the responsibility can be switched between the participating simulation systems during runtime), transient objects are like messages created in case of need and only used once.

Six service groups are provided as a result of generalizing the synchronization challenges ensuring that all the required information needed is delivered at the right time to the right simulation system. The purpose of *Federation Management* is to determine the federation. Federates join and leave the federation using the functions defined in this group. The purpose of *Declaration Management* is to identify which federate can publish and/or subscribe to which information exchange elements. This defines the type of information that can be shared. The purpose of *Object Management* is managing the instances of shareable objects that actually are shared in the federation. Sending, receiving and updating belong to this group. The purpose of *Data Distribution Management* is to ensure the efficiency of information exchange. By adding additional filters this group ensures that only data of interest are broadcasted. The purpose of *Time Management* is the synchronization of federates. The purpose of *Ownership Management* is to enable the transfer of responsibility for instances or attributes between federates.

HLA significantly increased the flexibility of simulation federation definitions. Instead of being limited to predefined information exchange groups, the developer can specify the objects and interactions and can even support different time model philosophies. It neither assumes the level of resolution nor does HLA assume the partition of the battle space into tactical unit or the phasing of a supported operation. HLA supports component level simulation, platform level simulation, and all levels of aggregation

4 What makes M&S Special?

The last section showed the development of M&S interoperability standards with an increase in flexibility and support of different M&S paradigms. *However, the mental model behind all these developments remained the idea of one shared virtual battle space that was populated by individual independent aggregates and/or platforms that interact with each other.*

These individuals, or group of individuals, were well defined by their own actions and interactions with each other, which could be represented by boundaries around the individuals – or a group thereof – being the boundaries of the simulation system that was responsible for their simulation and the specification of data that could be exchanged via these interfaces. The individual becomes a black box that can represent a simulated system or a live system, as long as the interface specifications are fulfilled. They build a perfect participation of the battle space and what goes on within it.

However, with the introduction of the flexibility provided by HLA, we opened Pandora's Box. While DIS enforced the one shared battle space view by defining syntax and semantics of the PDUs, and while ALSP ensured with the ghost concept that simulated entities are only available once (and merely reflected in other simulation), HLA said farewell to this paradigm.

The interoperability view of HLA is indeed that the same objects are represented in two simulations, and that these objects are represented as the persistent objects in the FOM. If an attribute changes in one of the representing systems, the attribute change is communicated via updates. Nonetheless, we have as many instances of the same object as we have implementing simulations.

As every participating simulation has been developed for a special purpose, it is unlikely that the representations are going to be identical. Actually, it is very likely that the

scope will be different, which means that attributes needed to describe the object in one context are meaningless and therefore not even modeled in another context. A simulation system written to support combat operations will use a different model to represent a main battle tank than a simulation system written to support logistics. A radio modeled for support of communications of dismounted infantry will look different than one modeled to be evaluated in the light of electronic warfare.

As all models are simplifications and abstractions of a perception of reality in order to support a certain task, they have to be different. And as simulations are implementations of models, the implemented objects will look different as well:

- Simplification takes things away. Even if we start with a common definition of a real object, we will chop off different aspects of this real object in the process of simplification. Therefore, we end up with different scopes.
- Abstraction in general leads to models with different structures and resolutions. Again, even when starting with identical observations, the detail represented in two models is likely to be different. Even worse, if aggregation is part of the abstraction process, the resulting aggregates may look very different, resulting in different structures.

To show the challenges deriving from abstraction, we already introduced the example of 'number world' and 'letter world' in "Federated Ontologies Supporting a Merged Worldview for Distributed Systems," [7]: a system exposes the six observables *a1, a2, a3, b1, b2,* and *b3*. In letter world, the three observables *a1, a2,* and *a3* are abstracted into attributes of *A,* and *b1, b2,* and *b3* are abstracted into attributes of *B*. In number world, the abstraction of *a1* and *b1* results in One, *a2* and *b2* in *Two*, and *a3* and *b3* in *Three*. Both are plausible models, but they are quite different. While on this lowest level the common attributes are still derivable, supporting the information exchange between the abstractions, what if the resolution for the model is changed and only *A, B, One, Two, a*nd *Three* remain in the models?

Even when starting from an agreed description of reality that comprises all possible attributes that a participating simulation may be interested in, the process of simplification and abstraction is going to produce very different modeling results. Furthermore, not everything going on in the real world referent is observable, even when perfect sensors are assumed. Then it depends on additional assumptions how to model these "hidden" attributes, and as no reference for them can exist by definition, different models may easily result from observing the same system with the same sensors.

It becomes worse when we take the aspect of perception into account. In this paper, perception is the physical-cognitive process of observing reality and building a conceptualization of the observation.

- The physical aspect defines what attributes of an object are observable with the sensoric system of the observer, or more general, the information about the object that can be obtained in the process of perception (this can include gaining insight from literature, discussions with colleagues, etc.).
- The cognitive aspect is shaped by the education and the knowledge of the observer. In order to conceptualize the observation the observer needs to have an internal model he can map this observation to. A physician will see more in an x-ray than a layman. An educated mechanic sees more in an engine than a novice. The subject matter expert has more internal models to explain an observation in his field than others do.

Physical and cognitive perception will therefore shape the model and resulting simulation significantly, even more than simplification and abstraction does, as perception results in a different starting point: We no longer can assume that everybody starts from a common reality, we all have individual perceptions thereof! This common conceptual starting point, however, is the necessary requirement and builds the conceptual foundation for developing a common information exchange specification between simulation systems.

As long as we are starting to support a common theory, like we did in the successful example of a common battle space following the laws of Newtonian physics, we can always track our models and resulting simulations back to the common ground defined by this theory. We can observe with more accuracy, we can model with higher resolution, and we can add "missing" attributes (those that are described in the theory, but not used in individual models). Actually, following the philosophy of science, ***a simulation system is an***

executable hypothesis or – once proven to be valid – an executable theory![1]

Mathematically, a simulation system is a production system representing the theory: starting with the initialization data, we apply production rules encoded as functions, procedures, and methods. Every state that is simulated is a valid state represented by the theory encoded as the simulation. This is equivalent to assigning TRUE and FALSE values to such states: if a certain state can be produced (and we can even add the constraint of 'within a given time') it is true, otherwise it is false. The M&S interoperability challenge comprises the task to ensure the logical equivalence of all representations of an object in the federation.

Again, we can start with assuming that we start from the common ground of a common and accepted description of reality in the form of an object model that can serve as the *Übermodell* from which all simulation representations can be derived by pruning and aggregating. We show in [8] how to apply model-based data engineering to construct the model from the information exchange needs, but this algorithm and similar ones only work if we can assure that all models started from the same common ground. And even then, strange effects can be observed.

To better address the challenges, a formal approach to simulation interoperability [9] has been developed and applied. Without going into the mathematical details, this approach showed significant shortcomings of our current M&S interoperability approaches. From the data modeling theory, we know two categories of dependencies of two objects *A* and *B*:

- *A* is existential dependent on *B* if *A* can only exist if, and only if, *B* exist.
- A is transformational dependent on *B* if *A* needs to be changed if *B* is changed.

None of our current standards support this kind of dependency. We can have a perfect FOM communication in every aspect of *A* and *B*, but we cannot communicate the dependencies. If now two simulation systems implement *A* and *B* identical despite the dependency, we can end up with two versions of truth in the same federation, if we delete or change *B*: in the simulation system that implements the dependency, the deletion or change of *B* implies the deletion or change of *A* as well; but that is not the case in the system that does not implement the dependency. While *A* continues to exist in one federate, it ceases to exist in another, and all under valid current standard conditions.

So far, all of the examples can be understood as examples that someone made a mistake: an important detail was not implemented, a model was over-simplified, an important relation was overlooked, etc. In addition, our focus has been on physical-technical models. As these models have a common referent, this 'real world' can always be used to find out if a model is sufficient or 'realistic.' The assumption here is, however, that truth exists on its own, it is independent of the observer, and reality is separated from the individual who observes it. The traditional scientific method is rooted in this world view called positivism. There exists one world and one truth, and it is possible to find this truth by observation and experimentation. This world view worked well for Newtonian physics and the physical-technical models that model it based on this common ground of a common theory.

However, the M&S community is currently starting to look into better approaches to support human, social, cultural, and behavioral modeling. Davis summarizes his research in as follows: *"Fortunately, the social science literature has a great deal to offer. However, the literature is fragmented along boundaries between academic disciplines, between basic and applied research, and between qualitative and quantitative research. ... Realistically, the research base is not mature enough to support a coherent expression of the body of knowledge. The uncertainties and disagreements are profound, on both subject-area facts and even the nature of evidence and the appropriateness of different methodologies. Those hoping to find a nicely compiled body of knowledge that can be used to write computer models will be disappointed. Further, they will often find that there are multiple competing "theories." And, even if a particular "theory" is chosen, it will be found upon inspection to involve numerous variants and uncertainties."*[10] These findings are supported by other researchers as well.

[1]Using the scientific method, a hypothesis becomes a theory only after it has been repeatedly tested and confirmed via real world data using experiments. This is in contrast to the every day use of the term "theory," where it is often understood as a collection of ideas that are not yet proven. In both cases, however, internal consistency is mandatory. In the rest of this paper, we will assume that our models are indeed grounded in theory that has been proven to be relevant and is backed by empiric evidence to avoid having to discriminate explicitly between hypothesis and theory. Whenever this is not the case, it only amplifies the implications of misuse of current practice.

To make things worse for the M&S engineer, we no longer deal with positivism in this domain, but with interpretivism. Interpretivism holds the belief that truth is a construct of the observer. Reality is relative and cannot be separated from the individual who observes it. The majority of social and human sciences subscribe to interpretivism. That means that we have to take the aspect of perception into account when evaluating if two simulation systems can operate together.

If two simulation systems implement competing theories, they can never become interoperable, as the underlying mathematical production systems produce different versions of truth. This does not make one of them wrong or the other solution better. It is a fact of life and no interoperability standard can solve this challenge: we simply do not know, and in some cases even cannot know what is needed to solve the conflict between competing theories. The challenge of the M&S engineer and of supporting M&S interoperability standards is to ensure that no competing theories (and following competing simulation systems) are federated to produce a common federation model.

In summary, our challenges lay often on the modeling side. It is understood that while modeling targets the conceptualization, simulation challenges mainly focus on implementation, in other words, modeling resides on the abstraction level, whereas simulation resides on the implementation level. Our interoperability problems are derived from the abstraction level, but our standards only focus the implementation level.

5 Implications

One of the first things to do about these challenges is to raise the awareness regarding them [11]. It would be naïve to apply standards that were developed for physical-technical models based on a common theory representing the positivistic worldview to integrate socio-psychological models derived from competing theories representing interpretivism and expect valid results. As pointed out in "Towards Methodological Approaches to meet the Challenges of Human, Social, Cultural, and Behavioral (HSCB) Modeling," [10], the best way ahead may be to live with contradicting models. It is highly unlikely that we will be able to address all problems with one common approach based on a common theory resulting in a consistent federation. It is much more likely that the multi-simulation approach based on multi-resolution, multi-stage, and multi-models envisioned by Yilmaz et al. [12] needs to be exploited to support the analysis of these multi-facetted challenges we are faced with as a community.

Generally, it is necessary to focus more on the abstraction level (the modeling) when building federations than on the implementation side. Our approaches to M&S interoperability have been shaped by software engineering and computer engineering principles that are necessary, but not sufficient. The alignment of conceptual constraints is not supported enough by the current approaches and standards. As we are connecting simulated things we need transparency of what we are simulating, as the real world referent use in other interoperability domains has been replaced in the modeling phase by its representing conceptualization in the M&S interoperability domain.

It is worth mentioning that it is possible to apply competing methods in one federation if they are coupled via a common theory. For example, two agents implementing competing theories can be coupled by purely exchanging their actions in the physical world. The underlying conceptual model, however, is well aware that one agent implements one theory, the other agent implements another theory. If we know the agents run into oscillating states or produce inconsistent results, this is part of the underlying common conceptual model that allows for this to happen, as both theories are contained in their agents.

Another aspect is the applicability of current methods for validation and verification to human, social, cultural, and behavioral modeling. As pointed out in the paper, there are many competing hypotheses, and the dearth of real-world data as well as the epistemological nature of simulation forcing us into interpretivism. However, as in interpretivism truth is subjective to the observer and not objective for the observation, validation becomes relative as well. As a consequence, socio-psychological hypotheses may remain in general objectively untestable and cannot graduate into general common theories. This challenge increases with the complexity of proposed solutions and the number of participating hypotheses, resulting in uncertainties and risks adverse to successful application of federated approaches.

The fundamental difference between M&S systems and other software systems is that M&S adds the level of conceptualization to what needs to be aligned. While other software systems connect with the real thing or support the real thing, in M&S systems the "conceptualization is the real thing" that is simulated: the model is the reality of the simulation. If we use technical means to make two simulations interoperable on the implementation level that are based on competing theories, we merge things together that do not belong together, and instead of creating a solution, the result is a conceptual chimera … or worse. However, it is well known that conceptual problems cannot be solved with technical solutions. More work is needed to make sure that the next generation of M&S interoperability standards contributes towards a solution of this category of challenges we are just becoming aware of.

Summary

After all this explanation we still did not have the answer to the question posted in the title of this paper: *How is M&S Interoperability different from other Interoperability Domains?* The answer is simple: M&S ***interoperability requires interoperability of the simulations*** – that is provided by the software engineering standards we focused on so far, including mediation of data representations, conversion of different unit of measures, mappings between different styles of enumeration, etc. – as well as ***composability of the models*** [13]. We have to ensure transparency of our conceptualizations, as they represent the real world references for the simulation. While other interoperability domains connect real things and can refer to the same real world referents, M&S interoperability connects conceptualizations, and we have to understand what the participating systems concepts look like in order to operate together. The same real world referent can have different conceptualization in different models.

The Levels of Conceptual Interoperability Model (LCIM) [14] addresses these issues for some time. Only interoperability domains that are model-driven have the second challenge.

- The battery is plugged into the system and either connects to the socket or does not. As long as power is left it is provided. The battery does not need a model of what it is powering.
- A web service that connects the fill out order for books with the inventory list of Amazon doesn't need a common model: it connects the real list with the real database. Integratability and Interoperability is all it has to be concerned about. The ordered book is either there, or it is not.
- If two simulation systems exchange data, they need to support common concepts of a model. As such, there is a conceptual overlap of the models implemented by the simulation systems. Within this overlapping area, the six interrogatives Who, What, Where, When, Why, and How need to be consistent.

In other words, for the simulation systems, the implemented model is reality. In order to couple two simulation systems, there needs to be an overlap; otherwise both systems have nothing in common to exchange data about. This overlap must be consistent, which means that the results of computations regarding the research questions must be identical. If this is not the case, we end up with two versions of truth in the federation. This problem of model-based reality is unique to M&S. Consequently, the application of software engineering standards cannot solve this problem. Therefore, a new generation of M&S standards needs to support the alignment of models to support and ensure not only interoperability, but also composability, in a form that allows the automation of such processes wherever possible.

This new generation of M&S standards must ensure the transparency of models, not only the mediation of simulations. While standards for real components can focus exclusively on the exchange of data, model-based components must ensure that the same concepts are represented consistently in all participating components. This problem does not occur outside of the model-based world. If the same real world referent is modeled or changed inconsistently in model-based components, this introduces inconsistencies on the conceptual level that are not necessarily observable. While in real components the real world reference exist only once, in model-based components the concept of this one real component can exist independently in every component.

Even more importantly may become the recognition that simulations are implemented theories, as it is the case when human behavior is modeled and implemented. As long as the simulation systems to be federated support consistent theories, the upcoming interoperability challenges can be resolved. In

new application domains, such as the emerging domain of HSCB, many conflicting theories exist. This is a conceptual block that cannot be solved by M&S interoperability standards. Federating such models into one common federation must lead to inconsistencies and meaningless results! Instead, alternative uses of alternative theories need to be supported by new approaches like the proposed Multisimulations [12].

This requires a domain of new standard efforts: the efficient and effective support of exploratory analysis under uncertainty and disagreement, and supporting development of strategies that are flexible, adaptive, and robust, as requested by Davis in [10]. SISO should address these challenges in respective efforts.

Although current standards are not sufficient, they are necessary and are building a strong foundation new approaches can extend. The authors made first recommendations in "Conceptual Modeling for Composition of Model-based Complex Systems" [8] and "Using a Formal Approach to Simulation Interoperability to Specify Languages for Ambassador Agents," [9], extending the work presented in [12]. It is now time to focus on building better tools to support the work of the M&S engineer sufficiently well to help avoid mistakes and guide him/her to better solutions in support of the customer not only in the military domain.

Acknowledgement

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References

[1] David Martin, Mark Burstein, Jerry Hobbs, Ora Lassila, Sheila McIlraith, Srini Narayanan, Massimo Paolucci, Bijan Parsia, Terry Payne, Evren Sirin, Naveen Srinivasan, and Katia Sycara (2004). "OWL-S: Semantic Markup for Web Services," *W3C Member Submission 22 November 2004,* last accessed January 2011 at http://www.w3.org/Submission/OWL-S

[2] Andreas Tolk, Saikou Diallo, and Charles Turnitsa (2006). "Ontology Driven Interoperability – M&S Applications," *Whitepaper in support of the I/ITSEC Tutorial 2548,* VMASC Report, Old Dominion University, Suffolk, VA

[3] Don Brutzman, Michael Zyda, J. Mark Pullen, and Katherine L. Morse (2002). "Extensible Modeling and Simulation Framework (XMSF) - Challenges for Web-Based Modeling and Simulation," *Workshop Report*, Naval Postgraduate School, Monterey, CA, 22 October 2002

[4] Curtis Blais, Don Brutzman, David Drake, Dennis Moen, Katherine Morse, Mark Pullen, and Andreas Tolk (2005). "Extensible Modeling and Simulation Framework (XMSF) 2004 Project Summary Report," *Project Report NPS-MV-05-002*, Naval Postgraduate School, Monterey, CA, 28 February 2005

[5] *Institute of Electrical and Electronics Engineers. IEEE 1278 Standard for Distributed Interactive Simulation,* IEEE publication, Washington, DC.

[6] *Institute of Electrical and Electronics Engineers. IEEE 1516 Standard for Modeling and Simulation* High Level Architecture, IEEE publication, Washington, DC.

[7] Charles D. Turnitsa, and Andreas Tolk (2007). "Federated Ontologies Supporting a Merged Worldview for Distributed Systems," A*ssociation for Advancements in Artificial Intelligence (AAAI) Fall Symposium, Technical Report FS-07-06*, AAAI Press, Menlo Park, CA, pp. 116-119

[8] Andreas Tolk, Saikou Y. Diallo, Robert D. King, Charles D. Turnitsa, and Jose Padilla (2010). "Conceptual Modeling for Composition of Model-based Complex Systems" *in* Stewart Robinson, Roger Brooks, Kathy Kotiadis, and Durk-Jouke van der Zee (Eds.) *Conceptual Modeling for Discrete-Event Simulation,* CRC Press, pp. 355-381

References (continued)

[9] Andreas Tolk, and Saikou Diallo (2010). "Using a Formal Approach to Simulation Interoperability to Specify Languages for Ambassador Agents," *Proceedings of the 2010 Winter Simulation Conference,* B. Johansson, S. Jain, J. Montoya-Torres, J. Hugan, and E. Yücesan (Eds.), IEEE CS Press, pp. 359-370

[10] Andreas Tolk, Paul K. Davis, Wim Huiskamp, Gary L. Klein, Harald Schaub, and James A. Wall (2010). "Towards Methodological Approaches to meet the Challenges of Human, Social, Cultural, and Behavioral (HSCB) Modeling," *Proceedings of the 2010 Winter Simulation Conference,* B. Johansson, S. Jain, J. Montoya-Torres, J. Hugan, and E. Yücesan (Eds.), IEEE CS Press, pp. 912-924

[11] Andreas Tolk (2010). "M&S Body of Knowledge: Progress Report and Look Ahead," *SCS M&S Magazine*, Vol. 1, No. 4, October

[12] Levent Yilmaz, Tuncer Ören, Alvin Lim, and Simon Bowen (2007). "Requirements and Design Principles for Multi-simulation with Multiresolution, Multistage Multimodels." *Proceedings of the 2007 Winter Simulation Conference,* S. G. Henderson, B. Biller, M.-H. Hsieh, J. Shortle, J. D. Tew, and R. R. Barton, (Eds.), IEEE CS Press, pp. 823-832

[13] Andreas Tolk (2006). "What comes after the Semantic Web, PADS Implications for the Dynamic Web," *Proceedings of the 20th ACM/IEEE/SCS Workshop on Principles of Advanced and Distributed Simulation (PADS 2006),* Singapore, May 2006, pp. 55-62

[14] Andreas Tolk, Charles Turnitsa, and Saikou Diallo (2008). "Implied Ontological Representation within the Levels of Conceptual Interoperability Model," *Journal of Intelligent Decision Technologies (IDT)*, 2(1):3-19

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The Live Virtual Constructive (LVC) Architecture Roadmap:

Foundations from the Past and Windows to the Future

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Abstract

Combining numbers of simulations in a single large exercise requires that the inter-communications architectures (e.g., HLA - High-level Architecture, TENA - Test & Training Enabling Architecture, etc.) that those systems use must also be present in the exercise. When systems that use different inter-communications architectures interact, the interaction must be transmitted between the architectures as a lossless communication. To many, this will seem a trivial consideration, given the commonplace and broad experience with communication between systems using the internet. However unexpected it may sound, HLA interactions will not be understood by simulation systems using TENA unless additional effort (typically, adding a gateway) is made supporting appropriate translation.

This small example symbolizes a broader but closely-related problem set that has impacted large simulation exercises for years. The Live-Virtual-Constructive Architecture Roadmap (LVCAR) Study was chartered to develop a future vision and supporting strategy for achieving significant interoperability improvements in LVC simulation environments, reducing the problem set to the trivial challenge that many internet-experienced consumers expect. The study addressed 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. For each area, the study provided near-, mid-, and long-term recommendations that together constitute a roadmap to guide the evolution of LVC architecture development to achieve a more seamless environment.

This paper reviews the study's assumptions, fundamental precepts, and conclusions and presents them as integral parts of a plan now being carried out. The paper also provides a view into the reasoning behind the study's recommendations and concludes with a description of the future for simulation architectures.

1.0 Introduction

In April, 2007, the DOD Modeling and Simulation Steering Committee (M&S SC) began sponsorship of the Live, Virtual, Constructive Architecture Roadmap (LVCAR) Study. The M&S SC recognized that the Modeling and Simulation Community had achieved great successes since the beginning of the SIMNET (Miller and Thorpe, 1995) program that allowed linkage of critical resources through distributed architectures. In part, the success was predi-

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CATED ON AN ITERATIVE AND EVOLUTIONARY DEVELOPMENT OF THE INTERCOMMUNICATION ARCHITECTURES, WITH PROGRESSIVE CAPABILITIES ENHANCEMENTS THAT ALLOWED MORE VARIED AND LARGER APPLICATION OF THE TECHNOLOGIES ACROSS MULTIPLE USER DOMAINS. WHILE THE ARCHITECTURES DISPLAYED IMPRESSIVE CAPABILITY TO MEET NEEDS AS DESIGNED, THEY WERE NOT IMPLEMENTED WITH A FOCUS ON ENSURING ARCHITECTURAL COMPATIBILITY WITH EXISTING CAPABILITY. THUS, EACH TIME SYSTEMS USING DIFFERENT ARCHITECTURES REQUIRED INTERCONNECTION AS PARTS OF A LARGER SIMULATION EVENT, SUBSTANTIAL DESIGN AND ENGINEERING EFFORT WAS REQUIRED TO ACHIEVE CROSS-ARCHITECTURE INTEROPERABILITY. GIVEN THIS ENVIRONMENT, THE LVCAR STUDY WAS CHARTERED TO:

"…methodically and objectively develop a recommended roadmap (way forward) regarding LVC interoperability across three broad areas of concern: notional definition of the desired future architecture standard, the desired business model(s), and the manner in which standards should be evolved and compliance evaluated."

During the study, emphasis was placed on analysis of the technical options that would achieve or make transparent architecture interoperability. A comprehensive analysis of these technical requirements across all of the architectures illustrated that there was a high degree of commonality between them, particularly HLA (Kuhl, et al, 1999) and TENA (Powell, 2005). While a few key differences have been indicated in the specifications of requirement for these architectures, a considerable amount of capability overlap (considering only major characteristics) is evident (see Figure 1). At the implementation level, however, there are substantive differences among the architectures. Such differences are characterized as "wedge issues", potentially becoming barriers to achieving crossarchitecture interoperability and are discussed in Richbourg and Lutz (2008).

2.0 Understanding the Problem

There is a perception by many in the LVC community that interoperability would be much easier (and less costly) if only there was a single architecture available for use. Included in this perception is the concept that the Department would benefit by eliminating the costs associated with maintaining overlapping capabilities. The desire to achieve a single-architecture state is based on a number of difficulties in the current situation that can be directly attributed to the existence of multiple architectures.

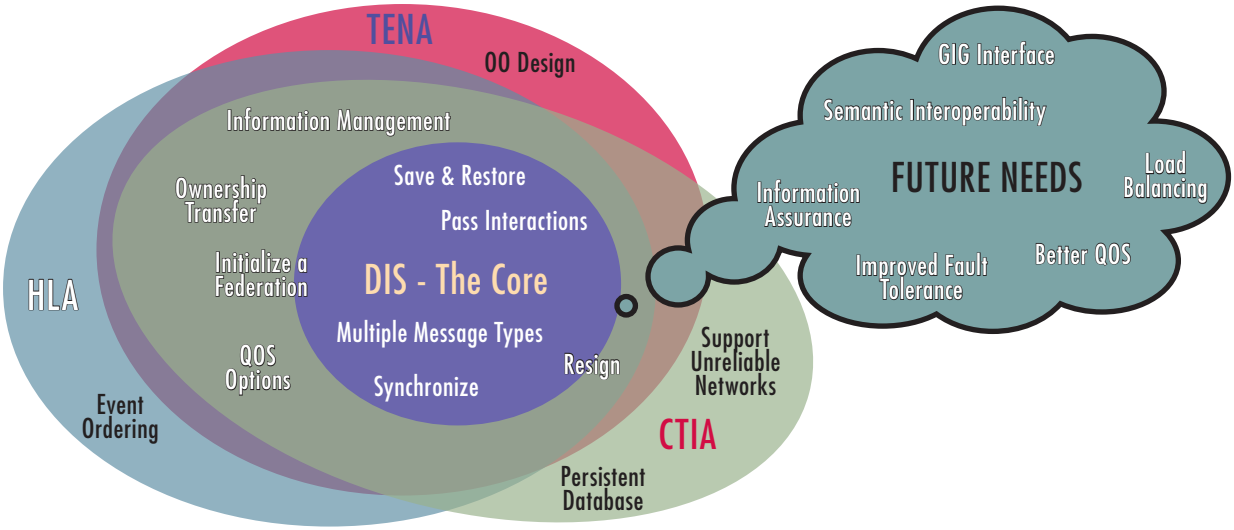

Figure 1. High-level Capability Overview

First, in many cases, mixed-architecture events can only use the set of capabilities common across all of the architectures to be included in the event (although this is as much a simulation system limitation as it is an mixed architecture constraint). Further, the costs required to integrate architectures rarely contribute directly to achieving simulation event goals. Instead, the associated costs usually provide point solutions, versions of which have likely been created in the past and probably will be paid for again in the future. Mixed architectures also impede "plug-and-play"; it is slower, more expensive, and sometimes impractical to compose simulation events using any of the wide range of assets (e.g., simulations, simulators, labs, ranges, C4ISR systems) available in the DoD inventory. In this view, one cannot simply choose an asset based on functional merit alone in all cases; frequently, the asset also is constrained to be compatible with a specific architecture. Typically, the associated cost cannot be ignored, so event designers will not even consider incompatible assets and will thus design events without having a complete picture of the resources that might have been used.

However, while each of these disadvantages can be attributed to the existence and use of multiple architectures, their existence does not necessarily justify an assumption that ridding the DoD of all but one architecture would result in an optimal state of affairs. There are at least five main factors suggesting that such an assumption is fallacious. First, legacy systems will continue to be used and it is unlikely that these systems will upgrade to using a new or different architecture. Thus, use of legacy systems is most likely to preclude the possibility of ever achieving a truly "single-architecture" state. Second, use of a single architecture may still require the use of supporting bridges, much as use of different RTIs can require bridges today. Third, gateways will be required for connecting any single simulation architecture to C4I systems, to the GIG, or, in general, to any type of system that has a primary purpose outside the simulation arena. Fourth, the alignment of a family of simulations on a single architecture represents a single point solution. Even if such standardization were attained, history points to the likelihood that the diverse group of simulation users would quickly diverge into specializations, leading to the need for gateways to bridge their differences. Fifth, the selection or creation of a single architecture assumes that the rapid advances of the commercial software industry will not lead to a better implementation in the future. When this does occur, the existing standard architecture would be abandoned by users who have needs for the superior architecture delivered by the commercial sources.

The concurrent existence of multiple architectures may allow benefits that are less likely to be achieved in a single architecture state. These include: 1) the ability to support multiple business and standards-use communities simultaneously; and 2) fostering the capability to "use the right tool for the job", avoiding the "one size fits all" problem.

In summary, there are advantages and disadvantages associated with having a number of architectures available for use. There is no paramount advantage or disadvantage that allows one to immediately recognize the best possible solution. 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.

3.0 Candidate Strategies

The LVCAR Strategy decision space considered in the analysis of alternatives (AOA) (see Figure 2) was based on requirements and capability analyses. These five strategies represent an expert team consensus-based opinion of the possible high-level approaches to addressing LVC interoperability issues from which a roadmap of lower-level actions and activities could be derived. These strategies are elaborated on below. As indicated in the figure, several of these strategies were rejected early in the analysis. The rationale for strategy retention and elimination is provided in Section 6.0.

3.1 Strategy 1: Maintain the Status Quo

In this strategy, no specific actions are taken to unify the current distributed simulation architectures. This can be thought of as the "natural selection" or "distributed, uncoordinated management" strategy, which recognizes that the various architectures will evolve as needed to meet the future needs of each user base, and that when mixed architecture environments are required, the current (but

admittedly ad hoc, inefficient, and decentralized) approach of using gateways and bridges will eventually become good enough to meet future needs.

3.2 Strategy 2: Enhance Interoperability of Mixed Architecture Events

In this strategy, the focus is to create solutions to improve the interoperation of existing architectures in a mixed-architecture environment. Examples of such solutions include establishing standard agreements (e.g., processes, terminology, object models) that cut across the various architectures and improving the performance, reliability and (re)usability of future gateways and bridges. The individual architectures would evolve to support their native user base.

3.3 Strategy 3: Encourage and Facilitate Architecture Convergence

This strategy is very similar to the preceding strategy, with the exception that policy actions and investment incentives would be added to cause the architectures to converge into either a single architecture or a reduced set of compatible and interoperable architectures. Thus, while the same roadmap actions would be taken with regard to improving both model and runtime interoperability in the near-to-mid term, this strategy would include additional actions as necessary to achieve some level of architecture convergence (including the potential for physical convergence) at a specified future date.

3.4 Strategy 4: Select One of the Existing Architectures

In this strategy, an evaluation of how well existing individual architectures satisfy all identified requirements (including projected future requirements) would be conducted, and the architecture that represents the "closest fit" to future needs would be chosen as the foundation of a single future architecture for LVC. Actions at that point would focus on adding (hopefully reusing from other architectures) features and capabilities needed by users that are not currently included in the chosen architecture, and on instituting policy and financial incentives to convince affected users to transition.

3.5 Strategy 5: Develop a New Architecture

In this strategy, an entirely new architecture would be developed based on current and future requirements for LVC environments. While reuse of the best ideas and implementations from existing architectures would be encouraged where appropriate, this strategy is intended to be a new start to incorporate emerging technologies and

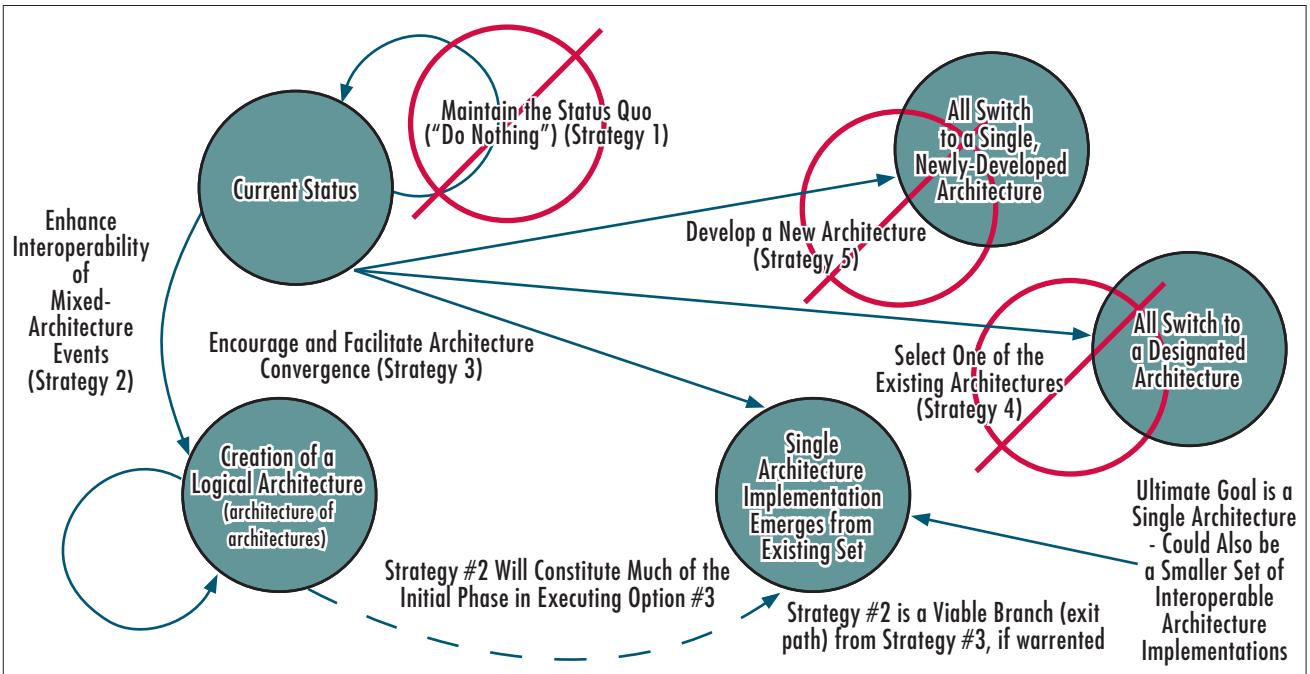

Figure 2. Candidate Strategies for the Analysis of Alternatives

modern design paradigms into the baseline architecture structure rather than trying retrofit such ideas into existing architecture(s). Policy and financial incentives would be used to spur adoption of the new architecture.

4.0 Observations

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 (see Figure 3). 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. The following 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.

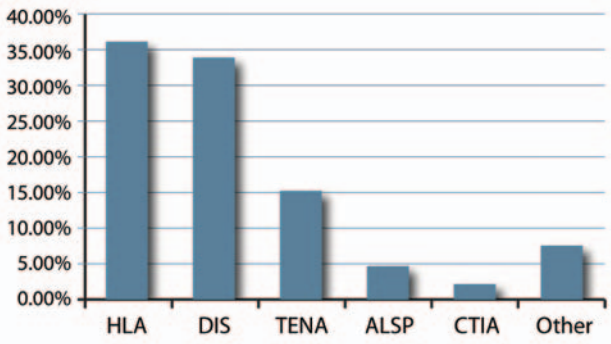

Figure 3. Sample of Architectures Being Used[1] (August, 2007)

- 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 the LVCAR study) and application-level choices of how to interpret received and encode transmitted data (semantic issues, beyond the scope of the study) both have impacts on interoperability.
- Significant improvements in LVC interoperability can also be achieved via supporting data, tool, and process standards.

In short, the currently available architectures were deemed to be 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 interarchitecture communication problem only occurs during mixed-architecture events. And, while there are advantages and disadvantages associated with the number of architectures 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.

Figure 4 characterizes the high-level trade-space in two axes (Control and Marketplace) from the perspective of the DoD enterprise. In this model, Control represents the degree of influence the DoD corporate level has over an architecture and its related business and standards prac-

[1] ALSP (Wilson and Weatherly, 1994) is no longer being used.

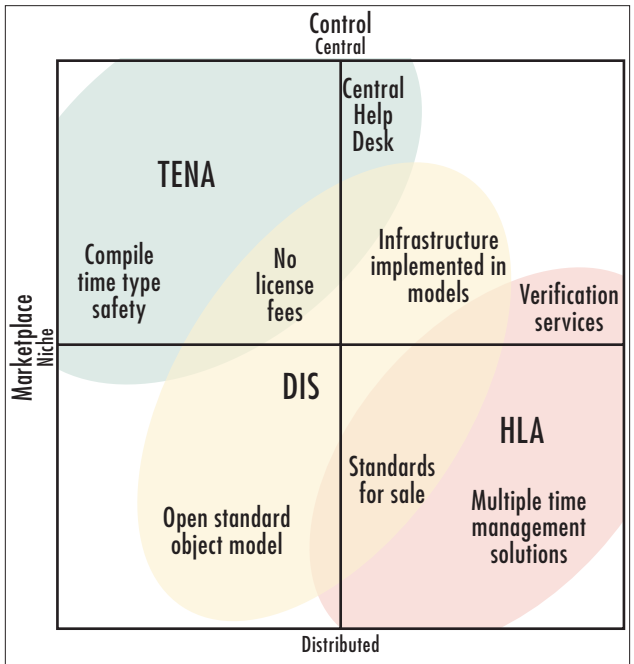

Figure 4. Conceptual Similarities, Contrasts and Progressions of LVC

tices and Marketplace represents the degree to which the architecture, including its corresponding business and standards processes, promotes cross-stakeholder and cross-user participation.

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 "(Government) Central Help Desk" 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 (Hofer and Loper, 1995) 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" 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 architecture ownership, and then TENA adjusted in the opposite direction to improve ownership but in so doing limited diversity. A significant problem for the LVCAR roadmap effort was 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.

4.1 Levels of Interoperability

Many of the known problems that impact LVC integration stem from technical incompatibilities among the various distributed simulation architectures. However, achieving the goal of a truly interoperable LVC operating environment requires that developers consider a wide range of issues beyond the basic question of how to pass runtime data along the simulation network. As examples, issues related to data modeling, coordinate systems, synthetic natural environment representation, and algorithmic consistency are frequently outside the scope of the problems that simulation architectures were ever designed to address. The consideration of such issues as part of a structured systems engineering methodology is critical if executions of the LVC environment are to produce valid results.

Tolk and Muguira (2003) identify five basic levels of simulation interoperability, with each level building on preceding levels. LVC interoperability is affected across all five levels. The distributed simulation architectures in use today all provide services for achieving technical and syntactic interoperability (e.g., levels 1 and 2); however, problems with how these services interact at runtime can adversely affect interoperability in mixed architecture environments. While solutions can be found to such problems, the LVCAR stressed the idea that most practical distributed simulation applications require interoperability at levels above the syntactic level. Addressing interoperability issues at the semantic level (and above) frequently transcends the architectures, and generally involves the establishment of cross-community agreements and standards on such supporting resources as data, processes, and tools. Thus, although the primary focus of the LVCAR was on the syntactic-level issues of mixed architecture integration, the general desire to reduce the technical, cost, and schedule risks associated with developing and operating future LVC environments also requires the consideration of higher level interoperability issues.

5.0 Fundamental Precepts

During development of the desired state properties, implementation strategies, and subsequent recommendations for the LVCAR Study, the Expert Team converged on a core set of beliefs, axiomatic 'meta-recommendations' that underscore the 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 (Henninger et al, 2008).

5.1 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 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 cost and 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.

5.2 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.

5.3 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 a moderate cost, and provide significant near- and midterm value to the LVC community.

5.4 Fundamental Precept #4: Provide Central Management.

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.

6.0 Strategy Assessment

The initial strategy assessment involved the evaluation of the various qualitative factors and other more practical considerations discussed earlier in this paper. The first, most basic architecture strategy is Strategy 1, "Maintain the Status Quo." The major concern with respect to this strategy is that the current inefficiencies and excessive integration and resource requirements inherent in today's mixed-architecture environments are intolerable even in the present, and the natural divergence of existing architectures will continue to degrade the situation. Clearly, this strategy does nothing to improve the current situation, by definition.

Strategy 5, "Develop a New Architecture", suffers from the impracticality of its implementation, at least in the near-term. Most who work in the distributed M&S community have experienced the clear failure of policy mandates and, based on that experience, are convinced that the similar tactics are unlikely to work in the future. Further, incentives to users of existing architectures to transition will be ineffective if the users believe that their existing architecture solution is already fully meeting their needs (which most do). Developing a new architecture to replace the existing ones will more likely result in yet another architecture being added to the existing set; history indicates that few, if any, architectures will be retired as the new one comes on-line. Thus, the combination of potentially high up-front costs, long development time, and (currently) weak justification for an entirely new LVC architecture effectively eliminates this strategy as a viable near-term solution.

Strategy 4, "Select One of the Existing Architectures", suffers from many of the same issues as the "Develop a New Architecture" Strategy. That is, users of existing architectures seem to be generally satisfied with them, and significant investments have already been made in supporting infrastructure. The users of architectures that were not the "one selected" would be asked to switch to an architecture that they may have already rejected or otherwise deemed to be cost ineffective. Thus, there would likely be significant resistance to migrating to an externally-designated architecture when that migration would require new investments (e.g., software, personnel training, supporting infrastructure) and may not work as well as their current architecture within their domain. Short of a policy mandate (which has historically been shown to be ineffective), an orderly transition is unlikely to happen. Thus, while this strategy could become a natural outgrowth of the "Encourage and Facilitate Architecture Convergence" Strategy, simply choosing an existing architecture and compelling other architecture users to migrate was considered to be impractical, ineffective, and unworkable as a near-term solution. As such, this strategy was also eliminated from further consideration.

Having eliminated these three strategies from further consideration, only Strategy 2 ("Enhance Interoperability of Mixed-Architecture Events") and Strategy 3 ("Encourage and Facilitate Architecture Convergence") remained as viable candidates for further evaluation. Based on analyses and expert opinion, these two strategies appeared to be the most promising for several reasons. Principally, they lack the impracticality of the other strategies while still providing needed improvements in LVC interoperability. Both are designed to prevent continued architecture divergence, and both provide sufficient flexibility to allow mid-term course corrections if evolving user requirements suggest a deviation. Both Strategy 2 and Strategy 3 could readily branch to either Strategy 4 or Strategy 5, or to one another, as the most desirable long-term course. In addition, both provide for the existence of an oversight body that will have vision over all of the separate groups that currently manage and evolve the existing architectures.

Strategy 2, "Enhance Interoperability of Mixed- Architecture Events", is 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 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 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", composed of as many different architectures and protocols as are required to interconnect the participating simulation systems.

Strategy 3 differs from Strategy 2 in the method of addressing the multi-architecture problem, the role of the oversight body, and in the primacy of effort. First, Strategy 3 takes the view that the many problems inherent in allowing redundant architectural capability to exist clearly outweigh the associated benefits. The existence of multiple architectures is a problem that must and shall be resolved. Gradual convergence of the architectures is a viable strategy to resolve the problem. As an example, if two architectures are so common in their capabilities that there is little, if any, significant technical difference between them, then those two architectures should be gradually converged into a single architecture. Similarly, if the complete set of technical capabilities offered by one architecture is a subset of the capabilities provided by another, the "smaller" architecture should be gradually converged into the larger one. Thus, Strategy 3 seeks to manage gradual convergence of the entire set of architectures where appropriate. Eventually, the convergence process could result in either a single architecture or a smaller set of compatible, interoperable architectures. Managing convergence in this way requires an oversight body that can influence the evolution of the architectures, using a combination of policy, incentives, and disincentives to shape the actions taken by the user communities that control architecture evolution. Finally, while Strategy 3 includes the same actions as Strategy 2 that will immediately reduce the costs and problems that arise when integrating multiple architectures, the primacy of effort is given to achieving convergence of the existing architectures.

As part of the final AoA, each of candidate strategies was decomposed and evaluated with a cost-benefits analysis by an expert team. The measure of "utility" applied was "Return on Investment" (ROI), which was defined as the ratio of the relative benefit of each activity versus the cost to perform each activity. "Benefit" in this case was defined to be the amount of savings that is achievable in future LVC environment development effort as a result of having performed that activity. So, for instance, if performing Activity Z results in a set of reusable products that will drive the cost of building an LVC environment down from "X" dollars to "Y" dollars in the future, then "X – Y" (multiplied by the number of expected LVC events) provides a reasonable measure of benefit for Activity Z. "Cost" in this context was the man-years associated with implementing the activity. The "break even point" is that point in time at which benefit equals cost. From a decision-maker's perspective, those activities that have early break even points and whose benefits increase rapidly with respect to cost in future years will be considered the most desirable.

To provide context to the ROI evaluation activity, the HLA Federation Development and Execution Process (FEDEP, IEEE [2003]) was employed in this analysis as a framework for identifying where certain costs and benefits are incurred while constructing LVC environments. While other process models could have been used, the FEDEP was chosen due its broad applicability to all simulation architectures and status as a recognized IEEE standard.

The input data to this analysis was primarily based on surveys from LVCAR Expert Team and Working Group members. Although real financial data from actual LVC user programs would have been a preferred source of information for this analysis, such data is not generally extractable from the Work Breakdown Structures (WBS) used by most programs. While the use of SME opinion rather than real cost data can be considered a possible criticism of this analysis, it should be emphasized that the surveys were specifically targeted to people with substantial experience in developing LVC environments, and thus the collective opinions of the targeted group was determined to provide the best possible estimation of both activity costs and the savings achievable via implementation of the various activities.

The results of this ROI evaluation exercise led to a "best-of-breed" that included some elements of both Strategy 2 and Strategy 3, in effect producing a blended strategy

that includes the most desirable components of both. In addition to optimizing ROI, this combination also ensured that the strategy provided the most robust posture and the agility necessary to adapt to changing situations (e.g., C4I systems, impact of Global Information Grid, embedded training in operational systems, Multi-Level Security). The following section showcases some of the high-level recommendations resulting from the AoA, and provides detail on some of the implementation-level activities.

7.0 Roadmap Recommendations

This section provides the summary focus area recommendations that drive the investment roadmap activities along with general related recommendations. The LVCAR provides the complete development for each recommendation, but that rationale is not summarized in this paper given the length of the discussions.

7.1 Strategic Level Recommendations

These recommendations are further elaborated with supporting rationale and data throughout the final report. The DoD should:

Technical Architecture

- Take actions that can reduce or eliminate the barriers to interoperability
- 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

Standards

- Develop adequate spheres of influence in relevant standards organizations (e.g., SISO) and related communities (C4I, DISA, etc.)
- Develop standards evolution processes that can provide required stability, yet be flexible and responsive to users

Business Model

- Identify an LVC Keystone[2] to gather and disseminate information across the M&S community, representing a unified consensus of opinion

Type	Activity
Architecture	Common components of architectureindependent object models
	Describe and document a common, architecture independent systems engineering process
	Create common, reusable federation agreement template
	Analyze, plan and implement improvements to the processes and infrastructure supporting M&S asset reuse
	Produce and/or enable reusable development tools
	Investigate – Convergence feasibility determination and design
	Convergence plan
	Convergence implementation
	Produce common gateways and bridges
	Specify a resource or capability to facilitate preintegration systems readiness
Standards	Make IEEE standards more accessible to LVC community.
	Engage SISO and the broader LVC community
	Coordinate activities and fund participation in commercial standards development groups
	Investigate - Increase sphere of influence in Standards Development Organizations
	Develop evolutionary growth path for LVC standards
Business	Identify LVC Keystone
	Investigate – Balance the marketplace
	Balance the marketplace
Mgmt	Decision Support Data

Table 1. Implementation Level Activities

- 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 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.)

[2] See Swenson (2008) 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.

- 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 midcourse corrections, and develop the next generation of goals

7.2 Tactical Level Activities

Table 1 below focuses exclusively on DoD-level investments, the Roadmap Activities. These are seen as common goods particularly worthy of DoD-level attention. Table 1 recommendations fall largely into three categories: architecture, business model, and standards. In tune with Fundamental Precept #4, the central management must direct technical efforts to perform the roadmap activities.

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. As stated earlier, 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 between the existing architectures and protocols. Effectively, the activities are designed to transparently create an "architecture of architectures" when necessary, while leaving the individual architectures relatively unchanged so that they continue to provide uninterrupted service to their constituent communities.

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 (Richbourg et al, 2008). This more elegant focus will direct us to a path towards improving the effectiveness[3] 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 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 that 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) 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 build a sense of community.

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

8.0 Closing Remarks

Ultimately, the goal must be 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. This is possible. Microsoft, for example,

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

has profound influence over the information technology (IT) marketplace; yet, "both its revenue and number of employees represent about 0.05% of the total" resources in that marketplace. (Iansiti and Levien, 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, 2005) spent annually on M&S in the DoD.

On 16 July 2007, 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 and LVC as a technology supporting the security and prosperity of the United States.

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REFERENCES

Cuda, D. and Frieders, M. (2005). Estimating DoD Budgets for Modeling, Simulation, and Wargaming. Institute for Defense Analyses Technical Report to the Defense Modeling and Simulation Office.

Henninger, A., Richbourg, R., Lutz, R., Saunders, R., Loper, M., Swenson, S. (2008). Live Virtual Constructive Architecture Roadmap (LVCAR) Final Report. Report developed for OSD P&R.

Hofer, R.C. and Loper, M.L. (1995). DIS today [Distributed interactive simulation] Proceedings of the IEEE Volume: 83 Issue: 8 Aug 1995 Page(s): 1124-1137.

Iansiti, M., and Levien, R. (2004). Strategy as Ecology. Harvard Business Review. (March, 2004).

IEEE (2003). 1516.3 - IEEE Recommended Practice for High Level Architecture (HLA) Federation Development and Execution Process (FEDEP)

Kuhl, F., Weatherly, R., and Dahmann, J. (1999). Creating Computer Simulation Systems: An Introduction to the High Level Architecture. Prentice Hall, Upper Saddle River, NJ.

Loper, M., and Cutts, D. (2008). Live Virtual Constructive Architecture Roadmap (LVCAR) Comparative Analysis of the Standards Management Processes. Report developed for OSD P&R.

Miller, D., and Thorpe, J.A. (1995). SIMNET: the advent of simulator networking; Proceedings of the IEEE Volume: 83 Issue: 8 Aug 1995 Page(s): 1114-1123.

Powell, E. (2005). Range System Interoperability. In the Proceedings of Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) '05. Orlando, FL.

Richbourg, R., and Lutz, R. (2008). Live Virtual Constructive Architecture Roadmap (LVCAR) Comparative Analysis of the Architectures. Report developed for OSD P&R.

Richbourg, R., Lutz, R., and Ceranowicz, A. (2008). My Simulation is from Mars; Yours' is from Venus. To be presented in the Interservice/Industry Training, Simulation and Education Conference. Orlando, FL.

Swenson, S. (2008). Live Virtual Constructive Architecture Roadmap (LVCAR) Comparative Analysis of the Business Models. Report developed for OSD P&R.

Tolk, A. and Muguira, J.A. (2003). The Levels of Conceptual Interoperability Model (LCIM) summarized online at: http://en.wikipedia.org/wiki/Conceptual_interoperability

Wilson, A.L. and Weatherly, R.M. (1994) The aggregate level simulation protocol: an evolving system. Proceedings of the 26th Winter Simulation Conference WSC '94. Orlando, FL.

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An Open Source MSDL/C-BML Interface to VR-Forces

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SISO Military Scenario Definition Language (MSDL) and Coalition Battle Management Language (C-BML) continue to progress as a means to interoperate Command and Control (C2) systems with simulation systems. However, the ability to use these powerful interoperation technologies is limited to national military groups who possess a C2 or simulation system and choose to invest in an MSDL/C-BML interface. In order to expand the experimental capability for C2-Simulation technologies, both in our laboratory and in the larger community, the GMU C4I Center is undertaking development of an open source interface to the MÄK VR-Forces computergenerated forces simulation, which is commercially available, to join our other free, open-source BML software. We plan to compare the result with other systems in our testbed, such as US Army OneSAF and Saab WISE. The open source interface will begin as a student project; if successful we will seek funding to create a complete implementation of MSDL/C-BML. This paper describes the basic design and initial implementation.

1. Overview

This paper presents an open-source interface between BML in general (MSDL and C-BML in particular) with MÄK's product VR-Forces through its Remote Control Application Programming Interface (API). So far as we are aware, this is the first trial to bring together opensource BML software with industrial-strength commercial software.

2. Introduction

THE WORK PRESENTED IN THIS PAPER IS BASED ON STANDARDS TECHNOLOGIES DEVELOPED IN THE SISO COMMUNITY. THE CORE OF THESE STANDARDS IS MSDL AND C-BML, WHICH WILL BE DISCUSSED IN THE NEXT SECTION. OUR WORK BUILDS ON OTHER ENABLING TECHNOLOGIES DEVELOPED BY GMU'S C4I CENTER THAT ARE AVAILABLE AS OPEN SOURCE SOFTWARE AND ALSO ON THE COMMERCIAL SIMULATION SOFTWARE VR-FORCES FROM MÄK. WE BELIEVE THAT INTEGRATING BML TOOLS AND STANDARDS WITH VR-FORCES WILL SYNERGIZE BOTH TECHNOLOGIES BY EXPANDING THE REACH OF THE OPENLY AVAILABLE BML STANDARDS AND TOOLS TO VR-FORCES. IT ALSO WILL ALLOW VR-FORCES TO BE USED BY THE WIDER COMMUNITY THAT IS INTERESTED IN STANDARDIZED AND OPEN SOURCE TOOLS AND TECHNOLOGIES. AMONG THOSE USERS ARE NATO AND OTHER COALITION NATIONS AND USERS.

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2.1 BML and C-BML

Battle Management Language (BML) and its various proposed dialects, among them Coalition Battle Management Language (C-BML) supplemented by the Military Scenario Definition Language (MSDL), are intended to facilitate interoperation among command and control (C2) and modeling and simulation (M&S) systems by providing a common, agreed-to format for the exchange of information such as orders and reports [1]. In the predominant model used today, this is accomplished by providing a repository service that the participating systems can use to post and retrieve messages expressed in BML/C-BML. The service is implemented as middleware, essential to the operation of BML, and can be either centralized or distributed. Recent service implementations have focused on use of the Extensible Markup Language (XML) along with Web service (WS) technology, a choice that is consistent with the Network Centric Operations strategy currently being adopted by the US Department of Defense and its coalition allies [1][8].

2.2 SBML

Experience in development of BML indicates that the language will continue to grow and change. This is likely to be true of both the BML itself and of the underlying database representation used to implement the BML Web Services. However, it also has become clear that some aspects of BML middleware are likely to remain the same for a considerable time, namely, the XML input structure and the need for the BML WS to store a representation of BML in a well-structured relational database, accessed via the Structured Query Language (SQL). This stability implies an opportunity for a re-usable system component: a Scripting Engine, driven by a BML Schema and a Mapping File. The resulting Scripted BML Server (SBMLServer) accepts BML *push* and *pull* transactions and processes them according to a script (also written in XML). While the scripted approach may have lower performance when compared to hard-coded implementations, it has several advantages:

- new BML constructs can be implemented and tested rapidly
- changes to the data model that underlies that database can be implemented and tested rapidly
- the ability to change the service rapidly reduces cost and facilitates prototyping
- the scripting language provides a concise definition of BML-to-data model mappings that facilitates review and interchange needed for collaboration and standardization

The heart of SBML is a scripting engine, introduced in [2], that implements a BML WS by converting BML data into a database representation and also retrieving from the database and generating BML as output. It could implement any XML-based BML and any SQL-realized underlying data model. Current SBML scripts implement the Joint Command, Control and Consultation Information Exchange Data Model (JC3IEDM). In the following description, any logically consistent and complete data model could replace JC3IEDM.

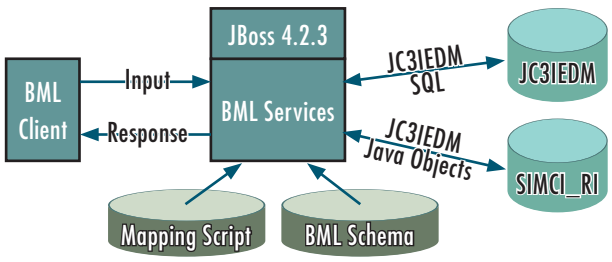

Figure 1: SBML Configuration

The current SBML implementation and scripts support two JC3IEDM database interfaces, as shown in Figure 1: one is a direct SQL interface, used with a MySQL database server. The other, SIMCI_RI [4], passes java objects through Red Hat's Hibernate persistence service, which performs the actual database interface function.

2.2.1 SBML Publish/Subscribe

Reference [3] describes the second generation of SBML. Version 2 of SBML implements a publish/subscribe capability [5], using the Java Message Service (JMS) as implemented by JBoss in open source (see http://www.jboss.com). Version 2 also implements the XML Path Language (XPath) (see http://www.w3.org/TR/xpath), wherever a relative path in the XML input is required. The BML/JC3IEDM conversion process is accomplished under control of the scripting language, as described in [3].

SBML runs under JBoss 4.2.3, which provides the JBoss Messaging or JBossMQ. JBossMQ is an implementation

of JMS 1.1 [6]. It provides both point-to-point messaging between two entities (JMS Queues) and a subscription based distribution mechanism (JMS Topics) for publishing messages to multiple subscribers. JMS provides reliable delivery of messages for all subscribers to a particular topic.

SBML version 2.3 provides a set of preconfigured JBossMQ Topics, which are used for the distribution of incoming orders and periodic reports to any interested subscribers. As BML messages are received they are processed by the appropriate script and written to the database. The successful completion of the transaction is an indication that there were no errors in incoming data and that the message can be forwarded to subscribers. There is an XPath [7] statement associated with each Topic, which serves as a filter to determine whether each received message should be written to that Topic. If application of the XPath statement to the message results in non-null result, the message is written to that Topic. A particular BML message may match more than one XPath statement and if so will be transmitted to more than one Topic. A client then might receive the same message more than once. The publish/subscribe architecture is depicted in Figure 2.

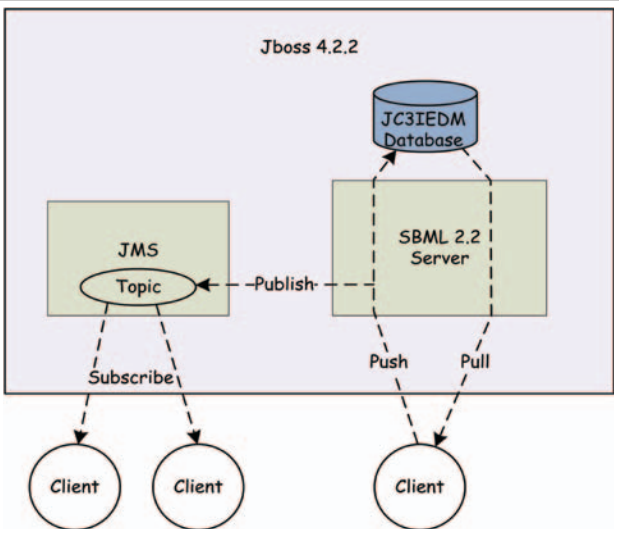

Figure 2: Publish/Subscribe Architecture for SBML

2.3 MSDL

The Military Scenario Definition Language (MSDL) is intended to provide a standard mechanism for loading Military Scenarios independent of the application generating or using the scenario [9]. Standard MSDL is defined utilizing an XML schema thus enabling exchange of all or part of scenarios among Command and Control (C2) planning applications, simulations, and scenario development applications. XML based scenario representations can readily be checked for conformance against the standard's schema.

The scope of MSDL is bounded by the situation, defined at one instant in time, combined with the course of action about to be taken in context to that situation. The intent is for MSDL to include that information which is either core or common to the situation and course of action (COA) of a military scenario. Definition of COA falls under the scope of the Coalition Battle Management Language PDG. The MSDL and C-BML Product Development Groups are collaborating on common elements of these two languages to ensure the two standards are compatible.

3. BML C2 GUI

The BML client depicted in Figures 1 and 2 above may be relatively complex to develop, requiring a variety of tools and capabilities such as: an XML editor, operating system command line knowledge, and Java programming experience. The difficulty is greater because the developer doesn't have the opportunity to see the actual geospatial information in the BML documents on a representative map. Inspired by the Fraunhofer FKIE's C2 Lexical Grammar (C2LG) GUI [10][11], we have developed the "Battle Management Language Command and Control Graphical User Interface" (BML C2 GUI) as one of the open source tools associated with SBML [12][13]. The BML C2 GUI is an open-source user interface tool that displays information flowing to/from C2 and simulation systems in text and image formats such as MSDL and CBML.

The BML C2 GUI is different from the C2LG GUI in two aspects. The first one is that it integrates two comprehensive Open-Source software packages, JAXFront and OpenMap. Using the Community version of JAXFront results in a comprehensive XML customizable editor and OpenMap gave us a fully functional Mapping application. The second difference is that the BML C2 GUI is open source software. This makes it possible for the BML community to add to the software and customize it for the most appropriate use. Thus there is potential for accelerated the development

time and reduced cost via re-use. The main purpose of the BML C2 GUI is to provide an easy-to-use graphical user interface to BML users and developers that can serve as a surrogate input/output GUI or alternately to monitor (and if necessary revise) BML documents flowing to/from BML client systems [10]. BML C2 GUI is a Java application that generates an interface using other open-source tools: Xcentric's JAXFront and BBN's OpenMap. Figure 3 shows a screen shot of the GUI.

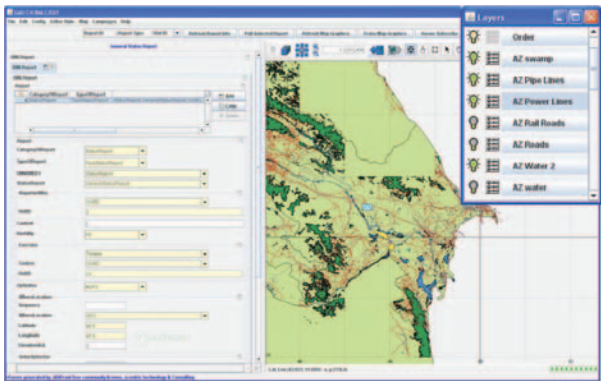

Figure 3: The BML C2 GUI

The BML C2 GUI provides an easy and efficient alternative for the end user to edit, validate, and push BML orders to the SBML Web Services and also to pull and view BML reports from the services. It also can subscribe to the SBML subscription service so that the GUI will be updated whenever a new report is pushed by another client with the SBML publish/subscribe capabilities. The map will depict geospatial information from the BML document the user is editing or revising and display the correct symbols representing the objects or units in addition to all the mapping capabilities supported by OpenMap. BML C2 GUI uses the OpenMap implementation of military standard MIL-STD-2525B for unit and object symbol representation [14].

Editing and issuing a BML order or report is very easy using the GUI, requiring only data field entry and selection of items from drop down lists, which are populated automatically from enumerations in the associated schema. The GUI can accommodate changes in BML schemas easily because all of the GUI generation happens at run time. Furthermore, the GUI satisfies the need of experienced users by providing a serialization method of the BML document enabling XML manual edit, validate, save and push capabilities. The BML C2 GUI has been enhanced to support viewing, editing, pushing and pulling of MSDL scenario files.

3.1 BML C2 GUI MSDL Enhancement

The MSDL schema was implemented in the BML C2 GUI, providing a run-time Java Swing interface for MSDL documents. Figure 6 illustrates a sample MSDL document in the editor part of the GUI and the corresponding Geospatial information on the right side. The geospatial capability included the representation of all geospatial informaton that can be found in a BML document. In the MSDL case, it includes the Organizations and Equipment information as in figure 4 and the Environment information as in figure 5.

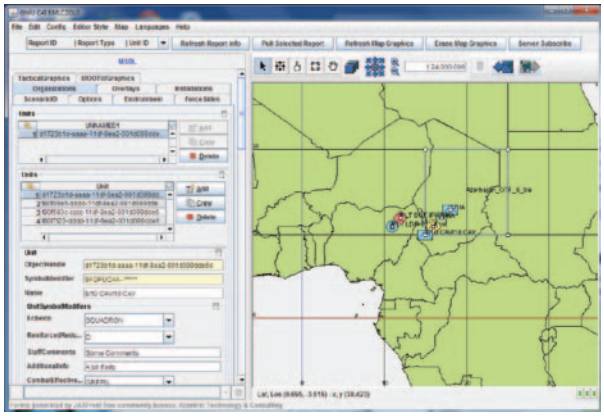

Figure 4: The BML C2 GUI displaying an MSDL document in the editor and a corresponding map with Organizations and Equipment

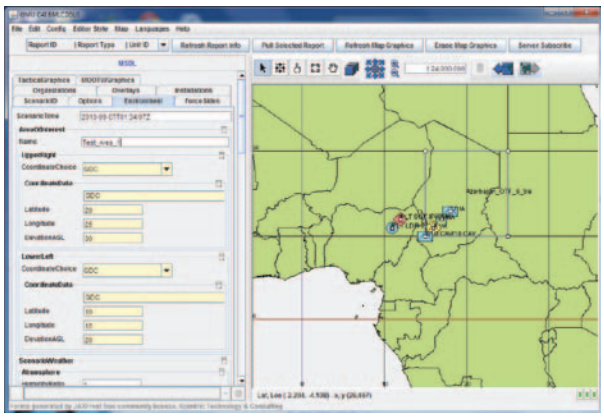

Figure 5: The BML C2 GUI displaying an MSDL document in the editor and a corresponding map with Environment information

The GUI employs the MIL-STD-2525B symbols provided by the OpenMap library to represent the units and equipment at their locations on the map. The fifteen characters

of the MIL-STD-2525B are all provided as part of the unit information in the MSDL document. The GUI can display all environmental objects present in the MSDL document which might be an area of interest, a route, a line or a point.

4. MÄK VR-Forces

VT MÄK's VR-Forces is a "powerful and flexible simulation environment for scenario generation. It has all the necessary features for use as a tactical leadership trainer, threat generator, behavior model test bed, or Computer Generated Forces (CGF) application" [17]. (See http://mak.com.) Figure 6 illustrates a typical VR-Forces configuration.

Some useful features of VR-Forces are:

- includes a C++ toolkit to extend or embed VR-Forces in another computer application
- can be used as distributed simulation engine with remote GUI control
- can aggregate unit and entity modeling
- supports standard simulation protocols such as HLA and DIS
- supports various kinds of terrain, including streaming terrain
- supports GUI-based entity and parameter editing

4.1 Simple Scenario Editing

"VR-Forces Computer Generated Forces provides an intuitive GUI that allows to build scenarios by positioning forces, creating routes and waypoints, and assigning tasks or plans with a simple point and click" [17]. The basic outline can be drawn on a 2D tactical map, and then switched to the 3D scenario editing mode to accurately position entities within a complex urban environment. An XR mode is available to provide a big picture to understand the scenario, without losing the 3D perspective. Figure 7 shows a sample VR-Forces layout.

4.2 Powerful Simulation Engine

"VR-Forces comes with simulation models for a wide variety of battlefield entities and weapon systems. During scenario execution, VR-Forces vehicles and human entities interact with the terrain, follow roads, move in convoys, avoid obstacles, communicate over simulated radios, detect and engage enemy forces, and calculate damage. Through multi-resolution modeling, VR-Forces can switch between aggregate and entity level movement models 'on-the-fly' based on scenario events such as sensor detection or area of interest" [17].

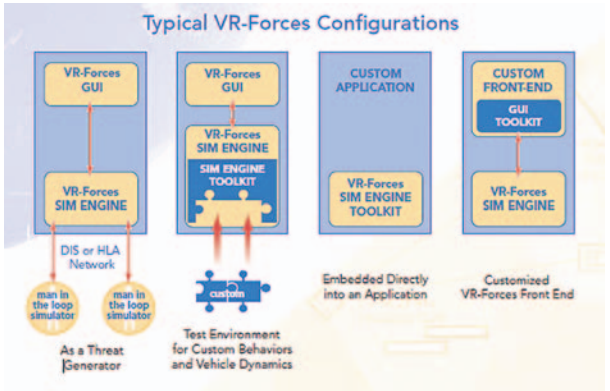

Figure 6: Typical VR-Forces Configuration [17]

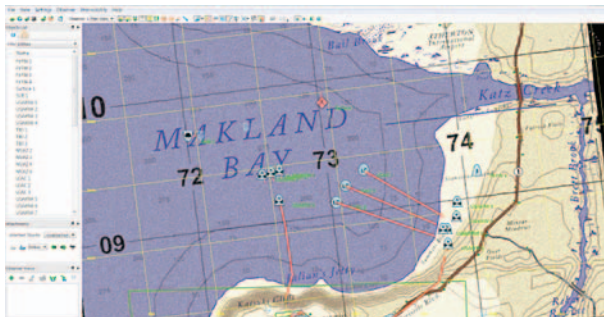

Figure 7: Example VR-Forces Layout

5. MSDL/C-BML and VR-Forces Integration

One of the our purposes in our BML work is to accommodate the growing demand for OpenBML use of C-BML standards and technologies by the Modeling and Simulation and Command and Control communities by providing open source tools such as SBMLServer and BML C2 GUI. We are now considering expanding our open source software to include and interface between MSDL/C-BML and the widely used, comprehensive and complex MÄK VR-Forces.

We are considering an open-source interface to reflect BML operations in VR-Forces. Here, we highlight the high level steps that must be taken to integrate C-BML Light with VR-Forces. Our goal is the arrangement shown in Figure 8.

5.1 Bridging MSDL/C-BML and VR-Forces

The new component we are planning is the open source Bridging Application to be created by the GMU C4I Center.

This software will be written in Java interfaced with C++ so that it can use a set of classes in the VRForces API to interact with the VR-Forces simulator from the BML C2 GUI. As shown in figure 8, the bridging software will be a client of a C-BML server such as SBMLServer. Orders and MSDL are received via subscription to the RESTful version of SBMLServer (subscription to the SOAP is not natively available to C++ clients) either from a standalone Java application, or directly attached to the BML C2 GUI. The bridging software also is a client of the C-BML server so that it can provide reports, for example Position Status Reports. To get reports out of the VR-Forces simulator, we will create an interface message from VR-Forces that will report on the state repository of all entities at a set interval (see section 5.2 below).

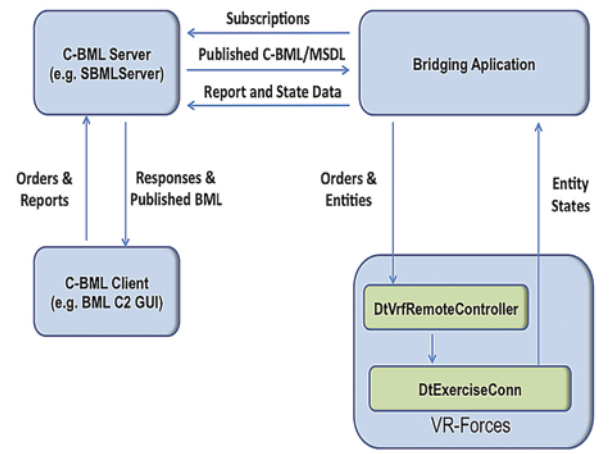

Figure 8: MSDL/C-BML – VRForces Integration Architecture

The Bridging Application will interface with the DtVrfRemoteController class within the VR-Forces Remote Controller API. MÄK provides an example that illustrates how to use the DtVrfRemoteController class so this portion of coding was relatively straightforward to extend its utility. The Bridge Application Software consists of two parts: the C-BML/MSDL side in Java, and the Remote Controller side in C++. The interface between the two sides will employ the terminal input capability of the Remote Controller, without disabling the ability to use the terminal mode for other purposes.

The C-BML/MSDL side receives input via subscription, maps that input to a series of commands for the Remote Controller, directs the Remote Controller to execute those commands, and then returns to listening on the subscription. The majority of interface processing done by the Java side of the Bridge Application Software; it consists of mapping MSDL and C-BML Light Orders to formats used by the Remote Controller interfacing with VR-Forces and mapping the responses back. The Remote Controller includes methods sufficient to implement the definition and execution of the components from C-BML or MSDL, and it also a new batch mode to receive commands from the C-BML/MSDL side. We have verified the utility of this approach by implementing a simple Move command that accepts a C-BML Task input and moves a VR-Forces object.

MSDL information input to VR-Forces will be achieved in the same way as C-BML inputs. Preparation of MSDL instance documents for input to aggregated coalition MSDL, as described in [18], will require that the Bridging Application receive the state information as described in the next section.

5.2 Obtaining C-BML Reports from VR-Forces

The above discussion concerns about sending a BML order from the BML Server through the CBML-VRForces Bridge Application to a unit in VRForces simulation scenario. The other direction of integration clearly involves getting information from the VRForces simulation back to BML Server and client. As illustrated in figure 10, the unit's entity state in the VRForces scenario will be sent back to the Bridging Application, which is, in turn, subscribed with the SBML Publish/Subscribe. Mapping will take place at the Bridging Application to convert VRForces entity state to standard position status BML report understood and supported by the SBMLServer and client. Once a new report is detected by any subscribed client (for example, the BML C2 GUI), the report will be rendered and presented to the client.

To develop this task, periodically, the Bridging Application asks DtExerciseConn about the state of his entities in simulation environment. DtExerciseConn is the class responsible for control all aspect in the simulation, as the scenarios files, time control and other simulations functions.

The information that DtExerciseConn provides is a list of reflection attributes of an entity (like positions in geocentric format, speed, acceleration, conditions of entity, etc.). This

will allow the Bridging Application to extract information needed to create C-BML Reports.

5.3 Integration Plan

The integration will follow these phases of work:

1. The planned first version of the Bridge Application Software will interface with VR-Forces and submit a CBML Light order to VR-Forces in the task format that it expects. This will require that entities referenced by the order be pre-loaded into VR-Forces using their GUI system. This version will subscribe to a RESTful version of SBMLServer. The Bridging Application will support only those C-BML actions matching VR-Forces tasks.

2. The planned second version of the Bridge Application Software will submit entities to VR-Forces from the MSDL received from SBMLServer via subscription. This will require mapping MSDL information to the VRForces entity format.

3. A third version of the Bridge Application Software will create an interface message between itself and VR-Forces. This interface message will report on the state of all entities currently being simulated, at a configurable time interval. This will require adding to the Bridging Application the ability to use the message information to create a C-BML Light position status report. The Bridge Application Software also will become a client of SBMLServer so that it can push these C-BML Light reports.

Figures 9 and 10 illustrate a VR-Forces scenario of a unit that has a task to move along a route. It is using the MILSTD- 2525B symbols in figure 9, while using a 3D display in figure 10. The goal of our work is to create an interface between C-BML/MSDL and such a scenario in VRForces, so that a two-way interaction can happen between the two environments. A BML open source end-user or client can send BML orders, tasks and reports to VRForces through the developed interface. The unit in VRForces will receive the BML order or task and execute

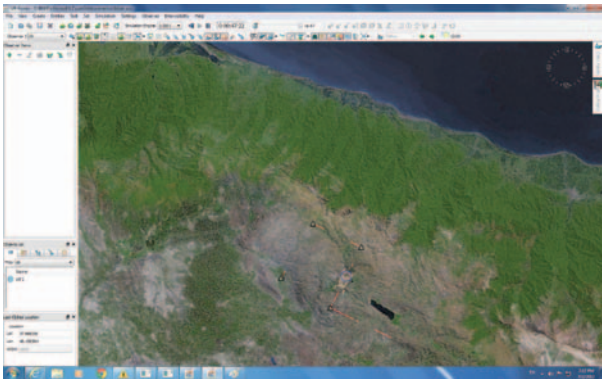

Figure 9: A Unit Moving in VR-Forces

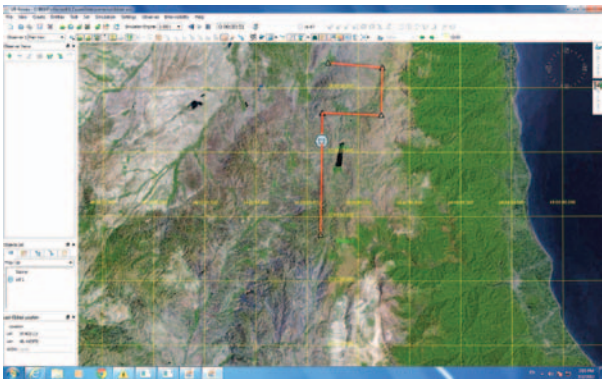

Figure 10: A Unit Moving in VR-Forces

it in a simulation environment, off-course after having it translated from BML format to a format that it can understand through the Bridging Application.

6. Conclusions

In this work we have presented a design for an interface between our open-source BML technology and the commercial simulation software VR-Forces. This interface will enable BML orders and tasks to be executed in the VR-Forces simulation environment. By integrating BML tools and standards with VR-Forces, we expect to synergize open source and commercial technologies by producing an open source C-BML/MSDL interface to VR-Forces. As a result, VR-Forces will be usable by the community investigating C2-simulation interoperation.

REFERENCES

[1] Carey, S., M. Kleiner, M. Hieb, and R. Brown, "Standardizing Battle Management Language – A Vital Move Towards the Army Transformation," IEEE Fall Simulation Interoperability Workshop, Orlando, FL, 2001

[2] Pullen, J., D. Corner and S. Singapogu, "Scripted Battle Management Language Web Service Version 1.0: Operation and Mapping Description Language," IEEE Spring 2009 Simulation Interoperability Workshop, San Diego CA, 2009

[3] Pullen, J., D. Corner and S. Singapogu, "Scripted Battle Management Language Web Service Version 2," IEEE Fall 2009 Simulation Interoperability Workshop, Orlando, FL, 2009

[4] Levine, S., L. Topor, T. Troccola, and J. Pullen, "A Practical Example of the Integration of Simulations, Battle Command, and Modern Technology," IEEE European Simulation Interoperability Workshop, Istanbul, Turkey, 2009

[5] Corner, D., J. Pullen, S. Singapogu and B. Bulusu, "Adding Publish/Subscribe to the Scripted Battle Management Language Web Service," IEEE Spring 2010 Simulation Interoperability Workshop, Orlando FL, 2010

[6] Sun Microsystems, "JAVA Message Service 1.1" April 12, 2002.

[7] World Wide Web Consortium, "XPath Language Version 1.0", November 16, 1999

[8] Pullen, J. *et al*., "An Expanded C2-Simulation Experimental Environment Based on BML," IEEE Spring Simulation Interoperability Workshop, Orlando, FL, 2010

[9] SISO Standards Organization web site; http://www.sisostds.org/StandardsActivities/DevelopmentGroups/MSDLMilitaryScenarioDefinitionLanguage.aspx

[10] Schade, U. and M. Hieb, "Development of Formal Grammars to Support Coalition Command and Control, 11th International Command and Control Research and Technology Symposium, Cambridge, UK, 2006

[11] Schade, U., and M. Hieb. "Battle Management Language: A Grammar for Specifying Reports," IEEE Spring Simulation Interoperability Workshop, 2007, Norfolk, VA

[12] Ababneh, M. and Pullen, J., "Battle Management Language – Command and Control Graphical user Interface (BMLC2GUI)", IEEE Fall Simulation Interoperability Workshop, 2010, Orlando, FL

[13] Ababneh, M. and Pullen, J., "An Open Source Graphical User Interface Surrogate C2 System for Battle Management Language Experimentation", 16th ICCRTS, Québec City, Canada, 2011

[14] US Department of Defense, "Interface Standard Common War fighting Symbology MIL-STD-2525B w/Change 1", July 2005

[15] World Wide Web Consortium, Extensible Markup Language (XML), http://www.w3.org/standards/techs/xml

[16] World Wide Web Consortium, "XML Schema: Formal Description", http://www.w3.org/standards/xml/schema

[17] http://www.mak.com/products/simulate/computergenerated-forces.html

[18] Pullen, J., D. Corner, R. Wittman, A. Brook, O. Mevassvik and A. Alstad, "MSDL and C-BML Working Together for NATO MSG-085," IEEE 2012 Spring Simulation Interoperability Workshop, Orlando, FL, 2012

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Improvement of simulation interoperability by introducing the CBML benefits into the HLA world

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Keywords

Coalition Battle Management Language (CBML), Military Scenario Definition Language (MSDL), High Level Architecture (HLA), Interoperability, Integration, Command and Control, Simulation, Systems Training.

ABSTRACT

The benefits of use HLA (High Level Architecture) standard to federate simulations has provided evidences for many years, especially since 2010 with the new release of the standard (IEEE HLA 1516-2010) and the birth of the NATO reference exchange model NETN (NATO Education Training Network Federation Object Model v1.0).

In some context such as the simulation of orders planned in C2 system, it is necessary to design a way to exchange information between the systems, mainly in automatic process without human operator. The lessons learned from the CBML (Coalition Battle Management Language) standardization works prove that this innovative solution will be the regular way to exchange C2-Simulation information in the next years.

In 2011, the French Ministry of Defense decided to conduct an experimentation to link these two main concepts of the simulation interoperability. To avoid developing for each simulation a new interface including a specific data transfer protocol (such as Web Service, Http RESTfull…), it appears obvious to develop an common CBML-HLA gateway to exchange information with an CBML server and to add to the NETN FOM a dedicated module to transport the CBML data to the simulations. The design of the new FOM module is totally based on the existing CBML specifications (XML schemas) defined by the NATO MSG-085.

The results of this experimentation will be used as an input in the improvement of the NETN FOM managed currently by the NATO MSG-106.

The aim of this paper is to describe the new CBML module, the design of the CBML-HLA gateway, the process of the exchanged data in the involved simulations and the lesson learned of the experimentation conducted in the frame of the major Army exhibition EUROSATORY 2012 at Paris in France.

1 Background

Simulation is now used in many contexts in the military world. From individual education until Computer Assisted Exercise, by way of planning activity, the simulation provides a realistic and secure environment to support military operations.

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However, two main constraints often disturb the use of simulation:

- The first one is the information exchange between Command and Control System (C2) and simulations. For a long time, the problem has been solved by introducing people to transfer manually information from one world to the other one.
- The second one is the interoperability between simulations. As a simulation is an imperfect representation of the reality, it is obvious that a simulation needs to be interoperable with another one in aim to provide a more accuracy and rich simulated world.

The purpose of this paper is to explain how the existing and future standards could help to solve these problems of interoperability of simulation.

2 The definition of the CBML-HLA interface concept

2.1 Benefits of the two interoperability standards

Before analyzing the benefits of the HLA and CBML for the simulation interoperability, it is necessary to take a moment to explain these standards.

The first standard HLA (High Level Architecture) is about the interoperability between simulations.

As its predecessor DIS (Distributed Interactive Simulation), the HLA is designed to support the exchange between distributed simulations. After fifteen years of lesson learnt, this architecture is now a recognized standard all over the world (IEEE HLA 1516-2010, also named HLA Evolved).

Associated with a reference data exchange model (called Federation Object Model), the HLA is an efficient support to federate distributed simulation. The most famous reference model is the RPR-FOM (Real-Time Platform Reference FOM). Since 2007, NATO RTO Modeling and Simulation Group (MSG) has supported the studies about the NATO reference FOM (MSG-068 and now MSG-106). In 2010, the first NATO reference FOM call NETN FOM (NATO Education and Training Network FOM) was created and provides now to the simulation community an enhanced reference FOM including modules such as RPR-FOM, logistics, L16 link…

The second standard described in this section is the CBML (Coalition Battle Managements Language) dedicated to support the interoperability between the simulation world and the CIS world.

At the end of 1990s, the Battle Management Language (BML) was created under the sponsoring of the US Army. In the beginning of 2000s, the BML was enhanced to become the Coalition-BML. In 2004, SISO started the standardization process of the C-BML (a Study Group in 2004 and then a Product Development Group in 2006). In addition, since 2005, NATO RTO MSG has supported study groups about the C-BML (MSG-048 and now MSG-085). The C-BML is not yet a standard but it is already used in many experiments in national, international and NATO contexts.

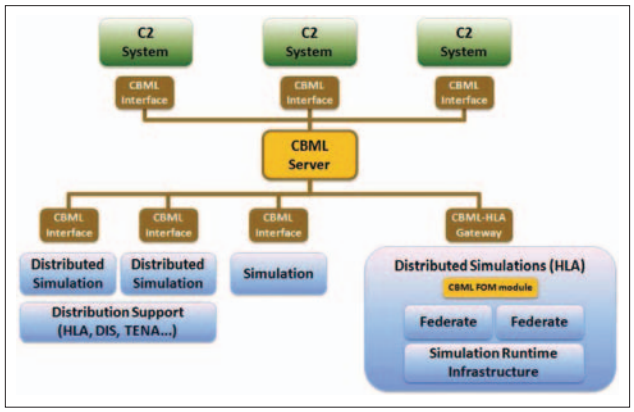
In few words, the C-BML provides a language (vocabulary and grammar) to describe without ambiguity the messages between C2 system and simulations. Different implementations of BML exist and all of them are based on a centralized server and interfaces to the client system (C2 and simulations).

These two standards HLA and C-BML (or almost standard for C-BML) are complementary to provide a simulation environment for military use.

The C2-Simulation exchange process could be summarized as following:

- Redaction of military order in C2 system,
- Sending the order from C2 system to the simulations using C-BML support,
- Simulation of the order in an alone simulation or within a federation of distributed simulations using the HLA support,
- Sending the military report from simulations to C2 system using C-BML support.

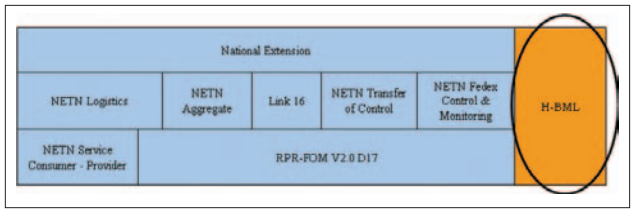
According to this process, each simulation has to develop its own interface to exchange C-BML messages. In the case of distributed simulations using HLA, an alternative solution is to develop a common gateway C-BML - HLA and to feed directly the FOM with the BML messages. This solution is described in the following sections.



2.2 The design of the CBML FOM module

A new FOM module was designed to introduce object and interaction which represent ORDERs and REPORTs BML on HLA. This new module is called HBML for HLA on BML and takes place on NETN FOM.

The NETN FOM is a NATO FOM developed by MSG- 068 to get a common reference model for the interoperability of simulations (logistics, aggregate representation, etc.)



The proposal design of the new experimental FOM module is totally based on this existing CBML specifications defined by MSG-085 (XSD schema). It does not translate the contents of the CBML message, only focus on the transportation of the information.

The benefits of this approach are:

- Few dependence between the H-BML FOM module and the MSG085 reference schema,
- Reduced time to design and maintain the HBML module,
- Filtering possible with Meta Data provided in the interaction (no necessary to process the entire CBML message).

Actually, the H-BML module proposes three interactions:

- MessageBML: Global interaction which describes a CBML exchange. This interaction is only subscribed by a HLA federate.
- OrderBML: Interaction which describes a CBML ORDER. This interaction can be subscribed or published by a HLA federate.
- ReportBML: Interaction which describes a CBML REPORT. This interaction can be subscribed or published by a HLA federate.

Module H-BML	
MessageBML(S)	OrderBML(PS)
	ReportBML(PS)

MessageBML - attributes	Description
OpsHeader	Military header describes the active actors in BML exchanges
BML Content	BML Content

OrderBML - attributes	Description
MetaData	Summary data (MetaDataOrderList) for filter information

ReportBML - attributes	Description
MetaData	Summary data (MetaDataOrderList) for filter information

3 The implementation of the concept

3.1 The architecture of the experimentation

In 2012, France decided to experiment an initial set of components needed to implement the CBML-HLA concept.

The legacy systems used in this experiment are the following:

- SICF, French C2 system used by Joint and Army forces,
- ORQUE, maritime simulation used by the French Navy forces,
- WAGRAM, land simulation including aggregated unit at battalion level.

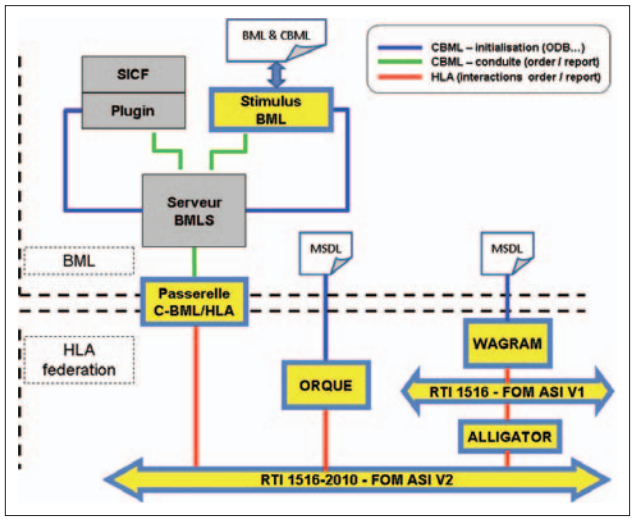
The systems taken on the shelf for this experiment are the following:

- The CBMS server (communication infrastructure provided by US VMASC - Virginia Modelling, Analysis and Simulation Center) to support the CBML exchange,
- The Pitch RTI to support HLA Evolved exchange.

The systems especially developed for this experiment are the following:

- The FOM module H-BML,
- The GATE tool, compliant with the CBMS server and the Pitch RTI, to support the CBML-HLA exchange,
- The Stimulus tools to test and control the BML-HLA process.

The following picture summarizes the architecture of the



experiment, including data flow between the components.

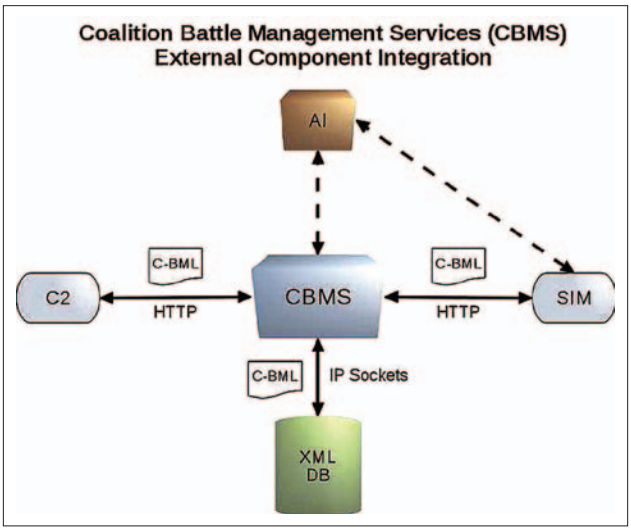
All the systems used during the experimentation were deployed within a local network.

3.2 The CBMS Server and the Stimulus tool

The French experimentation was based on CBMS infrastructure for BML exchanges.

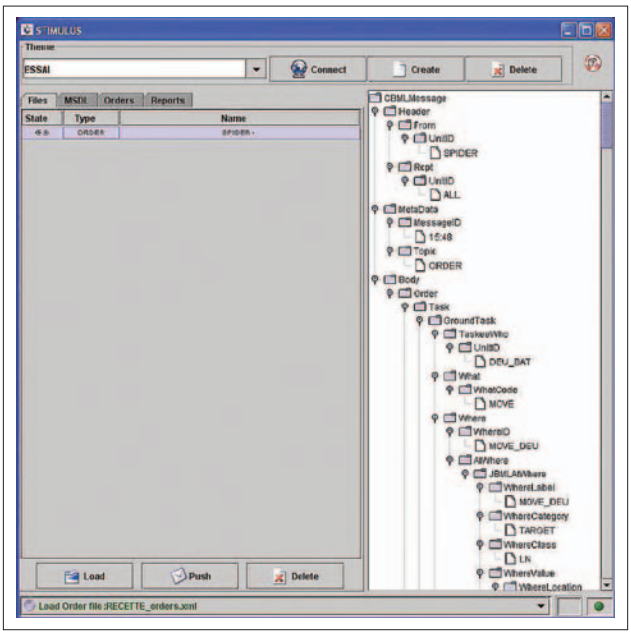
The Coalition Battle Management Services (CBMS) project is a software system that combines a set of RESTful web services along with a XML data storage. This system is optimized for document processing, in order to facilitate automated communication between disparate C2 systems and simulations, and to enable operations on the data (e.g., searching, replaying).

C2 and simulation systems communicate with CBMS via standard Hypertext Transfer Protocol (HTTP) operations: GET, PUT, POST and DELETE. The project currently uses BaseX as its backend data store but implementations with other data stores could be easily done, without modifying the application's interface (AI) to access to the stored documents.



The stimulus tool was implemented to interact with the CBMS server through a graphical interface. The available services are the followings:

- Create/delete a "theme" (storage area),
- Write CBML or MSDL information,
- Read CBML or WSDL information.



3.3 The CBML-HLA Gateway

This Gateway is the component which allows the interoperability between the CBMS server and the HLA federation.

First, the Gateway allows support the exchange of CBML message, in the two ways, between the two worlds (CBML and HLA).

The exchange ensure by the Gateway is the following:

- CBMS side:

BML Message		Type d'action S=Send, R=Receive
CBMS	ORDER	SR
	REPORT	SR

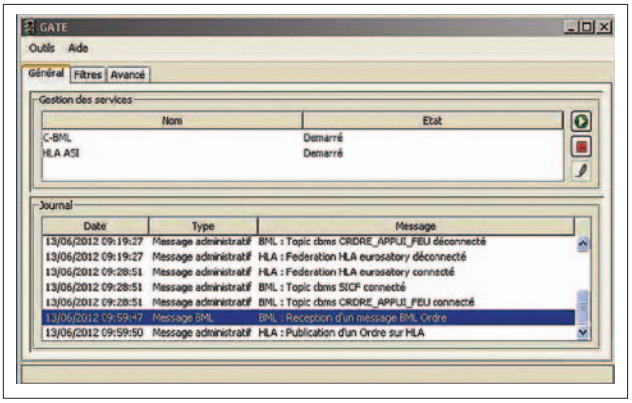
- HLA Federation 1516 evolved side:

HLA Module		Interaction type I = Initiates, S = Sense, R = React, N = Neither
H-BML	MessageBML	N
	OrderBML	IS
	ReportBML	IS

Gateway manages the connection on the two sides through a graphical interface which provides a visibility on the current and past activity:

- Status of connection,
- Journal log

In aim to control exchanges between the two sides, the Gateway allows to set filters to block or confirm the forward of a CBML message from HLA to CBMS or from CBMS to HLA.

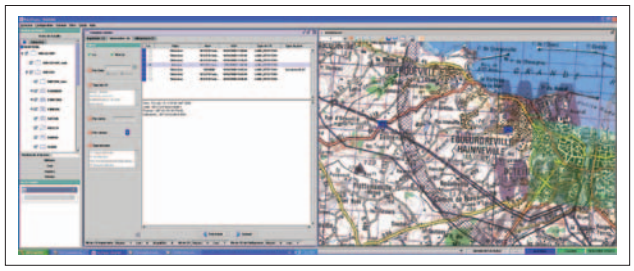


3.4 The Land WAGRAM simulation improvement

WAGRAM is a Land Army and Logistic simulation for Headquarters Staff training, developed in cooperation with the DGA, Joint Defense Staff and Army training centers.

Its main objectives are:

- Stimulation of C2 systems to train Land or Logistics HQ at level of Land Component Commander (LCC), using:
  - Simulation of Brigade missions and Subordinate Battalion/Companies,
  - Simulation of logistic dataflow from theatre entry point to Battlefield units,
  - Automatic or manual generation of ADatP-3 messages (OWNSITREP, ENSITREP, LOGUPDATE, PERSREP…), or equivalent XML messages,
  - Data consistency with C4I systems (ORBAT, terrain data, tactical map, …)
- Design to work in standalone mode or with other simulations (Air, Maritime, Joint) using HLA and ALLIANCE federation (French legacy federation dedicated to military training activity).



Its key features are:

- Small animation team for animation of large Army and opposite forces (more than 100 000 soldiers, up to 10 different sides, complete order of Battle including special forces, city population, refugees and terrain objects such as bridge, road, depot, …);
- Simulation of logistics including repair, supply, health, evacuation of injuries, deaths, refugees by road, rail, air/maritime transport and stocks management at different levels of command;
- Management of Rules Of Engagements (ROE) for the missions of units;
- CBRN site, weapons and effects;
- Tactical terrain pre-processing for road network of large countries, management of itineraries and road traffics.

WAGRAM simulation has been improved to import MSDL ORBAT compliant with the release "Military- Scenario_1.0.0".

WAGRAM has also been improved to process orders from a CIS C-BML order. The actions implemented are "move", "attack", "reconnaissance", "observe", "withdraw" and "Special Forces operations".

WAGRAM implements C-BML reports to send friend and enemy situation to the C2 system.

3.5 The maritime ORQUE simulation improvement

ORQUE is a naval forces training simulation used by:

- Joint staff command headquarters maritime and/or amphibious components: Maritime Command Component (MCC), Combined Amphibious Task Force (CATF),
- Naval force command headquarters: Commander Task Force (CTF) and Commander Task Group (CTG),
- Students of the Navy War College (ESCAN) at the Naval Training Centre (CIN) and students of the High Navy War College (CESM).

ORQUE is used to train and instruct staff officers in planning and carrying out air-sea operations. It provides them with preparation, command and postoperation analysis tools.

The third version was delivered in early 2011, including major performance improvement, enhanced user interface, new models and extended interoperability.

ORQUE simulation has been improved for the current experiment on several ways to implement CBML interoperability:

- **MSDL scenario to bring coherence with data exercise:** ORQUE is now able to import or export is scenario from MSDL files to ensure data sharing about ORBAT, geographical elements of interest and general scenario information (name, time start …),
- **BML ORDERs to simulate action need by SIOC:** ORQUE is able to received BML ORDERs throw his HLA interface and process it. The process of the ORDERS creates automatically the corresponding ORQUE behavior on the different assets to execute the scheduled missions. The simulation operator could modifiy and check the created behaviors but he could also let the execution processing without overriding.
- **BML REPORTs to report about simulation situation:** ORQUE is able to produce some reports about the situation of its assets and to inform C2 system about progress of scheduled missions. The report is pushed to the C2 system by an HLA interaction and then transformed by the HLA-CBML Gateway into a CBML message. Two reports are available: "BFT report" to inform about Friend situation, and "Rens report" to inform about perceived situation of opposite force.

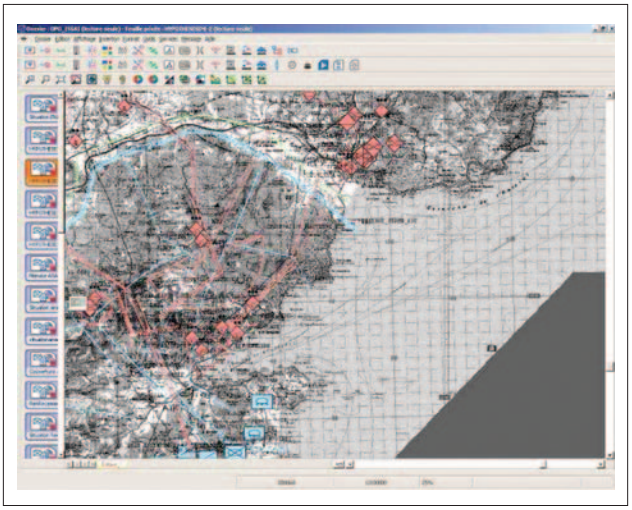
This improvement brings to ORQUE the capacity to exchange with the French Army C2 SICF (or other SIOC compliant with CBML) in the two ways and ensure coherency with data exchanged with it.

3.6 The Army C2 SICF and the CBML plug-in

SICF is the French C2 system used by Joint and Army forces. It is mainly composed of a mailing system and a tactical editor.

The CBML interface called SICF plug-in or Spider is in charge to transform CBML report into tactical spreadsheet compliant with the XML schema of SICF tactical editor.

In the opposite way, Spider is able to translate an order defined in SICF into a CML message format and published it on the CBML server.



3.7 Scenario and experimentation

The scenario is based on the engagement of a Battle Group as an Initial Entry Force in a littoral area (in the South of France) with air and sea intelligence and firesupport.

The Order of Battle is composed of a battalion with three companies.

The game plan of the scenario includes several phases during on one day:

- **Saint-Tropez Peninsula:** landing from maritime vessels and assembly area;
- **Sainte-Maxime area:** ambush in the suburb and destruction of insurgents;
- **Eastern border of Maures mountain chain:** blocking action against a mechanized counter-attack by main enemy forces.

The experimentation was split into three phases during in one week:

- One day for the setting of all components,
- One days of experimentation,
- One days of improvement of some components,
- One days of experimentation,
- One day of analysis and results.

The improvements of component done during the experimentation were about:

- Improvement of graphical interface,
- Update CBML interface due to minor evolution of the XML schemas of the CBML,
- Minor update in simulations to improve the automatic process of the orders.

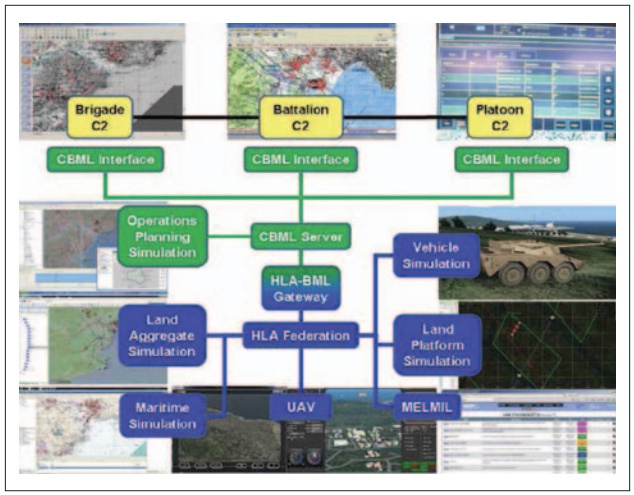
4 Lesson learned and way ahead

The first lesson learnt indicates that the draft FOM module H-BML needs to be improved by:

- Adding communication elements such as Request and Acknowledge;
- Replacing interaction by object for the ORDER in aim of persistency (for federate which joins the federation after the order sending).

The management of CBML in HLA is still studied in NATO MSG106 is aim to improve the representation of message (object or interaction, encapsulated order or explicit task message…).

The HLA and CBML standards were both used later during the VULCAIN experiment, in the frame of the major Army exhibition EUROSATORY 2012 at Paris in France.



The next step will be to experiment this concept in parallel of battalion training exercise, especially in military education center.

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A Practical Application of Interoperability

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Abstract

Interoperability is the focus of most of the work at a standards organization like the Simulation Interoperability Standards Organization (SISO). Thus, it stands to reason that most of the people and organizations involved with SISO have practical applications to demonstrate interoperability to some level, particularly utilizing the standards that they actively support. Recently, we have proposed several solutions to problem areas for interoperability, specifically regarding avoiding the stovepipe solutions, and this paper provides a practical application using those proposals.

In this paper, we examine the concrete application of interoperability solutions provided by the U.S. Army Synthetic Environment (SE) Core program in the context of a real interoperability event conducted at Science Applications International Corporation and other facilities in Orlando, Fla., in the month of December 2011. This event connected the Close Combat Tactical Trainer (CCTT), Aviation Combined Arms Tactical Trainer (AVCATT), SE Core One Semi-Automated Forces (OneSAF®, Department of the Army), and various SE Core products. We will discuss lessons learned and actions taken during the planning process of scenario generation through exercise debrief and present a detailed analysis of the test event results.

The U.S. Army Program Executive Office for Simulation, Training, and Instrumentation (PEO STRI) initiated the SE Core program. This contract is tasked with developing a virtual simulation architecture (VSA), common virtual components (CVCs), virtual-capable semi-automated forces (SAF), databases, and common moving models (CM2) with the goal of providing the warfighter with enhanced training by increasing interoperability between training systems, increasing the reuse of products developed for training systems, protecting the investments made in developing current virtual training simulations, and increasing the adaptability and extensibility of the virtual training simulations that are developed to enable the easy incorporation of new features.

1 Introduction

THE PURPOSE OF THIS PAPER IS TO PRESENT A PRACTICAL APPLICATION OF INTEROPERABILITY BY DESCRIBING AN EXERCISE PERFORMED BY THE SYNTHETIC ENVIRONMENT CORE (SE CORE) PROGRAM. THIS EVENT TESTED THE INTEROPERABILITY CAPABILITIES BETWEEN SE CORE ONESAF® (DEPARTMENT OF THE ARMY), CLOSE COMBAT TACTICAL TRAINER (CCTT), AVIATION COMBINED ARMS TACTICAL TRAINER (AVCATT), AND VARIOUS OTHER PRODUCTS FROM SE CORE AND THE OTHER PROGRAMS, SUCH AS GATEWAYS AND TACTICAL INTERNET TRANSLATION APPLICATIONS.

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FOR THIS TEST EVENT, WE DIDN'T FOLLOW THE DISTRIBUTED SIMULATION ENGINEERING AND EXECUTION PROCESS (DSEEP), BUT WE WILL RELATE THE STEPS TO THE DSEEP STRUCTURE RETROSPECTIVELY SO THAT KNOWLEDGEABLE READERS CAN APPRECIATE HOW THE PROCESS COULD BE APPLIED FOR IMPROVED INTEROPERABILITY. DSEEP IS A STANDARD OFFERED BY THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS (IEEE) AND WAS DEVELOPED BY THE SIMULATION INTEROPERABILITY STANDARDS ORGANIZATION (SISO) AS A RECOGNIZED SPONSOR COMMITTEE. [1]

1.1 Test Events

This event was not a training event and was not conducted by training operational personnel. The purpose was to evaluate against known CCTT and AVCATT training objectives the interoperability capabilities between the three core programs: AVCATT, CCTT, and SE Core. For the purposes of this paper, however, we will present it using a standard training exercise structure, so that it can be easily related into well-defined and established processes, and the data presented can be readily understood.

1.2 Synthetic Environment Core

The U.S. Army Program Executive Office Simulation Training, and Instrumentation (PEO STRI) SE Core program is supporting the training of our warfighters by providing a common virtual environment (CVE) that links system and non-system simulations into a fully integrated and interoperable training capability. The SE Core concept includes the development of a virtual simulation architecture responsible for providing the warfighter with enhanced training by increasing interoperability between training systems, increasing the reuse of products developed for those training systems, protecting the investments made in developing current virtual training simulations, and increasing the adaptability and extensibility of the virtual training simulations that are developed to enable the easy incorporation of new features. [2][3][4]

2 Exercise Planning

Step 1 of the DSEEP process is to define the simulation environment objectives. This relates to exercise planning in general and encompasses identifying the participants (players), defining the objectives themselves, and the administrative aspect of establishing the exercise schedule. Because this is a test event and not an actual exercise, we have inserted a step to define the evaluation criteria of the testing.

2.1 Identify Players

Identification of the participants was relatively straightforward for this test event, which is why it was performed at this stage instead of Step 3 as indicated in DSEEP. The goal was mostly predetermined, thus effectively choosing the players as CCTT, AVCATT, and SE Core. As will be evident in the scenario definition and asset assignment, CCTT provides the ground manned module (MM) capabilities while AVCATT provides the air MM capabilities. SE Core provides the virtual computer generated forces (CGF) and exercise support, as well as several additional capabilities. CCTT and AVCATT similarly provided support and the facilities housing their training simulators.

2.2 Define Objectives

OneSAF was approved for fielding in both CCTT and AVCATT prior to this event, but approximately one year prior to CCTT fielding AVCATT had taken and then modified an earlier baseline to get to an earlier fielding date. Because of this early branch, there are significant differences in capabilities between the CCTT and AVCATT versions. AVCATT program has modified the OneSAF system to enhance the air and air defense capabilities (no updates were made to the ground assets) in order to fit their needs and training objectives. On the other hand, SE Core and CCTT worked in the current baseline and made significant enhancements to ground domain assets and several core capabilities (e.g., obstacle avoidance, dynamic terrain, damage, tactical smoke, perceptions). The AVCATT changes will be merged back into the SE Core baseline in 2012, rectifying the differences as AVCATT then steps up to a merged version.

The objective of this test event is therefore to determine the state of interoperability between the CCTT and AVCATT systems, as integrated with their versions of SE Core OneSAF. The intent was to test most of the capabilities and look for artifacts on the MM visuals, after action review

(AAR) visuals, planned view display (PVD) visuals, and AAR reports. We tested as many of the capabilities of both systems as time permitted, including voice communications, digital communications (command, control, communications, computers, and information [C4I]), and of course simulation interoperability.

2.3 Define Evaluation Criteria

Because this was an evaluation event and not a training event, we defined the evaluation criteria for determining the state of interoperability. We didn't need a threshold for success, as training success is determining by the training systems themselves, namely CCTT and AVCATT, for their specific training objectives. We didn't have training objectives; therefore our criteria were geared towards interoperability parameters as listed below:

- Terrain database correlation – the terrain database represented on the MM must match that as represented in the AAR stealth display and the PVD for each of the operator's station
- Voice communications – personnel in the manned modules must be able to communicate with each other and with SAF roleplayers; this includes therefore both tactical voice and simulation control (admin)
- Tactical digital communications – the tactical systems located in each of the MM need to communicate with each other and with standalone or external systems, including the SAF systems
- Entity comparison – the visual models for the platforms and static objects must match those on either system, including articulations and weapons' fire or other special effects
- Semi-automated forces (SAF) actions – determine how consistent and accurate the SAF behaviors are visualized in and respond to the two virtual systems
- Damage consistency – vehicular and environmental damage must be represented consistently across all of the 3-D visuals, and described accurately on the PVD

Each of these parameters will be discussed further in the results and qualified or quantified with respect to establishing a state of interoperability. There are certainly other potential evaluation parameters to consider (e.g., weather, engagement speed, perception ranges), but we were limited on time, personnel, and equipment access.

2.4 Establish Schedule

This is an important step in the actual execution of the test event, but surely won't interest external reviewers. The actual schedule will not be identified here, but the basic steps at the point of the event are setup, a series of dry runs including C4I testing, motor pool review, one day for the test itself, and then data analysis and reporting. The test event occurred on 15 December 2011.

3 Design, Construct, and Test

Steps 2 through 5 of DSEEP are mapped into the same phase within the context of a DIS exercise as indicated in the DSEEP annex. This is the design, construct, and test exercise phase. These specific steps are further mapped in the following subsections.

3.1 Scenario Generation

Step 2 of the DSEEP process is to perform a conceptual analysis, which includes developing the scenario and conceptual model. Whenever you build a scenario, you have to do so with respect to the lowest common denominator (lowest fidelity capability) from the involved participants.

3.1.1 Coordinate Control of Forces

Friendly air and air defense assets were controlled by the AVCATT OneSAF baseline. Friendly ground assets were controlled by the CCTT OneSAF baseline. All opposing and neutral entities were split between the physically separated systems so cross engagement activity may be evaluated.

3.1.2 Define Scenario

Typically an exercise scenario is defined by the trainer (commander) to meet specific training objectives. Because our purpose was to facilitate a test, we tried to design a scenario that would best support the testing activities. It was therefore decided that the demonstration scenario would have three operational phases to be executed sequentially:

1. Small test vignette with AH-64D Manned Module issuing a call for fire request on targets to artillery simulated on the CCTT OneSAF baseline.
2. The AH-64D MM will link up with an M2A3 platoon (led by the CCTT MM) to provide security for a supply convoy moving through an urban area.

3. Both the M2A3 and AH-64D manned modules provide security at the convoy destination while supplies are being unloaded.

We created a scenario for each virtual training system OneSAF baseline to be executed in tandem. From evaluating limitations of each system, we determined that the demonstration scenario needed to contain no more than 144 entities. This limitation is derived from the AVCATT functionality of removing entities from the visual scene of the MM within a ten-kilometer radius based on a priority scheme that ensures that flight performance is not impacted during runtime. We decided that allowing the system to remove entities (even though based upon system-specific priorities) would unnecessarily complicate the evaluation for purposes of interoperability; therefore, we avoided the issue by purposefully using a lower entity count. Thus, including the manned modules, there are 74 entities controlled by CCTT and 70 controlled by AVCATT.

In addition, we created six sets of duplicate scenarios using both baselines (i.e., 12 total scenarios). Each scenario (informally referred to as a "motor pool" scenario) contains entities displayed in north-to-south columns on flat terrain (an airfield) in the Ft. Bliss database. A screenshot of the motor pool scenario is shown in Figure 1. When each set of scenarios was loaded and "executed" (no behaviors or movement) in the AVCATT and CCTT systems, the result was a single exercise with two identical rows of entities that could be compared side-by-side using the PVDs, stealth, and out-the-window (OTW) visuals on both systems. This testing was broken out into two sets: group one for those entities identified by AVCATT as functionally tested, and group two for the remaining entities supported by SE Core. Unlike in the main test scenario, these entity comparison tests were performed on as many of the available visual models as possible. The SE Core master entity list (MEL) provides 456 entities with corresponding visual models that we identified as being useful for this testing. We eliminated from contention those entities belonging to a post-fielding effort, those explicitly defined to support MM ownships, flyout munitions, and relocatable terrain features.

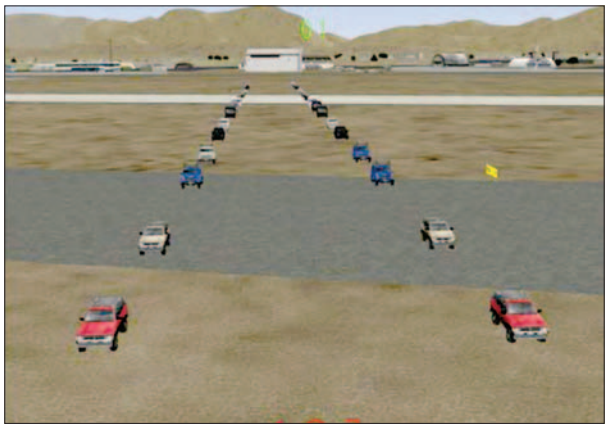

Figure 1. Motor Pool Scenario

3.1.3 Define Tactical Digital Communications

The virtual manned modules have the capability to transmit and receive various joint variable message format (JVMF) tactical data link messages. These include furnishing automated location updates to support situational awareness (SA) or requesting fire support from artillery by requesting a call for fire. The JVMF message tests were only conducted against Software Block II (SWB2) formats. To facilitate the testing of these messages, the demonstration scenario included tactical message tests.

A total of 30 of the scenario entities (including the manned modules) are digital-capable. None of the opposing or neutral forces have a tactical representation and not all of the friendly forces have this capability, either. For example, most of the logistic vehicles do not have tactical support. The digital capabilities include Force XXI Battle Command Brigade and Below (FBCB2), Blue Force Tracker (BFT), and Advanced Field Artillery Tactical Data System (AFATDS).

3.1.4 Define Voice Communications

Tactical and administrative voice capabilities were configured to be used on each of the four types of stations (CCTT AAR/SAF operator, CCTT MM, AVCATT SAF or battle master controller (BMC) station, and AVCATT MM). The radios were configured for plain text (unencrypted) and setting the power amplifier to the highest setting without use of the signal degradation (attenuation) database. This configuration should maximize the interoperability.

3.1.5 Establish Operator Assignments

Two SE Core personnel were assigned to the CCTT and AVCATT facilities to control the SAF operator stations, stealths, AAR, and controller workstations. One person was responsible for all of the applications at each site.

Two more SE Core personnel were assigned to the CCTT M2A3 MM (one driver, one commander/gunner). A retired U.S. Army aviator was assigned as the AVCATT AH-64D pilot. Additional people from AVCATT, CCTT, and SE Core were available during the whole process to help set up the facilities and provide support. Members of PEO STRI and the U.S. Army Training and Doctrine Command (TRADOC) Capabilities Manager – Virtual (TCM-V) were also present to witness the testing on the final day.

3.2 Content Creation

Steps 3 and 4 of the DSEEP process are to design and develop the simulation environment. For the most part, this has been accomplished already, as you would expect, understanding that this is just a test evaluation event.

3.2.1 Database

Two terrain databases were used in scenarios during the test event. These included parts of Afghanistan and areas surrounding Ft. Bliss near El Paso, Texas. These databases were provided by SE Core. We included the Afghanistan database to demonstrate that uncorrelated databases will show anomalies such as floating and burrowing.

3.2.2 New Entities and Units

Depending on the goals of the exercise, new entities and units may be required. Indeed, training with and against new platforms, weapons, and environmental capabilities is a common reason for establishing an exercise. For our test event, however, nothing new was needed. Our objective was to test the existing capabilities and not new ones as needed for training.

3.2.3 Data Products

Data products are generated for the C4I devices, including the FBCB2, BFT, and AFATDS. As you can see from Figure 3 in the next section, several C4I capabilities were tested during the event and thus data products were needed. However, we didn't acquire new ones just for this event, as may normally be done for a specific training exercise. We used preexisting data products for the Digitized Army United States message text format (USMTF)/variable message format (VMF) Stimulator (DAUVS) system and the CCTT internal MM capabilities. We also used preexisting data products for the AVCATT systems.

3.2.4 Maps / Handouts

For training events, details maps and other handouts are used as part of fulfilling the objectives. Because this was

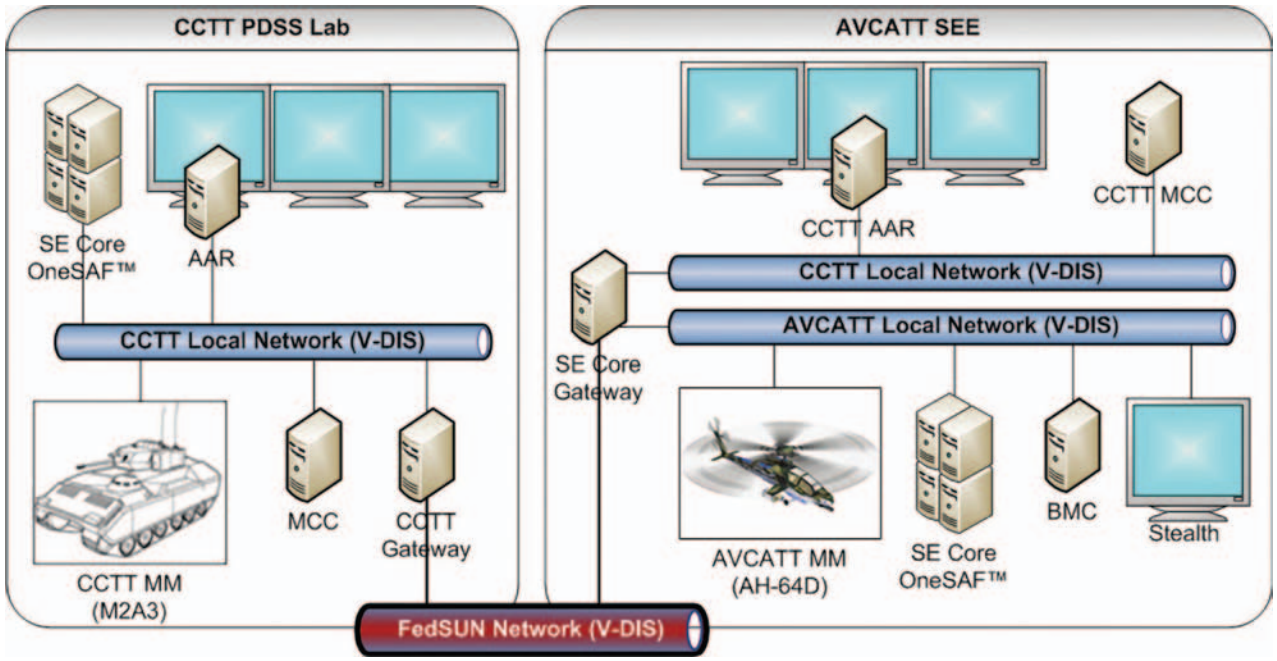

Figure 2. Simulation Network Diagram

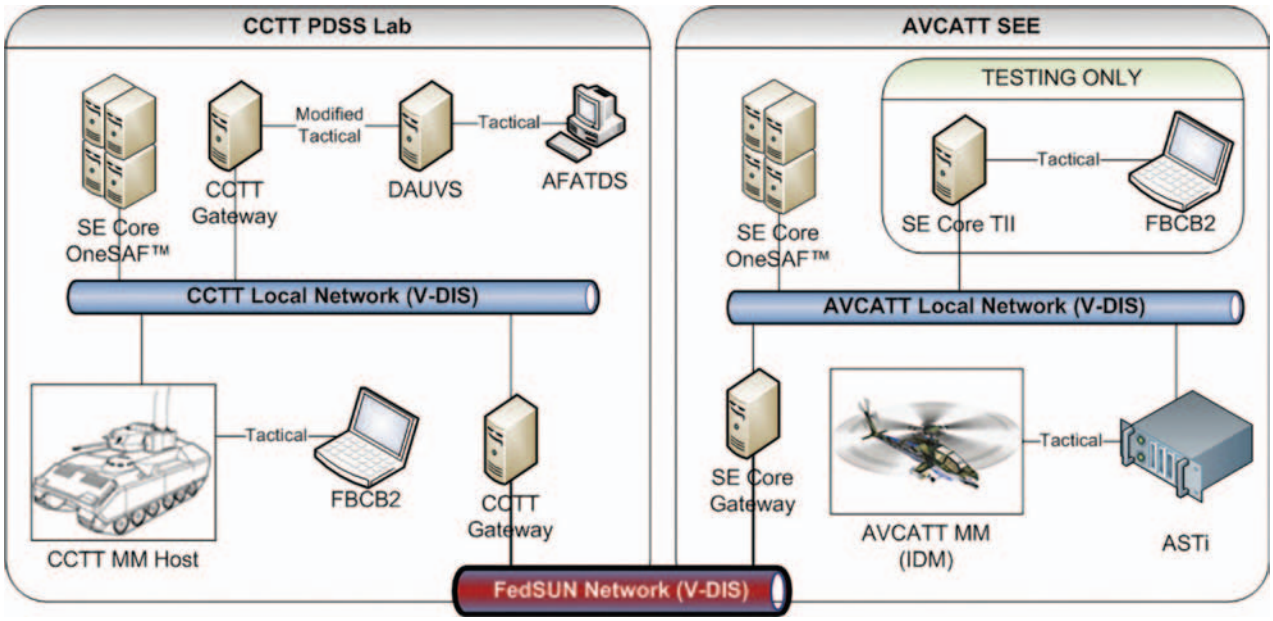

Figure 3. Digital Communications Network Diagram

only an evaluation exercise, we didn't generate any paper products to be distributed to the support personnel.

3.2.5 Distribution of Materials

At some point as defined by the schedule, all of the materials generated or collected to use for the exercise are distributed to the exercise participants. These aren't just the paper products; they include all of the visual models as necessary, terrain databases, scenario files, software, and C4I data products. Each participant might be responsible for acquiring the materials on their own or the products could be distributed directly from a third party.

This step in the process can become particularly complicated for exercises with a classified level and especially with a cross-domain exercise (multiple level security classifications). Regardless, however, the processes and procedures are usually well established for these types of setups.

For our test event, the databases, visual models, C4I data products, and necessary software updates were already available on the test systems. The scenarios were generated in our SE Core software integration lab and hand-carried to the two test sites (CCTT and AVCATT) during the dry runs. Minor modifications to the scenarios were made during the dry runs and the final versions were brought back to the SE Core file repository.

3.3 Asset Assignment

Step 5 of the DSEEP process is to plan, integrate, and test the simulation environment. This certainly includes dry runs and is related to the area of asset assignment.

3.3.1 Define Network Diagrams

We have separated the network diagrams into three functional areas for readability. The first diagram as shown in Figure 2 highlights the major components used in the main demonstration scenario from both the CCTT post-deployment software support (PDSS) lab and the AVCATT systems engineering environment (SEE) lab.

The primary CCTT assets consist of an AAR station (both 3-D and PVD visuals), SAF and CGF workstations running SE Core OneSAF, a CCTT M2A3 MM, a CCTT gateway workstation, and a CCTT master control console. All of these devices are connected to the local network communicating via a dialect of distributed interactive simulation (DIS) called V-DIS, for virtual DIS. The data packets are transmitted between the labs over the Federal, State, and University Network (FedSUN) also using V-DIS, forming a small wide area network (WAN). The assets in the AVCATT Software Engineering Environment (SEE) are segregated onto two separate local networks, one containing some CCTT assets and the other for the AVCATT-specific assets.

Another CCTT AAR is located in this lab because it is here where the side-by-side "motor pool" and database correlation comparisons are made. An MCC is needed to support the AAR (see section 3.3.2 for more information). On the AVCATT local network are the AVCATT AH-64D MM, SAF and CGF workstations running SE Core OneSAF, a stealth, and the AVCATT BMC workstation. An SE Core gateway connects both local networks to each other and to the FedSUN network.

Figure 3 shows the digital communication network diagram to support tactical messaging. An additional CCTT gateway is used in the CCTT PDSS lab to connect to the DAUVS application. The gateway and DAUVS communicate using a modified tactical messaging schema and then the DAUVS system communicates using actual tactical to the AFATDS station. The FBCB2 in the manned module communicates directly to the CCTT MM host computer, which is able to interpret the tactical messages and retransmit them on the V-DIS network. Another gateway then communicates these messages on the FedSUN network to the AVCATT SEE. The AVCATT system uses an ASTi[1] device to translate the V-DIS digital messages into tactical messages that can be processed by the manned module's internal improved data modem (IDM). Although not used in fielded training configurations, the SE Core tactical Internet interface (TII) application is used during testing at the AVCATT SEE to communicate with an external FBCB2. This is represented in the diagram, though it wasn't part of the exercise described in this work. In both labs, the SE Core OneSAF distribution is able to process the tactical V-DIS messages directly. It's interesting to point out that this diagram can be easily modified to support linking to an external live tactical device by connecting a similar DAUVS application to the CCTT gateway and the tactical network.

Figure 4 shows the voice communication network diagram. Voice is handled very similarly to digital C4I messages in both systems. The CCTT single channel ground and airborne radio system (SINCGARS) radio devices connect directly to the CCTT MM host computer, which packetized the voice into V-DIS packets. In the SEE, the AVCATT system obtains its voice translations via the same ASTi system.

3.3.2 Configure Assets

In order to support digital messaging in the AVCATT system, we needed to include a situational awareness (SA) server entity in the AVCATT-based scenario. This entity is actually a high mobility multipurpose wheeled vehicle (HMMWV) variant as visualized in the CCTT visuals. This entity also needs to be assigned a uniform resource number (URN).

We configured the CCTT AAR within the AVCATT SEE lab by connecting it to the SE Core gateway. Originally, it was planned to use the CCTT gateway, but a hardware failure caused us to try an expedient workaround. The SE Core gateway functioned superbly. Additionally, in order to initialize the CCTT AAR, a dummy scenario needed to be run on a SAF workstation, although the network diagram doesn't have that SAF workstation.

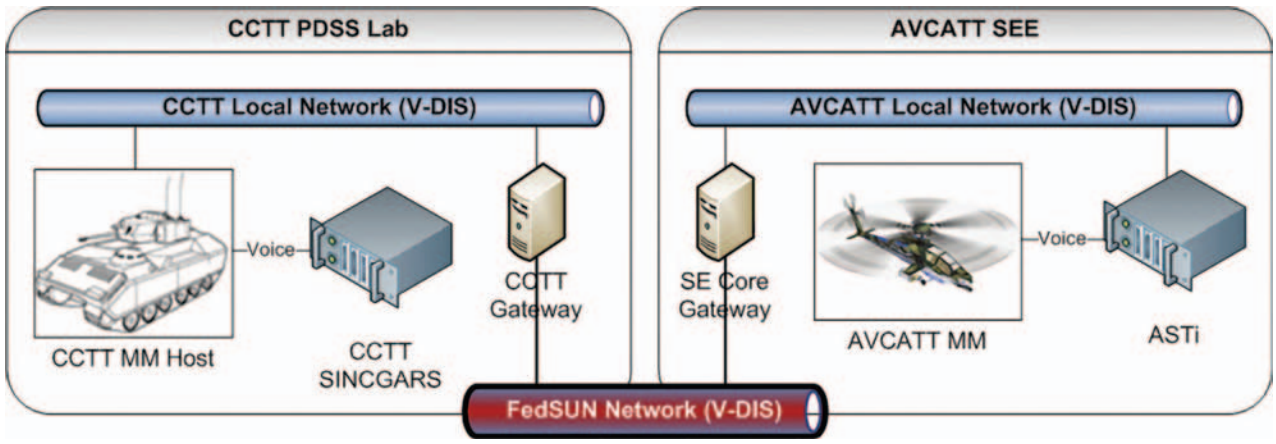

Figure 4. Voice Communications Network Diagram

[1]Advanced Simulation Technology, Inc. (http://www.asti-usa.com/)

3.3.3 Define Simulation Management Approach

At the beginning of the SE Core effort to integrate OneSAF into both CCTT and AVCATT systems, it was decided to defer establishing a common simulation management (SIMAN) approach until a following phase. AVCATT and CCTT are therefore initialized and simulation-managed via different protocols. The SE Core OneSAF baseline was modified to support both the legacy CCTT and AVCATT SIMAN network protocol structure and system design. The caveat for this testing is that neither the AVCATT simulation manager nor the CCTT simulation manager can control (start, stop, pause, resume, checkpoint, etc.) each other. In order to synchronize the start of each exercise at the physically separate sites, we used a phone call with a countdown. This was necessary because even the simulation-based voice communication is not functional until exercise start. What made this even more complicated is that the two systems do not initialize or start within the same timeframe, so the start time of one needed to be estimated based on the slower start time of the other.

4 Execute and Collect Data

Step 6 of the DSEEP process is to execute the simulation environment and prepare the outputs. For our purposes, this simply means enabling the data capture devices and performing the exercise with the involved participants.

The planning, assignment of assets, dry runs, and preliminary assessments were made over the course of a little over a week prior to the test. The test itself took less than a day. The results of the testing are presented in the next section, but the analysis of the traffic will be presented here.

As explained previously, the demonstration scenario itself is not large, containing only 144 entities. We captured data from the SE Core gateway located in the AVCATT SEE because it was the single point that could view traffic on all three local area networks (LANs), albeit the CCTT LAN traffic was only seen by what it sent out over the FedSUN line. Figure 5 shows a graph of the number of packets received per 10-second interval over the course of the approximately 70-minute exercise for the two main networks (the AAR traffic is not important for this analysis as it is mostly a consumer).

We captured the local startup traffic on both networks and you can see a steep rise at the beginning and then stabilization throughout most of the exercise. About two-thirds of the way through, the traffic experienced a spike and then a significant drop. This was the point in the scenario of

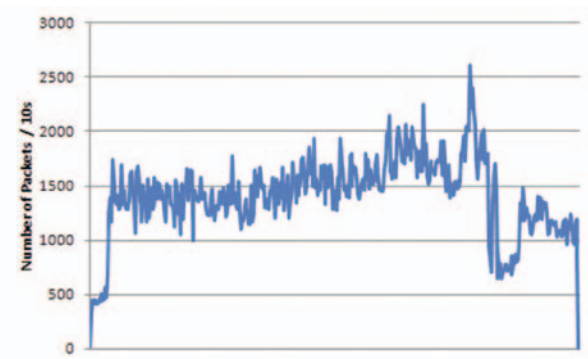

Figure 5. Number of PDUs Received / 10s

heaviest engagement and, in our experience, is a normal occurrence. Our scenario had light engagement activities, but others might show a much more pronounced spike and subsequent drop as large numbers of entities are destroyed and stop producing so much ancillary data and routine but time-intensive entity traffic.

The gateway is also able to capture data by protocol data unit (PDU) type as shown in Figure 6. This column chart clearly demonstrates the dominance of the Entity State PDU

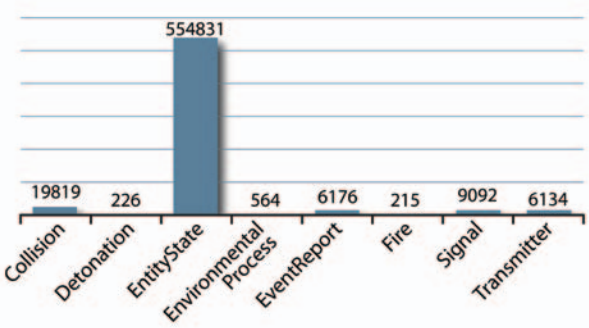

Figure 6. Number of Packets Received by PDU Type

during an exercise. It's also interesting to note that the next highest PDU type issued is the Collision PDU. Whenever an entity collides with another entity or a terrain object, then a Collision PDU is transmitted, and the collided entity / object responds with a similar PDU to acknowledge the

collision. The chart therefore suggests that approximately 10,000 collisions occurred during this exercise.

We can look at this data received during the course of the exercise by PDU type as well. In Figure 7 we present a graph of the simulation data traffic, meaning not the SIMAN or radio communications. Also, we removed Entity State PDUs due to their dominance (it would be impossible to see the remaining lines). As expected, there are a lot of collisions and the Detonate PDUs closely follow and correlate with the Fire PDUs. An interesting observance can be made, however, in the lower left, independent peaks. These represent the Point Object State PDU issuances and illustrate that few changes are made during the exercise and they are not heartbeated.

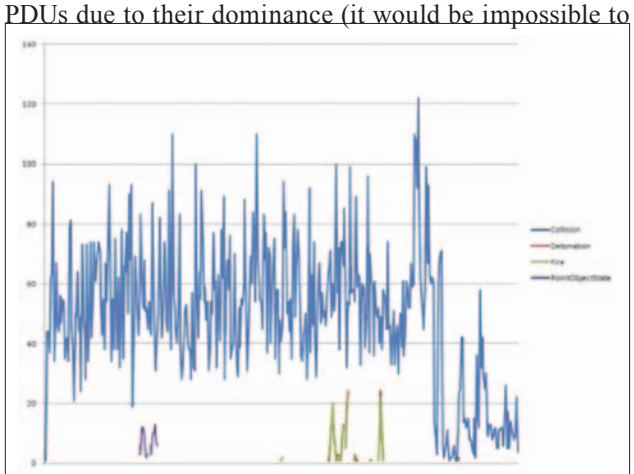

Figure 7. Number of PDUs Received / 10s by Type

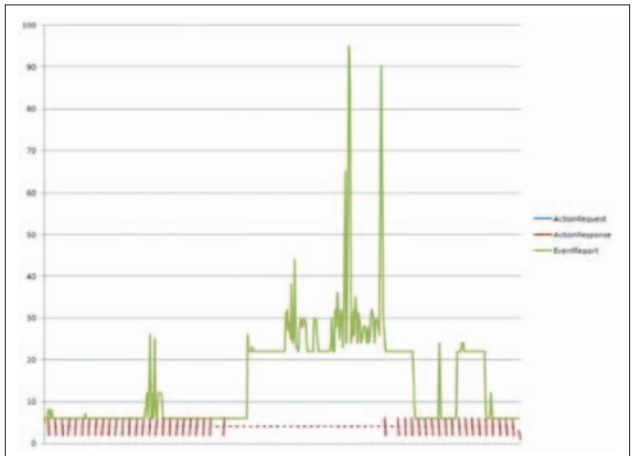

Figure 8. Number of PDUs Received / 10s (SIMAN)

Conversely, a plot of the SIMAN functions that contribute the most to the traffic accumulation shows a very regular distribution of packets. The large spikes are Event Report PDUs and correspond to the main engagement point in the scenario. Other SIMAN capabilities such as Start / Resume, Data, and Data Query PDUs are not shown because they are too few and contribute insignificantly to the overall traffic.

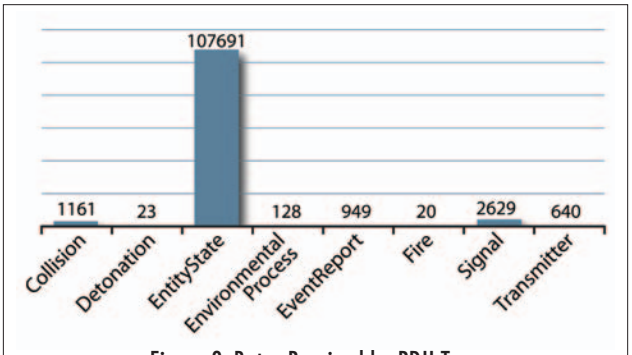

Figure 9. Bytes Received by PDU Type

The plot in Figure 9 of the number of kilobytes captured shows a similar trend to Figure 6, but with a smaller footprint for the PDUs like Transmitter and Collision that don't really have a lot of data. Although there are fewer than half the number of Signal PDUs as there are Collision PDUs, Signal has more than twice the amount of data.

5 AAR and Debrief

The final step (7) of the DSEEP process is to analyze the data and evaluate the results. This closely matches our view of acquiring the after action review data, reviewing the reports, and evaluating the collected data with regards to the defined test objective.

5.1 Database Correlation

We selected random locations in each of the terrain databases to evaluate correlation. These were towns, airfields and other tactically advantageous terrain locations. Entities (moving platforms) were then placed at these locations and given routes to traverse or some other stationary behavior.

The Ft. Bliss database correlation errors (if present) were identified to be within a foot for all locations. Also, some of the high-fidelity details such as street signs and traffic lights were present in the CCTT database, but not in the AVCATT version. This was expected due to database-thinning performed for the AVCATT database to support further viewing distances.

The Afghanistan database had significant inconsistencies in correlation and was deemed unusable for the demonstration scenario. The databases are different between the two systems due to different source data, processes, and software baselines for production. Figure 10 is a screen capture from the CCTT AAR image generator (IG) and

Figure 10. Floating M1A2 in AAR IG

Figure 11. Sunken T-80 in Stealth IG

illustrates one of the examples of the correlation errors found in the Afghanistan database. The M1A2 entity on the right is being modeled by the AVCATT OneSAF baseline and is floating about two meters above the terrain. The T-80 tank on the left is located properly and was being modeled by CCTT. Similarly, the second picture in Figure 11 shows a screenshot from the AVCATT stealth. Note how the T-80 is sunken while the M1A2 is correct.

5.2 Voice Communications

Tactical and administrative radio voice communication was verified via a radio check with a slow count from one to ten. This is performed from each of the four types of stations to each of the other stations. Clarity of the transmission is then noted by the listener. Communication from the two CCTT systems to either AVCATT system was clear, but the voice was very faint. On the other hand, communication from AVCATT to CCTT was full of static and difficult to understand. It is noted, however, that CCTT uses a modified, proprietary continuously variable slope delta (CVSD) modulation protocol. For interoperability, AVCATT downgrades their internal voice communications from pulse code modulation (PCM) 8-bit mulaw (G.711) by using the military standard CVSD protocol (MIL-STD-188-113).

5.3 Tactical Digital Communications

Table 1 identifies the success (✓), failure (⊘), or partial success (◗) for each of the tested JVMF messages (K-series). An empty cell in the table indicates that the capability wasn't available or simply not tested. A partial success means that there was some degradation in the message, but it was not a total failure (for example, the originator URN might not be properly filled out). Not all messages have applicable use cases, so the table might seem sparse.

The data products available to virtual fielding baselines do not match. As noted previously in section 3.2.3, we did not acquire new data products for this event. Some commonality does exist between the data products available; however, the user does not have a tool that can look through the data products to determine what URNs are common enough to support digital communications capabilities. Instead, this determination was performed manually using text editors.

5.4 Entity Comparison

Upon reviewing the motor pool scenarios, the discrepancies noted were categorized as either major or minor. Major issues are those that would cause a behavioral change in SAF or virtual operators, such as displaying the wrong entity (a tank instead of an armored utility vehicle) or not displaying significant visual cues such as flames or smoke. For entities that are typically nonviolent, such as animals or unarmed civilians, these significant visual cues were

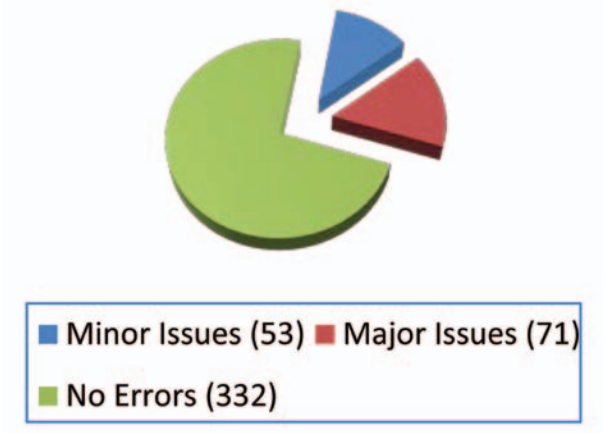

Figure 12. Motor Pool Entity Comparison Issues

still considered a minor anomaly. We understand, however, that specific training objectives could make these entities more important than this classification would imply. For example, dead animals could be used to hide improvised explosive devices (IEDs) and a civilian sedan of a certain color could be the target of a cordon and search operation. Figure 12 is a pie chart illustrating the total number of entities tested broken up into the three categories of minor issue, major issues, and no errors.

Detailed in Table 2 are several of the minor issues to provide a sample of what types of errors were noted. Table 3 lists several of the major issues. Note that if there are multiple errors, the severity of the worst takes precedence. For example, with the M997 HMMWV ambulance, not having the Red Cross markings on the white or tan versions of the entities is only minor. However, not displaying significant visual cues such as flames or smoke is a major issue. In fact, this particular error occurred on many of the entities with major issues.

Entity	Issue
BTR-60 Command Post	Deployed vertical antenna in AVCATT; none in CCTT
Light Points	No CCTT AAR PVD symbols
ZU-23-2	When mobility damaged, wheel base disappears causing the entity to appear to be floating in the air
M-60 AVLB	Bridge disappears when set to firepower kill
Stryker M1129	No visual animation for 120mm mortar indirect fire engagements, but audio is present on the MM

Table 2. Minor Issues from Entity Comparison

Message \ To/From	AVCATT MM to CCTT MM	CCTT MM to AVCATT MM	AVCATT MM to CCTT SAF	SAF to MM	SAF to SAF
K01.01 Free Text	✓	✓	✓	✓	✓
K01.03 Info Request Message	◗	⊘			
K02.01 Check Fire			✓		
K02.04 Call For Fire			◗		
K02.06 Observer Mission Update				✓	✓
K02.12 On Call Fire Command			⊘		
K02.14 Message to Observer				✓	✓
K02.16 End of Mission & Surveillance			✓		
K02.22 Subsequent Adjust (Check Fire)			✓		
K02.37 Observer Readiness (OBSTAT)			✓		
K04.01 Spot/Salute Report	◗	✓	◗	✓	✓
K05.01 Position Report	✓	✓		✓	✓
K05.14 Cdr's Situation Report (SITREP)	◗	✓			
K05.19 Entity Data Message	◗	✓			

Table 1. C4I Testing by JVMF Message Type and Destination

5.5 SAF Actions

Due to the difference in SE Core OneSAF branches, AVCATT has updated air asset behaviors and mobility while CCTT has updated ground capabilities. For example, even through the gateway and remote site the movement of the AVCATT-modeled air entities looks better on the CCTT AAR than the CCTT-modeled air entities. The movement is smoother and does not jitter. This difference is mirrored in the ground mobility of the CCTT-modeled entities. However, part of this discrepancy could be due to the AVCATT IG performing smoothing on all entities.

This makes the movement of a tank look awkward, because even though a tank can take a 90-degree turn, the AVCATT IG cannot visualize it properly.

We noticed that AVCATT entities are slower to engage opposing forces than their CCTT counterparts and that the rate of fire of AVCATT burst fire weapons is significantly slower (e.g., the M2A3 25-mm auto-cannon fires five rounds on the CCTT system for every round fired on the AVCATT system). Changes to starting engagement and burst fire weapons were made in the SE Core OneSAF baseline after AVCATT had branched and these (and other) updates will be merged back into the AVCATT system in 2012.

Entity	Issue
M997 Ambulance	AVCATT-modeled entity does not display flames or smoke when destroyed; no Red Cross markings
HMMWV Sling Load	Not seen on CCTT/AVCATT visuals; icon visible on OneSAF PVD
Rapier Missile Launcher (Towed)	When mobility damaged, wheel base disappears causing the entity to appear to be floating in the air; disappears entirely when mobility/firepower killed
Boston Whaler with/ 500lb IED	PVD icon changes to an aircraft carrier when damage state is set
Dismounted Infantry	Various opposing forces with specific weapons do not show those weapons in the CCTT visuals
KrAZ-255	Does not display any visual damage

Table 3. Major Issues from Entity Comparison

5.6 Damage Consistency

Because the AVCATT baseline branched early, there are differences in the damage tables and calculations as compared with the CCTT baseline. In our testing, we found that the CCTT MM and SAF baseline had a hard time damaging AVCATT ground entities from their SAF baseline. For example, the CCTT MM M2A3 engaged a T-80 tank modeled in the AVCATT suite with four tube-launched, optically tracked, wire-guided (TOW) 2B missiles. All were hits and caused no damage to the target entity.

6 Summary

Despite several issues through the exercise planning and execution, we consider the interoperability demonstration a success. The interoperability concerns we encountered are surmountable and, more importantly, we have identified them and possess the tools and experience to resolve them. The virtual SE Core OneSAF baseline operates on the same physical network as both CCTT and AVCATT systems; though AVCATT and CCTT communicate through a gateway to each other. Even in our demonstration, however, no important translations (except for exercise ID and minor administration details) were performed by the intervening gateways, effectively putting both CCTT and AVCATT on the same network. They could see each other, shoot at or near each other, and interoperate very effectively. Additionally, they can communicate on both voice and digital messaging systems, performing critical combined arms training missions such as call for fire and cordon and search. We hope that readers can use this work as a foundation and motivation for similar efforts so that the entire distributed simulation community can benefit from the accumulated collective experience.

Furthermore, the derivation of the AVCATT changes being merged back into SE Core OneSAF during 2012 demonstrates a key performance parameter (KPP) of SE Core: the establishment and development of simulation services and architecture standards provided to confederate systems, and the reuse and integration of changes by those systems. In this case, when the changes are integrated to the SE Core baseline, CCTT and any other confederates benefit from the work performed by AVCATT. Similarly, AVCATT benefits when stepping up to the merged version that contains all the other changes made to support CCTT and core OneSAF capabilities.

SE Core products were also used during the 2011 Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) held in Orlando, Florida. Two virtual training systems

from Product Manager for Air and Command Tactical Trainers (PM ACTT), AVCATT and Non-rated Crew Member Manned Module (NCM3), were connected in a live demonstration on the exhibition floor. The AVCATT system provided pilot capabilities for the CH-47F. The NCM3 system provided the non-rated crew-member capabilities for the NCM3, including two side gunners operating M240H 7.62mm machine guns and a crew chief for the sling load, ramp, and hoist operations. The hoist operations were demoed separately in standalone mode (not with AVCATT) on a UH-60M Black Hawk. These demonstrations at I/ITSEC were very successful and were received favorably by the attendees.

7 Future Work

For future events, we plan to continue capturing the Ethernet traffic and performing analyses on them. We plan to investigate more details on the packet content, including data sizes and bandwidth usage. For example, one area of this content analysis could be to investigate the types of collisions and any damage occurring from them. The AAR reports can also help provided this data or corroborate it from the collected packets. As new capabilities emerge from the various systems, and when the AVCATT OneSAF baseline is merged back into SE Core, additional testing will be conducted.

8 References

[1] Distributed Simulation Engineering and Execution Process (DSEEP), IEEE 1730-2010.

[2] Faulk, Mark, Richard Fuchs, Jeffrey Todd Littlejohn, Brian Kemper. "A Product Line Approach for the Virtual Domain." 06F-SIW-041, SISO Simulation Interoperability Workshop, Fall 2006.

[3] Marrou, Lance, Mark Faulk, Terry Tyson, and Brian Kemper. "Enhancing Virtual Simulation Systems Interoperability through V-DIS." 07F-SIW-076, SISO Simulation Interoperability Workshop, Fall 2007.

[4] Marrou, Lance, Mark Faulk, and Keith Nielsen. "An Interoperability Solution: Avoiding the Stovepipe." 11F-SIW-065, SISO Simulation Interoperability Workshop, Fall 2011.

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