M&S JOURNAL

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FROM THE EXECUTIVE EDITOR

Welcome to the Spring 2013 Modeling and Simulation (M&S) Journal that provides interesting reading on the topic of standards. Before I introduce the excellent articles in this issue, I would like to take a moment to introduce myself as the new Executive Editor. While Dr. Lashlee has taken on new responsibilities with the Navy Modeling and Simulation Office, I am now filling the position of Associate Director for Data at the Modeling & Simulation Coordination Office (M&SCO), and along with those responsibilities the honor of being the Executive Editor for this journal. Dr. Lashlee has set a high bar with regard to the quality of this periodical, and with the help of the editorial staff, we will do our best to continue to meet that standard. I have spent a number of years working in the realm of M&S, which dates back to terrain boards, rolling dice, and the use of "look-up" tables. As this community moves into a spectrum of technologies that include virtual worlds, gaming, and on-demand training through handheld smartphones, it is amazing to me to see how far we have come from the days of relying on a simple crapshoot.

While the miracles of ever improving technologies provide the engine for our current simulation technologies, underlying that success is the application of standards. The commercial world would not be profitable without them, and in the Department of Defense (DoD) we have also developed standards that enable us to provide world-class M&S capabilities to our warfighters. The article on large-scale simulation interoperability provides a clear picture to the scale and complexity of interoperability issues, giving the reader an appreciation for all the effort required to make theater-level exercises possible. As with all DoD efforts, there is the ever-present question of cost. The commentary covering the financial aspects of M&S standards makes use of data the Virginia Modeling and Simulation Center (VMASC) study collected on the use of standards, standards organizations, and standards development. Discussing the topic of M&S standards would not be complete without providing some specific examples. The discussion on successes in military M&S standards provides those examples in areas that include interoperability, natural environments, and system engineering processes. I would like to draw your attention to the piece on common methods and terminologies in data mappings. The use of standards covers a myriad of areas; not least of which is the ability to accurately manipulate data. This article provides an overview of the intricacy that revolves around the exchange of data in simulations.

It is my hope that you will find this issue both interesting and helpful, and I look forward to working with our editorial team to bring more quality issues to you in the future.

GARY W. ALLEN, PHD
Associate Director for M&S Data

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A Guest Editorial: Standards

GUEST EDITOR

Mr. Stephen P. Welby
Deputy Assistant Secretary of Defense
(Systems Engineering)

AS THE DEPUTY ASSISTANT SECRETARY OF DEFENSE FOR SYSTEMS ENGINEERING (DASD(SE)), I HELP LEAD ONE OF THE WORLD'S LARGEST ENGINEERING ACTIVITIES – THE ENTERPRISE THAT MANAGES AND EXECUTES THE DEVELOPMENT, PRODUCTION AND ACQUISITION OF ADVANCED MILITARY SYSTEMS AND CAPABILITIES TO SUPPORT THE DEPARTMENT OF DEFENSE. TODAY IT IS MORE CRITICAL THAN EVER TO FOCUS ON SMART SYSTEMS ENGINEERING AND STRONG TECHNICAL MANAGEMENT TO ENSURE THAT OUR WARFIGHTERS GET THE CAPABILITIES THEY NEED, WHILE INSURING THAT THE AMERICAN TAXPAYER GETS THE VALUE THEY DESERVE.

In support of our mission, it is vitally important that we provide our program managers and systems engineers with effective tools that support the design, development and deployment of the increasingly complex weapons systems and capabilities critical to our soldiers, sailors, airmen, and Marines. As the complexity of our systems has increased, so has the need for effective engineering insight across the product life cycle. Modeling and simulation are critical tools in our engineering processes, supporting all phases of our engineering activities from concept and analysis, through design and development, through manufacturing and production, to training, support, and eventual disposal. The insight obtained from modeling and simulation is increasingly critical to the cost-effective implementation of our advanced engineering efforts.

Mr. Stephen P. Welby

For our modeling and simulation efforts to be affordable, efficient, and effective, we need to facilitate data exchange and reuse between models and simulation systems, across applications and databases, and across disciplines. Common and shared technical standards provide the foundation and basis that allow modeling and simulation tools to be efficiently and effectively deployed and scaled to address enterprise challenges.

We have published the *Strategic Vision for DoD Modeling and Simulation* to guide our efforts in modeling and simulation, and the very first goal of the *Strategic Vision* document is to promote and enable the technical standards, architectures, networks, and environments that will support the sharing of tools, data, and information across the Enterprise; that will foster common formats; and that are readily accessible and can be reliably applied by modeling and simulation users. I believe technical standardization activities play a critical role in improving the Department's effectiveness in weapon systems acquisition and sustainment.

Technical standards are an enabler to the Department's larger goals of interoperability, improved operational readiness, and reduced total ownership costs between and among the Services, other Agencies, industry, and our allies. Technical standards provide the corporate process

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memory needed for a disciplined systems engineering approach and help ensure that the government and its contractors understand the critical processes and practices necessary to take a system from design to production, and through sustainment. In my role as Defense Standardization Executive, I have been engaged with the Military Departments and Defense Agencies to assess areas where improved technical standards are needed, or where existing standards are inadequate. In areas where deficiencies have been identified, we have been working to close these gaps through the revision of existing standards, development of new ones, or by creating guidance to improve implementation of existing standards.

In all of these activities, industry is a key partner. As we seek to insure that the right technical standards are available to the Department and to the broader acquisition community, we work hand-in-hand with the technical committees of standards developing organizations to identify standards that reflect best commercial practices and processes in use across industry sectors. Our engagement with industry ensures that technical standards capture shared technical understanding while also addressing any unique defense acquisition and contracting needs.

The Department of Defense remains committed to engineering excellence across our extended enterprise. We anticipate that the needs of the Department will continue to challenge our engineering capabilities and we are focused on ensuring that we have the right technical capabilities to meet future and emerging needs. With the energy, focus, and talent of our acquisition, engineering, and modeling and simulation communities, supported by a robust set of technical standards, I am confident that we can continue to meet these challenges.

Author's Biography

Mr. Stephen P. Welby is the Director, Systems Engineering for the Director, Defense Research and Engineering, in the Office of the Under Secretary of Defense for Acquisition, Technology and Logistics. Mr. Welby is responsible for establishing both systems engineering and acquisition technical workforce policy across the Department of Defense (DoD). This includes early systems engineering and pre-acquisition development planning programs; system design, development and manufacturing policy; and independent program review and analysis for more than $60B per year in major weapon system acquisition programs across the Department. As acquisition technical workforce executive, Mr. Welby is the Department's systems planning, research, development, and engineering (SPRDE) functional leader, as well as the production, quality, and manufacturing (PQM) functional leader, together these career fields encompass more than 40,000 DoD acquisition professionals.

Mr. Welby has more than 22 years of government and industrial experience in cross-disciplinary technological product development, including leadership positions at the Defense Advanced Research Projects Agency (DARPA). His areas of focus included technology and program mangagement for development of advanced aeronautical and space systems, high energy lasers, ground and maritime systems, robotics, advanced weapons, high-performance software, real-time signal and image processing, and military sensor systems. Mr. Welby holds a bachelor of science degree in chemical engineering from The Cooper Union for the Advancement of Science and Art, a master's degree in business administration from the Texas A&M University, and master's degree in computer science and applied mathematics from The John Hopkins University.

The Challenge in the CAX

Large Scale Simulation Interoperability Issues and Approaches

AUTHORS

Mr. Thomas C. Irwin & Mr. Alex H. Hoover
J7, the Joint Staff
Suffolk, VA

Abstract

JOINT TASK FORCE STAFF-LEVEL COMPUTER ASSISTED EXERCISE IS AN ESSENTIAL AND COMPLEX PART OF THE JOINT LEARNING CONTINUUM THAT PREPARES WARFIGHTERS FOR JOINT OPERATIONS IN THEATER IN SUPPORT OF AN EVER EVOLVING MISSION. THE COMPLEXITY OF THE PROBLEM SPACE AS WELL AS THE CURRENT SERVICE SIMULATIONS THAT SUPPORT THE EXERCISE CREATES A DIFFICULT AND UNIQUE INTEGRATION PROBLEM FOR JOINT STAFF, J7, JOINT AND COALITION WARFIGHTING. THIS ARTICLE DESCRIBES THE CHARACTER OF THE MAJOR CHALLENGES FACED BY THE J7 IN DEVELOPING AND PROVIDING THESE EXERCISES AND THE TOP-LEVEL APPROACHES THE J7 IS TAKING TO TAKE ADVANTAGE OF INNOVATIONS IN INTEGRATION AND SIMULATION INTEROPERABILITY TO REDUCE THE COST AND IMPROVE THE QUALITY OF THE PREPARATION PROVIDED TO THE WARFIGHTER.

Joint Staff, J7, Joint and Coalition Warfighting (JCW) is developing the Joint Information Enterprise to provide a single, secure, reliable, timely, effective, and agile command, control, communications, and computing enterprise information environment for use by the joint force and non-DoD mission partners across the full spectrum of operations, at all echelons, and in all operational environments. This effort will both modernize the current modeling and simulation (M&S) support infrastructure and implement DoD mandates for an enterprise approach to information management.

The Joint Task Force (JTF) staff-level Computer Assisted Exercise (CAX) is an irreplaceable opportunity for Combatant Commanders to direct the readiness of their personnel prior to deployment, instilling a sense of priorities, the mission context, and commander's intent. Prior to this CAX, the JTF has formed within the shifting context of their upcoming operational mission to the unique composition of skills and experience of its members.

Beyond the dynamic operational challenge, warfighters will find themselves to be part of a unique organization. Even the most junior of these personnel are already accustomed to arriving in a billet to learn the job as they go. But unlike Service tours, very few will be arriving in a billet where the superior has done a job at that level and their subordinates are doing a job similar to one in their past.

This combination of conditions makes the opportunity to practice as a whole, under the direction of the commander, invaluable. It also makes delivering an appropriate training environment a demanding task. While we never know the precise conditions our force will face, we do know the operations they are likely to need to conduct. While we cannot predict the exact reaction of enemy elements, we do understand the type of challenges our people are likely to confront. While we do not detail warfighters to the staff from a controlled training and experience pipeline, we do have a wealth of experience and skills from which to draw. Given these constraints, we should not replicate the current

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environment in detail (which would be months old upon arrival in theater), but rather provide a tailored practice environment where commanders can focus attention on the elements they determine to be critical based on the unique knowledge, skills, and abilities needs of their staff for that mission.

The tool suite that JCW uses to construct this environment is the Joint Live Virtual Constructive (JLVC) federation. At its core the JLVC is a collection of Service, DoD Agency, and Joint-developed models, a range of functional models, and several enclaves of run time infrastructures that are integrated and retro-fitted to enable interoperability. Its composition is a reflection of the varied operational experience of the personnel detailed to the staff, encapsulating the tools, systems, and interfaces they grew up with in their Service careers. The majority of the models in the current JLVC inventory focus on platforms, threats, and the environment at the operational level being fed from lower level representations provided by Service simulations. The Combatant Commands are thus able to use the events generated with this federation to direct their staffs' practice of battle rhythm and warfighting skills to any part of the domain, while maintaining the entire context of real operations.

In addition to the JLVC's primary role to support JTF staff training, the Services use it to better train in the environment they will operate in by providing joint context for their simulation-supported training events. DoD Agencies and Coalition partners also leverage these capabilities to provide a large-scale environment for their own staff processes and training needs.

The JLVC is a proven capability, but it requires significant resources of time, expertise, and infrastructure to plan, configure, and operate. The multiple training events it supports create data requirements, availability challenges, and distribution requirements unparalleled in the training arena. At the same time emerging warfighting capability challenges in cyber, anti-access area denial (A2AD), ballistic missile defense, and hybrid threats have been specifically directed for Joint M&S development and will need to be quickly incorporated in Joint M&S tools. The cumulative effect of JLVC operating and sustainment costs, increasing demand to maintain the battle edge of post OEF forces, and increasing scope of their readiness in critical mission areas, requires foundational architectural changes to deliver an adaptive and affordable joint training environment for Joint Force 2020.

The current joint training environment was forged in an environment of urgent need that was focused on supporting immediately deploying units. Due to the urgency of the need, the JLVC was assembled in a way that paralleled the building of the staffs it would train. The best of the best from the Services were brought together and then integrated through the use of unique Joint-developed capabilities. Unlike the staffs, however, the simulations are collections of computer code. They cannot adapt to their context, but must be adapted by others. They cannot find information on their own, but must be explicitly fed precise data. They do not use judgment to choose from among alternatives, but must be given explicit criteria to systematically evaluate.

The current approach to integrating these simulations further increases the complexity of providing this very detailed data. We mandate that each element of each simulation must be validated for proper interaction with every other element of each other simulation. A building in the land simulation must provide cover to targets in the air simulation. A GPS position for a unit in one simulation must correlate with an artillery grid coordinate in another. A threat emission in the constructive domain must align with every sensor on the live units. These very detailed requirements for information management scale geometrically when federating simulations, creating an integration problem that, while analytically solvable, quickly becomes fiscally intractable.

The key issue that compounds the effect of geometric growth is the myth of "realism" that we impose on our training simulations. Identifying the demands for realism as a myth does not mean the behaviors and outcomes of our training environment do not need to be accurate, but rather calls out that for an application for which we need exacting detail to build and validate, we also need exacting detail in the standards we use to measure that accuracy. We have already discussed how the dynamic nature of the operational environment means we don't establish the standard of accuracy for training as the reality of the theater

on the day of training, but instead a projected, hypothetical reality at the time of deployment. In order to understand the demands on the future training environment, we must also address the impact of the emphasis of the Commander's intent on the requirements for training events.

Basic Operational Risk Management (ORM) tells us that the risk associated with an event (*e*) is the product of the probability of its occurrence with the cost of its occurrence:

$$Risk_e = P_e \times C_e$$

Often, we feel compelled to evaluate the cost element in terms of some measurable quantity, such as money or time, and allow risk to be collapsed into a one-dimensional value. While this may be appropriate for guiding investment decisions or projecting acquisition schedules, for military operations the costs associated with mission failure are far more significant than loss of money or time. Equally as important is the loss of life, vulnerability of national security, and decrease in international stability that are not quantifiable in simple, linear terms. We end up with a deceptive ORM relationship when we consider the impacts of failure in routine operations (*r*) and crisis operations (*c*):

$$P_r[high] \times C_r[low] = P_c[low] \times C_c[high]$$

Intuitively, we know these cases are not equivalent. The fact that we spend a higher amount of time in routine operations where risks of failure are low and lower amount of time in crisis operations where risks of failure are high, does not mean that we consider the need to train for routine and crisis operations to be equivalent, or that we allocate the same resources to each.

These nonlinearities in requirement for training are the source of one of the most challenging difficulties in modern CAX support. When we use a tightly bound set of resources to manage a low-density requirement in a high-density environment, we are forced to "bring along" a lot of capabilities that do not feed tasks being simulated, but rather are necessary to maintain the context of the whole battlespace in which the simulated task is immersed. These additional capabilities come with their own, often substantial, resource demands. With the current technology, we find ourselves making a choice between using scores of uninvolved machines and operators to maintain the consistency of the simulation or ablating requirements because we cannot justify the overhead for a requirement that impacts a low number of personnel.

If we are to move forward toward Joint Force 2020 imperatives and our next fight, we must move beyond intuitive understanding of our training needs. For example, when a commander determines that, to be prepared for cyber attacks, his staff must practice at least two battle rhythm cycles in a 10-day exercise under conditions of degraded communications (limited bandwidth, increased latency), we must provide an exercise that stresses his staff in that way. Moreover, if the Computer Network Defense (CND) team finds, isolates, and eliminates the cyber attack within minutes, the simulation cannot respond "realistically" and restore full communications to the staff. Alternately, if the CND team fails to overcome the cyber attack after two battle rhythm cycles, we must restore communications to the staff to avoid losing training opportunities for other critical tasks that would not be possible under conditions of degraded communications.

Clearly, the above set of requirements is not the only interpretation of the commander's intent for the exercise. It is equally clear that the different interpretations would result in different requirements for the training environment, and thus, different configurations for the simulations to support them. Given the complexity of the current operational environment and the number of possible excursions, we can no longer afford to spend resources to build training capabilities that will not be used. A key element of the future training environment will be the use of an Architecture Neutral Data Exchange Model (ANDEM) to act as a broker between the operational and technical views of the training environment. This will allow both sides to negotiate a common understanding of the training objectives and how to meet the commander's intent. This underlying technology will allow true tailoring of exercises to meet the training needs of the staff.

For the training environment to affordably keep pace with the rate of change and uncertainty of the operating environment, capitalizing on advancements in cloud computing and web technologies (i.e. DoD DISA cloud and the OSD Virtual World Framework) will be critical. The future "interoperability standard" will derive from cloud

based functional services that provide a full spectrum of warfighting capabilities instead of organization focused standalones arranged by platform and program of acquisition. It will enable a composable joint training environment determined by training objectives and training audience needs, not by specific simulation or model choices and tightly coupled applications.

Moving past the current architecture of tightly bound representations of military entities, where each is copied and continually updated ("ghosted") in every simulation, this composable environment will integrate using a minimal set of behavior transactions. The simulations services will only communicate about the state of the entities they simulate when and to the extent needed by the other services. By focusing the simulation composition to only the needed functions at the appropriate resolution, we can mitigate the need for large cadres of machines and operators that do not contribute to the outcome of the simulation, but are required to maintain the consistency of the simulation as a whole.

The current demand for constant high bandwidth will be replaced by a varying demand for bandwidth that is based on the current level of dynamic behaviors in the models. This demand may, at times, be higher than the current demand for bandwidth, but it will neither affect all simulations at once nor remain that high for the entire event. The result will be a lower average demand that needs to be dynamically allocated, reallocated, and balanced as the event progresses. The Cloud Enabled Modeling and Simulation (CEMS) architecture will provide this function.

Within this cloud will reside numerous simulation services. These services will present small subsets of the warfighting behaviors resident in current simulations. Beyond simply partitioning these behaviors out over a larger space of smaller applications, they will be bundled, grouped, and layered to provide more options than in the current environment. When composing an event support application in CEMS, only the appropriate services will be invoked and integrated. Trainers will be able to more easily compose scalable events with collaborative partners, which can operate at high or low fidelity based on training requirements. The training management process will gain more structure based on the ontology of content services available to represent events and the technical process will gain more agility based on the functional understanding of the entities being simulated. Where gaps and seams exist, tailored content will be developed to meet the need instead of representing the entire domain. By bringing the trainer and developer processes for events closer together, leadership will be able to gain efficiencies in terms of shorter event lifecycles that require fewer people, the ability to scale based on training need, current capabilities, and fiscal constraints, and lower infrastructure overhead demands.

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Authors' Biographies

Mr. Thomas C. Irwin

Thomas C. Irwin, assistant deputy director for synchronization and integration, J7, the Joint Staff, helps to oversee an organization that provides a one-stop-shop for preserving jointness and developing the joint force, and works closely with Allied Command Transformation and multinational partners. Irwin entered the Senior Executive Service in November 2009 and has served in various engineering and program management positions during his 28 years of federal service.

His most recent assignment was the director of the Enterprise Business Group, U.S. Joint Forces Command (USJFCOM), Suffolk, VA. The position provided leadership and executive oversight of all joint experimentation programs and projects across USJFCOM and DoD's Joint Concept Development & Experimentation (JCD&E) Enterprise. He was also responsible for development, planning and execution of long-term strategic vision pertaining to joint experimentation, and coordinating the vision with Enterprise partners and resource sponsors.

Prior to entering the Senior Executive Service, he served as the director of the Marine Air Ground Task Force (MAGTF) Command and Control, Weapons and Sensors Development and Integration Product Group at the Marine Corps Systems Command in Quantico, VA. Irwin was awarded a Meritorious Civilian Service Medal for procuring and fielding command and control technologies to the Marine operating forces in October 2009.

He has a bachelor of science in mechanical engineering from North Carolina State University and a master of science degree in systems engineering management at the Naval Postgraduate School. Additionally, Irwin is a certified Project Management Professional by the Project Management Institute, and DAWIA level III certified in both Program Management and SPRDE.

Mr. Alex H. Hoover

Alex H. Hoover is a researcher in the Futures Group in the Joint Staff J7 Synchronization and Integration branch. He provides technical direction for research teams developing the future architecture that will underlie the Joint Live Virtual Constructive (JLVC) federation. Prior to working in collective training, he was the chief of Assessment for individual training at USJFCOM.

Mr. Hoover is a former Naval Surface Warfare officer, where he served in the CRUDES and Combat Logistics fleets, as well as serving at the Navy's Operation Test authority. He holds a bachelor of science in computer engineering from the Ohio State University and a master of science in computer science from the University of Phoenix. Mr. Hoover is DAWIA level III certified in SPRDE.

Financial Implications of Modeling and Simulation Standards:

Practical Aspects and Theoretical Analysis

AUTHORS

Dr. Charles D. Turnitsa
General Dynamics IT
Suffolk, Virginia 23435
cturnitsa@gmail.com

Dr. Andrew J. Collins, Mr. David Meyr,
Mr. Solomon Sherfey
Virginia Modeling, Analysis and Simulation Center
Suffolk, VA 23435
ajcollin, dmeyr, ssherfey@odu.edu

KEYWORDS

Modeling and simulation standards, government standards, return on investment

Abstract

THE PURSUIT OF MODELING AND SIMULATION IN BOTH NATIONAL AND INTERNATIONAL DEFENSE ORGANIZATIONS HAS BEEN AFFECTED OVER PRECEDING DECADES BY THE USE OF TECHNICAL STANDARDS FOR A WIDE VARIETY OF REASONS. AN ONGOING STUDY OF THE TOPIC OF M&S STANDARDS, STANDARD ORGANIZATIONS, AND STANDARDS DEVELOPMENT BY VMASC THROUGH OPEN WORKSHOPS AND PUBLICATIONS HAS RESULTED IN EXPLORATION OF TOPICS SUCH AS THE GROUNDS FOR DEVELOPMENT OF FURTHER STANDARDS; THE EXTENSIBILITY OF EXISTING STANDARDS TO OTHER GOVERNMENT PURSUITS; AND THE UNDERSTANDING OF THE TRIPLE-RELATIONSHIP BETWEEN STANDARDS, SERVICE-PROVIDERS, AND THE GOVERNMENT CUSTOMER. NOW IN ITS THIRD YEAR, THE STUDY ORGANIZED BY VMASC WILL UNDERTAKE TO EXPLORE THE FINANCIAL IMPLICATIONS OF STANDARDS. SPECIFIC APPLICATION AREAS WHERE STANDARDS CAN AFFECT THE FINANCIAL ASPECTS OF M&S DEVELOPMENT AND OPERATIONS ARE EXPLORED AND HOW STANDARDS INTERACT WITH THOSE PRACTICES. ALSO, THE INDUSTRIAL PRACTICES RELATED TO SOFTWARE DEVELOPMENT – COMMONALITY OF APPROACH, DIFFERENT DESIGN PARADIGMS, RESOURCE SAVING TECHNIQUES – ARE CONSIDERED AS TO HOW THESE ARE SPECIFICALLY AFFECTED BY M&S STANDARDS. FINALLY, THE THEORETICAL VIEW IS PRESENTED IN TWO DIFFERENT FORMS. THE FIRST IS OF THE COMMONALITY OF, AND REPERCUSSIONS OF COMPLIANCE WITH, ALL STANDARDS – M&S AND THOSE FOUND ELSEWHERE. THIS THEORETICAL VIEW IS PRESENTED, TO SEE WHAT CAN BE LEARNED FROM OTHER COMMUNITIES WHERE STANDARDS HAVE BEEN USED BEFORE, AND THEIR FINANCIAL IMPLICATIONS MAY ALREADY BE KNOWN. THE SECOND THEORETICAL VIEW IS OF THE UNDERSTANDING OF THE IMPACTS ON THE CUSTOMER AND SERVICE PROVIDER OF HAVING STANDARDS – USING A GAME THEORETICAL APPROACH.

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1. Introduction

Standards, whether government mandated, or market derived, are an important part of all engineering and development endeavors, and the modeling and simulation community is no exception. Understanding what the financial aspects of such standards are is important for the government, as it becomes increasingly involved in the use of modeling and simulation in a wide variety of enterprise pursuits. There has been a multi-year study performed at VMASC (Virginia Modeling Analysis and Simulation Center, of Old Dominion University) to look at the different aspects of M&S standards with the third year focusing on the financial benefit of standards. This paper represents a summary of the findings from that third year of study.

The main body of this paper is divided up into four sections; each represents the findings of the individuals of the research team. The subject of financial implications of standards is a large topic so each researcher has focused on a different aspect of the problem which has been highlighted in figure 1. The individual researcher's interest areas were chosen in an attempt to cover as broad a range as possible of the problem.

Section 2 highlights some of the impacts of organizational misbehavior on the M&S standardization process. Section 3 considers Total Quality Management (TQM) standards over the last 50 years and lessons learnt for M&S standards. The problem of valuing standards is addressed in section 4 and section 5 discusses software development standards relating to M&S. Each section summarizes the aspect of the financial implications of standards under consideration and gives an introductory dialogue of the current research in that area; where appropriate, observations and conclusions have been drawn.

2. Game Theory and Organization Misbehavior

There is very little literature on organizational misbehavior within a M&S standards context, which might be for a variety of reasons. The M&S standards community is relatively small thus there might not be a need to communicate such issues to a wider audience. Another reason is that there is generally accepted silence on discussing any such issues; this silence on openly discussing the issues regarding the current M&S standards might be for

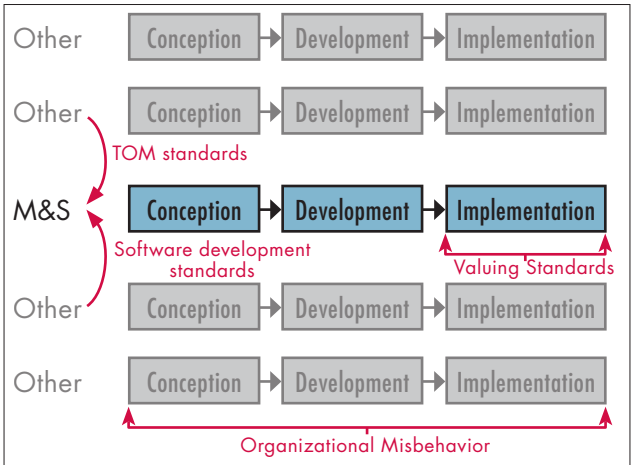

Figure 1. Diagram illustrating the relationship of the research sections within this report and the M&S standards development process

political reasons which, ironically, can be considered a form of organizational misbehavior. What evidence that does exist is discussed here.

Hollenbach gives a history of the rise and fall of the High Level Architecture (HLA) standard [1]. Hollenbach describes how the initial "good" intention of the Department of Defense (DoD) to adopt a single interoperability standard to use within their training simulations, was weakened over time due to the diminishing leadership for the initiative.

2.1 Organizational Misbehavior

As part of a workshop by the Virginia Modeling, Analysis and Simulation Center (VMASC) in May 2011, a non-attributable discussion was had among a group of roughly thirty M&S professionals on the anecdotal evidence of misbehavior within the development of M&S standards [2]. There were several different misbehaviors provided as anecdotal evidence at the workshop; these misbehaviours were generalized within the report and a sampling is given here:

- *Persistent Obstructionism:* This behavior occurs during the development of a standard. The organizations that exhibit this behavior might object to the standard in principle but have somehow managed to become involved in the development process. The organization intends to derail the development of the standards through a series of delaying tactics, i.e., raising many specious objections to the ideas under development.

- *Malicious compliance:* This occurs when an organization says that it will adopt a standard in public but actually has no intention of doing so. This passive-aggressive behavior can be achieved by claiming a series of internal delays / funding issues which are hard for any outsider of the organization to determine.
- *Sloppy Implementation:* The standard is adopted by organizations but implemented in a haphazard or low-cost way, so that the standard causes more problems than it cures.

The motivation behind such behaviors varies depending on the circumstances of the individual organization. The motivations might not simply be financial; some misbehavior might occur for no malicious reasons. It may just be that the organizations involved in the development of the standard are at cross-purposes.

The problems faced by non-M&S standards development organizations are similar to those faced by the M&S community. Proof of this statement is seen throughout the literature. For example, when Frits Tolman discusses building and construction modeling standards [3], he concludes that:

"ISO [International Organization for Standardization] is not the optimum organization to steer the pre-standardization process and there is not even consensus among the researchers that are carrying out the efforts. As there is no strong management commitment and no funding, it is not realistic to expect that STEP [the construction modeling standards organization] will solve the industry's problems."

Tolman's statement could have easily been found in many a report on M&S standards by simply substituting out the organization's names for those relating to the M&S industry.

Game Theory is the analytical study of situations that involve more than one decision maker. Standards, by their very nature, are also about multiple things and so involve multiple decision makers. It thus seems appropriate that Game Theory could and has been applied to understanding the organizational behaviors of standards development and its application.

Unsurprisingly, there have been already been multiple applications of game theory to standards. Probably the most famous example of Game Theory to a standards situation is found in Hardin's *Tragedy of the Commons* [4].

2.2 Game Theory

Game theory has also been used to example behavior that is not immediately obviously. For example, Tim Gardner and Jim Moffat tried to explain why major defense contracts are rarely on time or budget in what they term the *conspiracy of optimism* [5]. Using a simple game it is shown that both the defense contractors and the military desk officers benefit from underestimating the resource requirements for a given project. The desk officers, who usually serve a two to three year post, have little or no accountability for the actual budget of the defense contract. The defense contractors gamble on the DoD supporting the project due to its low cost and that they will make their money through eventual changes that happen to the requirements.

Game theory has been applied to variety of other areas like the negotiation of royalty rates for propriety standards [6]; or the adoption of a new technology standard over time [7]. Though these papers provide insight into their particular areas, they do not directly address the issue of malicious behavior. The problem with investigating such misbehavior is two-fold:

1. Companies are unwilling to release data on their more malicious activities due to the image problems that might lead from it.
2. Even if data was available, suggesting that a particular company or organization has conducted malicious behavior might result in libelous action. Thus it would be difficult to report even case-studies on company misbehavior.

The critical point here is that just because organizational misbehavior is not heavily reported within the literature, does not mean that it does not happen. This author speculates that organizational misbehavior is more endemic in our modern business culture than our simple antidotal evidence would suggest.

2.3 Financial Implications

Though there have been many studies that claim the financial benefit of standards. For example 25% of France's economic growth in 2009 was reported to be due to standardization [8]; this approach of quantifying standards' financial benefit is questionable. According to David and Greenstein [9]:

"The [economics of standards] field remains young and in quite fluid state. Economists have hardly settled on a

standard terminology, much less converged on paradigmatic modes of theoretical analysis and empirical inquiry."

Given that there is no agreed upon approach for quantifying the benefit of standards and there is no universal method to quantify the benefits of M&S, it is hardly a surprise that there is no useful methodology to quantify the benefit of M&S standards. This leaves us to use comparative case studies and anecdotal evidence on standards to highlight certain phenomenon that could be changed to increase the efficiency of the standards development process.

Does organizational misbehavior have a substantial impact on the development and benefit of M&S standards? Yes. How much of an impact? We are not sure. By collecting and supporting the more pioneering work like that of Gardner and Moffat [5], there might be a large enough body of literature to form a theory of the financial implications of organizational misbehavior on M&S standards. The first step in this process is to acknowledge that there is a problem in the first place but sadly this author believes that is likely to remain as "whispers in the night."

3. Applying Quality Management Standards to M&S

The concept of developing standards for Modeling and Simulation (M&S) poses unique challenges. Parallels may be drawn from the US military's over a half-century of experience applying and adapting to production-management quality standards such as Total Quality Management (TQM) and Six Sigma. The financial implications of standards implementation and adapting to new or evolving trends in process standardization for the military will be drawn from various case studies, and potential repercussions will be suggested for application to M&S.

Beginning in the 1950's, both the US military and US manufacturing sectors recognized the need to improve the quality of equipment, hardware and processes. Initiated to respond to Cold war pressures and international competition, early work was productive but disjointed [10]. It was found that some efforts such as Vietnam War-era "body-count metrics" were more than unsuccessful; they were seen as deliberately misleading and counter-productive [11]. The resulting stigma was hard to shake off.

"Guilt by association" to those metrics from Vietnam War impeded later work with standards such as Total Quality Management (TQM) in the military. This work to standardize processes was seen as redundant (especially because ad-hoc and localized efforts were already producing positive results) [12], hindered by military personnel assignment and transfer policies, counter-productive to the carefully-developed military mindset and prerogative of Command, and disruptive to unit identity and the Chain of Command [13]. The return on investment in terms of dollars and time was difficult to quantify, and the resultant savings were as suspect as the Vietnam War's body count metric.

Eventual savings and improvements in quality were notable but remained hard to quantify for most military personnel [14]. Benefits from the current emphasis on transitioning from previous work to Six Sigma processes remain equally elusive [14]. Most importantly, several works cautioned regarding the potential for the drive for process standardization and rigid adherence to metrics, to squelch the underpinnings for M&S [15, 16, 17].

4. The Value of Standards to the M&S Company

An important aspect of consideration for the SISO audience, of course, is the relationship of standards to M&S service providers and product developers. This has implications not only for those providers/developers (companies), but also for their customers (government, military), and independent researchers (academia) who inform both producers and users as to the best use of such developments.

4.1 Valuing standards: It's more than your company's bottom line…

Finding the value of standards is a multifaceted endeavor, with multiple disciplines having their own take on what constitutes the proper measure. Economists track the impact of standardization as a national process affecting socioeconomic health, while business analysts struggle to define or predict the impact of standard adoption on a company's bottom line. Social scientists look at the diffusion of knowledge and technology as driven by the medium of standards, while legal scholars struggle to find the balance between anti-competition and pro-innovation.

4.2 Measuring "the bottom line…"

Case studies using the ISO Standard Valuation Methodology assign improvements from 1% to 33% on various businesses' "bottom line" – but notably fail to capture empirical improvements in some cases despite "obviously improved operations". Secondly, the real financial impacts of standards use reach well beyond the balance sheets of individual firms or projects. In January of 2010, the International Standards Organization (ISO) reported the development of a methodology for the economic assessment and quantification of benefits from the application of standards [23]. Since then a number of analyses have been conducted, with several posted on the ISO website. A sampling:

- PTT Chemical (March 2011). Impact of standards employment on revenues estimated to be approximately $9.4 million, or 3% [24].
- Siemens Switch Technology (March 2011). Assessment indicated an impact on profits of 1.1-2.8% for the affected divisions. Siemens AG posted after-tax profits of 4,068 million Euros in 2010 - 1.1% of that figure is over 45 million Euros [25].
- Nanotron Technologies GmbH (June 2011). Estimated impact of standards on revenues is 33% - 14% in cost savings and 19% in increased revenue [26].
- Pretoria Cement (March 2011). Overall impact of standards judged to be 2.5% of revenues (R 5.9 billion) [27].
- Festo Brasil (March 2011). Assessment revealed an economic impact of standards of 1.9% of revenues [28].

An observant reader will note that all the examples above are "conventional" manufacturers; i.e., they use traditional manufacturing techniques to produce real, physical products. The ISO Assessment Methodology is relatively new, and with time we should probably see these same detailed assessments for R&D intensive, service oriented ventures with less routine product lines, such as modeling and simulation.

In a 2003 study, the Delphi Group gathered responses to a survey from more than 800 software developers and end users regarding the value of standards [29]. One of the interesting results posted in the report is a comparison of the answers to similar questions asked from different perspectives. The questions are "What do you *believe* to be the greatest benefit offered by standards in software development?" and "Which of the benefits derived from standards have you or your organization *experienced?*" While only 4-7% of respondents *believed* that standards would enable leveraging of existing skill sets, fully 61% *experienced* a benefit from skill set reuse. What we can read from this is that the implementation of standards has provided an unexpected economic benefit to users and developer's alike in that they have not been required to implement costly, proprietary training programs. In other areas experience bore out the anticipated benefits. 31% of consumers and 28% of developers believed that software development standards would "Increase the value of existing and future investments in information systems"; experience proved to be double that rate at 65% and 71% respectively.

In Part 'A' of their report, Beuth Verlag used a survey of industry to discern attitudes and, in broad, subjective measures, fiscal impacts on ten sectors of industry [30]. Questionnaires were sent to over 4000 randomly selected companies, and 707 were answered for a response rate of 17%. Some of the interesting, and pertinent, findings were:

- General competitive advantage thru the use of standards.
- Real production and transaction cost reductions.
- Reduction of dependence on individual suppliers.
- Movement to International Standards to reduce costs of international trade.

4.3 Macro Level…

At the macro-economic level, it is abundantly clear that the globalization of trade we have witnessed over the past few decades is intrinsically linked to international standards. Numerous studies by the ISO and national standards bodies have detailed both the economic and the social impacts of standards on the international stage. For example, a study conducted for the British Standards Institute (BSI) demonstrates that standards effects account for approximately £2.5 billion a year to the UK economy [31]. Research reported in an economic report by the Department of Technology and Industry attributed 13% of post war UK productivity growth to standards-mediated dissemination of technology, management practices and other knowledge, as part of the innovation system [32].

In the first work of its kind, Blind, Grupp, and Jungmittag (hereafter BGJ) conducted an empirical study of

technological impacts on the German economy in 1999 [33]. The researchers used German economic data for the time period 1961 thru 1996 and used various statistical methods to analyze the results of their model. They found that standardization accounted for anywhere from 0.2 to 1.5% of annual growth, which in total ran from 1.1 to 5.2% over the time period. The Beuth Verlag report of 2000 finds the economic benefit of standards to be roughly 1% of the German gross national product. This is basically a re-statement of the BGJ findings (they were members of the team) , but they go on to say that the positive macroeconomic effects far exceed the sum of individual benefits for the economy, justify public financial support for standards work, and give standardization a firm role in economic, research and innovation policy-making [30].

4.4 Over a Span of Time…

Another perspective on the value of standards can be gained by examining their development with respect to the historic eras of human development. Researchers identify five historical ages of development – Hunter-gatherer, Agrarian, Industrial, Information, and Post-information. Associated with those ages are "Standards Successions" [34] – Symbols, Measurement, Similarity, Compatibility, and Adaptability, respectively – that in many respects made that march of progress possible. An important trend in this portrayal of technological development is the accelerating advance from one age to the next, with time spans for the eras decreasing by an order of magnitude through the first four eras. Another key trend, or pair of trends, is the decreasing involvement of governing authorities in the standards successions paired with the increasing interest and exploitation of standards by the entrepreneur. Finally, the number and scope of our standards increases inversely with the span of time of our technological eras. Is that a coincidental or causal relationship?

It is clear that standards have played a central role in the economic and technological development of human society. How does one measure the financial impact on the standardization of our number symbology on Hindu-Arabic characters? Or the standardization of internet protocols? Or on what standardization may mean to the next era of technological development? While these are complex (and perhaps rhetorical) questions, history suggests that standards are essential to our lives. What is difficult is assessing or establishing a financial impact of those standards.

5. Software Development Standards and M&S

There are, of course, many different standards (of practice and of artifact) within the software development community that could be of use to M&S. In many cases, their adoption would not be markedly different than adoption by any other enterprise that deals with the development, maintenance and operations aspects of software. In a few cases however, due to the unique nature of modeling and simulation, some differences arise that may affect how these standards could be used, and specific needs for there to be beneficial financial impact on the employing organization.

5.1 Software Reuse

One of the key goals for having a positive financial impact on a software development organization has long been the promise of software reuse. This can take place in several different ways, and there are approaches and documentation that address these ways. The first way is to enable the reuse of software within a project, by allowing the software development teams to reuse code fragments and algorithms that may make sense in different projects or different parts of a large project. The second way is to enable the reuse of completed segments (tools, programs, etc) of code that is no longer under development, but may be reused in a different situation other than what it was developed for.

In both cases, for all sorts of software development pursuits (M&S and others), these two different goals mandate the adoption of standards in order to enable the possibility of reuse. In the first case, providing suitably robust and detailed documentation is required in order to make use of the code fragment in a new environment, which (to support M&S) should be in the form of standardized modeling techniques. In the second case, the adoption of a standardized cataloging technique (meta data, use case descriptions, etc) – also a standard of practice –is necessary in order to be able to not only discover the reusable component, but also to determine if it suits (evaluated against use criteria, in a systems engineering sense) the new use it will be put to.

In both cases, in order to support M&S, since the software developed is motivated by a model, and exists in order to partially (or fully) implement that model, it is important that the standards of practice (documentation; cataloguing) be accompanied by standardized artifacts (a capture of the model, at least at the conceptual, and perhaps also at the logical and/or physical levels). The artifacts are used to describe and convey the model that is being used. A standardized approach is used in selecting a modeling technique to allow for software-to-software comparison (again for systems engineering needs). This approach (adopting the capture and transfer of standardized models along with the software, to enable M&S software reuse) has been reported on to SISO in the past [18].

5.2 Standard Development Process and M&S

Since approximately the mid-90s, software development processes have been divided up into the two camps of "lightweight" and "heavyweight" approaches to development [19]. An example of a lightweight approach (perhaps one of the most popular examples) is that of the Agile Software Development Process [20]. It is intended to be more of a dynamic, reactionary approach to guiding the development of software, vs. a more rigid hierarchical approach taken by some of the older versions. An example of a heavyweight approach would be the "waterfall" approach, which is identified by proponents of the lightweight school as being slower, more lock-stepped, and more rigidly defined. Proponents of the waterfall system (presented originally for use by the US Navy at a symposium in 1956 [21]) might point out that it has a long history; allows for formal project management techniques; encourages internal documentation, and so on.

Evaluating which might be better or worse for an M&S project is nonsensical – it depends on the projects and the organizations. Each approach, however, has some implications when used in an M&S setting – coming from the nature of both the project and the organization doing the development. In the case of the Agile process, it is important to retain knowledge of the model that is inspiring the development of the software. One of the features of Agile is that the original requirements may change over time as each iteration of development (fast, small iterations in this case) takes place, and uncovers problems with the original requirements. In the case of M&S software, the requirements are model driven. To change them (which does happen) requires both changes to the software being developed (the simulator that enables the model) but also to the model itself, *ex post facto.* As the model must be known for other aspects of the whole M&S lifecycle (such as validation and verification) it is crucial that these changes be made to the model.

In the case of the waterfall approach [22], it is suitable for very large software organizations. This is because there are finite limits to the rounds of iteration; each part of the organization is aware of those rounds, and the developmental goals (and incremental testing) that will take place between each round. Because of this, the specific goals and activities, and results of each waterfall increment can best be described and shared among the organization by using models (or, more appropriately, smaller versions of an overall project model). Enabling verification- and validation-supporting activities within a waterfall model approach, especially when incremental adoption of the motivating model is being done, also require that these models be present and shared.

For the same reasons as with the software reuse approaches described above, it would be extremely helpful to the teams involved in these two very different process approaches to have modeling standards to describe the models required. In many cases, some of the diagramming techniques of the UML or SysML families would be suitable.

6. Conclusion

Though different, we can still draw from the very large non-M&S standards community for information that might be appropriate to our world. In some cases, like software development standards, this information will show possible avenues to consider for future M&S standards, i.e. model reuse. In some cases, like TQM, this information will show which avenues to avoid.

The larger standards community has been making efforts to determine the financial benefit of standards. In the last year, the International Organization for Standardization (ISO) released a prototype standard method for establishing the financial benefit of standards which has only been applied to a very limited number of industrial case studies. M&S development is much less repetitive and

more inter-disciplinary an endeavor than any of these case studies thus it remains to be seen if this new methodology can determine the financial benefit of standards to M&S.

Other financial-benefit-determining methodology do exist but have been rejected by the ISO. There is no reason to believe that M&S standards are a special case, so we are left without a formal methodology to determine the financial benefit of M&S standards.

However, by every measure, it is clear that standards have an impact on our lives that far transcends the 'conventional wisdom".

- Intuitively, it "just makes sense" that they would – and when you consider that even the language in which we discuss standards is in itself a "standard" it becomes a natural assumption that they are both invaluable and inescapable.
- Rationally we can state the logical reasons that standards, in the balance of pro and con, are beneficial to us not only technically, but economically and socially.
- Historically, we can look back over time and observe the impact that standards of one type or another have had on our development as the dominant species on earth.
- Empirically, we can measure the impact that standards have on us in our everyday business.

Knowing what standards mean to us and what role they have played in our ongoing development, emphasizes the importance of fully understanding the mechanisms by which they come into being. In view of the ever-accelerating pace of technological advance and its relationship to standards, it also is a clarion call to be proactive, and yet cautious, in how we go about facilitating, governing, or regulating standards development.

The question arises to why the financial benefit of standards cannot be easily measured. We conclude that this is because the purpose of the M&S standard is not necessarily known. Organizations involved in the development of a standard might intend to use it for different purposes and these purposes might not be publicly announced, i.e., the purpose derives from organizational misbehavior. Thus it is difficult to measure something when you do not know what you are measuring it against.

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Authors' Biographies

Dr. Charles D. Turnitsa

Charles Turnitsa is currently Assistant Professor for Modeling and Simulation, at the TSYS School for Computer Science of Columbus State University. He teaches and develops M&S courses, mentors graduate students, and also serves as the director of the Games, Education, Modeling and Simulation (GEMS) Institute, a research institute of Columbus State University. His research areas continue to be in modeling theory, modeling and simulation for systems engineering, and the modeling of human systems. He received his PhD from Old Dominion University in 2012.

Dr. Andrew J. Collins

Andrew J. Collins has spent the last 10 years, while conducting his Ph.D. and as an analyst for the UK's Ministry of Defence, applying game theory to variety of practical operational research problems. Dr. Collins is the principle investigator on a federal funded M&S standards governance project and he is currently the principle analyst on an award winning investigation which applies agent-based modeling to the foreclosure crisis. Other recent research areas include entrepreneurship modeling and bio-terrorism.

Mr. David Meyr

David Meyr is a retired US Navy officer and A6E Intruder Bombardier/Navigator. Following earning his MS at the Industrial College of the Armed Forces, Mr. Meyr was assigned to Strike Force NATO in Naples, Italy as NATO Carrier Operations for both computer-simulated/aided, and real-world exercises and operations. Following retirement, David was a technical analyst for science and technology issues relating to US, NATO and Coalition Command, Control and Intelligence, Surveillance and Reconnaissance (ISR) system integration. Mr. Meyr now works at VMASC in support of the Joint Chiefs of Staff Deputy Director J7, Joint and Coalition Warfare Mission Rehearsal Exercises, and the M&S standards governance project.

Mr. Solomon Sherfey

Solomon Sherfey, a VMASC project scientist, was a US Navy submariner and then manager of Simulation Database Services for the Joint War Fighting Center before coming to VMASC in 2008. He is a "mustang", earning his bachelor's degree while on active duty and then being awarded a commission in the Navy. He went on to complete a Master's degree in Computer Science from Naval Post Graduate School and has continued his post-graduate coursework in Modeling & Simulation and Geographic Information Systems.

Solomon's research interests include Artificial Intelligence and Social, Behavioral & Cognitive Modeling. He's also very active in Lions Clubs International and is an avid "gear head" who delights in turning a wrench on any mechanical project.

Correlation of Characterizing Attributes and Success in Military M&S Standards

AUTHORS

Dr. Mikel D. Petty & Ms. Retonya L. Dunning
Center for Modeling, Simulation, and Analysis
University of Alabama in Huntsville
301 Sparkman Drive, Shelby Center 144, Huntsville AL 35899
pettym@uah.edu 256-824-4368,
retonya.dunning@yahoo.com 256-824-4631

Dr. Andrew J. Collins
Virginia Modeling, Analysis and Simulation Center
Old Dominion University
1030 University Boulevard, Suffolk VA 23435
ajcollin@odu.edu 757-638-4437

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Abstract

A CRUCIAL ENABLING FACTOR IN THE SUCCESS OF DEFENSE-RELATED M&S HAS BEEN THE DEVELOPMENT AND USE OF STANDARDS. INTEROPERABILITY STANDARDS (E.G., DIS, TENA, AND HLA), NATURAL ENVIRONMENT STANDARDS (E.G., SEDRIS), SIMULATION DEVELOPMENT PROCESS STANDARDS (E.G., FEDEP), AND MANY OTHERS HAVE ALL MADE CONTRIBUTIONS TO ENHANCING THE INTEROPERABILITY, REUSABILITY, AND CAPABILITY OF DEFENSE-RELATED M&S SYSTEMS. THE TECHNICAL CAPABILITIES OF THESE STANDARDS ARE IMPORTANT PREDICTORS OF THEIR SUCCESS. HOWEVER, THE GOVERNANCE STRUCTURES AND PROCESSES AND OTHER NON-TECHNICAL CHARACTERISTICS OF THE VARIOUS STANDARDS HAVE ALSO AFFECTED THEIR ACCEPTANCE AND UTILIZATION AND ULTIMATELY THEIR SUCCESS AND IMPACT. AN INITIAL STUDY WAS CONDUCTED TO IDENTIFY POSSIBLE CORRELATIONS BETWEEN THE ELEMENTS OF A SET OF CHARACTERIZING ATTRIBUTES OF MILITARY M&S STANDARDS AND THE SUCCESS OF THOSE STANDARDS. A TOTAL OF 22 STANDARDS IN 9 CATEGORIES WERE STUDIED AND 10 CHARACTERIZING ATTRIBUTES OF THOSE STANDARDS WERE IDENTIFIED AND EVALUATED. THE STANDARDS' SUCCESS WAS ASSESSED BY A GROUP OF STANDARDS EXPERTS USING A LIKERT-TYPE SCALE. TECHNICAL SPECIFICITY AND GOVERNANCE FORMALITY WERE FOUND TO CORRELATE WITH STANDARDS SUCCESS. RANGE OF OPINION AMONG THE EXPERTS WAS NOT FOUND TO CORRELATE WITH STANDARDS SUCCESS.

1. Introduction

This paper is organized into three main sections. This section sets the context for the work; it describes the overall project, a study of the governance forms and processes for standards, and the specific task within that project, an investigation of factors leading to the success of military modeling and simulation (M&S) standards. The second section lays out the methodology for the investigation. The third section reports the results of an analysis of the correlation between selected standards attributes and success for military M&S standards.[1]

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1.1 Overall project background and objectives

A congressionally funded project entitled "Standards in Modeling and Simulation" has brought together a team led by Old Dominion University's Virginia Modeling, Simulation, and Analysis Center, to investigate the possible future national M&S standards governance processes and what future M&S standards requirements might be. The project has also received contributions from individuals in many application domains of M&S, including the National Aeronautics and Space Administration (NASA), the Society of Simulation in Healthcare (SSIH), the Department of Defense (DoD), and the North Atlantic Treaty Organization (NATO).

The project was motivated by two current issues with M&S standards: a decline in leadership in M&S standards policy over the last 10 years within the DoD, and the lack of reuse of simulations and simulators within the federal government. The first issue is well summarized in [1]. Interest in the second issue stems from the widespread belief that simulation reuse will provide cost-savings and that standards will enable such reuse. However, standards' development and implementation is not free; thus determining the Return on Investment (ROI) of an M&S standard is critical to achieving any cost-saving from reuse.

The project has been collecting information through basic research and workshops, over the last two years, to investigate these issues. To date, four multi-day workshops have been conducted within the project's framework. Each workshop covered a variety of topics as diverse as organizational misbehavior to the future of M&S itself. The workshops provided the M&S community, including academia, government, and industry, an open non-attributable environment to express their viewpoints and experiences, and provided the project team with a wealth of data to draw upon for their own investigations which, in turn, have been presented back to the workshop participants.

The first year of the project concluded with several recommendations relating to M&S standards [2]. For example, M&S standards should be developed and governed through voluntary consensus standards organizations, which is the dominant approach to standards development throughout the world; SISO is an example of such an organization. Another recommendation was that ROI measures of M&S standards are fundamental to the successful long-term adoption of standards; however, ROI measures are not obvious and further research must be conducted into them. The results presented in this paper are an attempt to tackle this difficult problem; other attempts include the research of the Naval Postgraduate Schools into cost-benefits of interoperability standards [3].

1.2 Military M&S standards success

M&S has arguably been used more extensively by the United States military than any other organization, and taken in total, that use has been hugely successful. M&S in general is often used in situations where exercising or experimenting with the real-world subject of the simulation would be too difficult, too expensive, or too dangerous, and military applications in particular include some of the most extreme examples of those situations. Consequently, use of M&S permeates the DoD with an extensive range of applications that includes training, acquisition, analysis, experimentation, engineering, and test and evaluation, with many subcategories of application within each of these [4]. The nearly ubiquitous adoption of M&S technologies throughout the DoD provides incontrovertible evidence of its efficacy and cost-effectiveness. Ample anecdotal evidence is available as well; for example, one soldier upon return from the 1990-1991 Gulf War asserted that "the enemy we faced in [the SIMNET virtual training simulation] was more challenging than the Iraqis" [5].

A crucial enabling factor for the success of DoD M&S has been the development and use of standards. Virtually every implementation or application of M&S technology in DoD uses or is influenced by standards, in many cases multiple standards [6]. Two factors contribute to an explanation of this. First, the DoD M&S community has been quick to recognize the value of standards in general, and practitioners within the community are generally willing to volunteer time to participate in creating, maintaining, and using standards [7]. Second, there are many types of standards relevant to the practice of M&S in the DoD. Interoperability standards (e.g., DIS, TENA, and HLA), synthetic natural environment standards (e.g., SEDRIS), simulation development process standards (e.g., FEDEP and DSEEP), object modeling standards (RPR FOM and BOM), and many others have all contributed to enhancing the interop-

[1]The text of this paper is largely based on earlier reports of this work [14] [15]. This paper includes additional expert survey responses collected after those earlier reports and presents new qualitative and quantitative correlation results based on the additional data.

erability, reusability, and capability of defense-related M&S systems, thereby supporting their widespread application. Clearly, the technical characteristics and capabilities of the military M&S standards have much to do with their success (or in some cases, lack thereof). However, non-technical considerations, including financial support, leadership continuity and commitment, and governance structures and processes for the various standards have also affected their acceptance and utilization, and ultimately their effectiveness and impact.

The importance of standards in the DoD M&S community, and the complicated and inter-related set of factors that determine their success, motivate the study of M&S standards. The goal of such study is to better appreciate what makes a military M&S standard successful, and thereby increase the return on investment for future DoD resources expended on standards development and to develop more effective processes for standards governance [8].

In contrast to most of the standards-related effort in the DoD M&S community, the goal of this study is not to develop or revise a standard. Instead, standards are the objects of study, thus in some sense, standards are data. Fortunately, military M&S standards are generally well-documented in terms of both their technical characteristics and governance processes. An approach to studying standards should be derived from the set of specific research questions that are the objectives of the study. In this case those questions are:

1. What current and past M&S standards and standards categories exist within the U. S. DoD?
2. How successful have the various military M&S standards been?
3. What characteristics of military M&S standards, and the context in which they are developed and used, lead to their success (or non-success)?
4. How do the governance processes employed to control the creation and revision of military M&S standards affect the standards' success?
5. How should current and future military M&S standards be governed?

1.3 Categories and definitions

The military M&S standards studied were grouped into categories to enable improved understanding and more direct intra-category comparisons of standards' attributes and success. The categories, and the standards studied within each category, are:[2]

1. *Distributed simulation;* standards intended to allow independently executing simulation applications to interoperate, typically via a network, so as to collaboratively simulate a common scenario or environment. Standards studied: SIMNET, ALSP, DIS, HLA, TENA, XMSF
2. *Live training;* standards intended to allow instrumentation supporting live training to interoperate, typically via wireless communication, so as to exchange and record information needed to manage and mediate an exercise. Standards studied: MILES, CTIA
3. *Object modeling;* standards intended to provide common notations and methods to specify object models.[3] Standards studied: RPR FOM, BOM
4. *Conceptual modeling;* standards intended to provide common notations and methods to specify conceptual models.[4] Standards studied: UML, DoDAF
5. *Synthetic environment;* standards intended to define representation and interchange data formats and access algorithms for data defining the synthetic environment (sea, atmosphere, space) and terrain (surface of the earth and surface features, such as buildings). Standards studied: SDIS, NFDD, SEDRIS
6. *Simulation development;* standards intended to provide guidance to simulation developers during the process of designing, implementing, testing, and executing simulation systems. Standards studied: FEDEP, DSEEP, VV&A Overlay, VV&A RPG
7. *Scenario definition;* standards intended to provide a common specification and data interchange format military scenarios that could be loaded into different applications. Standards studied: MSDL
8. *Command and control;* standards intended to define a shared, unambiguous, and comprehensible language for communicating command and control, situational awareness, and common operational picture information among real or simulated forces. Standards studied: C-BML

[2]To save space in this list, only the abbreviated names (acronyms) are used for the standards. The expanded names for these standards will be given later.
[3]In the context of military M&S, an "object model" is most often a specification of objects classes and their attributes which define the entities that can exist within the simulation.
[4]A "conceptual model" is a non-executable model that identifies in an informal or semi-formal way the objects, relationships, and actions to be modeled in a simulation system and their relationships and interactions.

9. *Enumerations;* standards intended to provide common lists of specific data values used to encode entity types and other shared attributes within a given protocol. Standards studied: DIS Enumerations

Even a cursory examination of the preceding list of categories and standards for "military M&S standards" will reveal that in developing the list both the terms "military" and "M&S" have been interpreted rather loosely. For example, UML is certainly not solely a military standard because it is used for a much larger range of applications than just military applications, C-BML is not strictly an M&S standard because it is meant to be employed for real command and control applications as well, and standards purists would argue that TENA is not a standard at all because it has not been approved by a formal standards body. This definitional looseness is certainly not careless semantic imprecision, but rather an intentional inclusiveness. This initial study was meant to "cast a wide net" and consider a wide range of standards, as long as they had some substantial relevance to the practice of military M&S. Hereinafter, the term "standard" should be understood to have a meaning closer to "standard-like construct" than "official standard". In other words, the term will be used to include both official (de jure) standards that have been sanctioned and certified by a recognized standards body and unofficial (de facto) standards that, while lacking formal approval, have the technical and structural characteristics of a standard and by virtue of their widespread adoption have some of the benefits of a standard. However, the distinction between official standards and non-standards will not be ignored. The type and specificity of each standard studied, which can help to distinguish those standard-like constructs that meet the formal definition of a standard from those that do not, will be reported for each standard.

Abbreviation	Expansion
SIMNET	Simulator Networking
ALSP	Aggregate Level Simulation Protocol
DIS	Distributed Interactive Simulation
HLA	High Level Architecture
TENA	Test and Training Enabling Architecture
XMSF	Extensible Modeling and Simulation Framework
MILES	Multiple Integrated Laser Engagement System
CTIA	Common Training Instrumentation Architecture
RPR FOM	Real-time Platform Reference Federation Object Model
BOM	Base Object Model
UML	Unified Modeling Language
DoDAF	Department of Defense Architecture Framework
SDIS	SIMNET Database Interchange Format
SEDRIS	Synthetic Environment Data Representation and Interchange Specification
NFDD	National System for Geospatial Intelligence Feature Data Dictionary
FEDEP	Federation Development and Execution Process
VV&A RPG	Verification, Validation, and Accreditation Recommended Practices Guide
VV&A Overlay	Verification, Validation, and Accreditation Overlay
DSEEP	Distributed Simulation Engineering and Execution Process
MSDL	Military Scenario Definition Language
C-BML	Coalition Battle Management Language
DIS Enumerations	Distributed Interactive Simulation Enumerations

Table 1. Military M&S standards selected for study

2. Methodology

This section lays out the study methodology.

2.1 Process

Historically, the emphasis in the military M&S community has been on developing and using standards, not studying them, so the unfamiliar perspective of the latter naturally raises questions regarding an appropriate methodology. The study process used has these basic steps:

1. List military M&S standards, and select a representative sample for closer study.
2. Identify a set of attributes (individual data items) about those standards to examine.
3. Collect the attributes regarding the selected military M&S standards.
4. Analyze the collected data to determine if any of the identified attributes correlate with success.

2.2 Standards and attributes studied

A total of 22 military M&S standards in 9 categories were selected for study; they are listed in Table 1. For those standards, 10 attributes were identified and evaluated.

These attributes were initially chosen as the data to be gathered about military M&S standards:

1. *Name;* name by which the standard is commonly known
2. *Category;* class of application for which the standard is intended (discrete value definitions given later)
3. *Status;* values: pending, active, inactive
4. *Year;* year in which the standard first went into effect
5. *Type;* values: official/de jure, unofficial/de facto, proprietary [8]
6. *Form;* values: recommend practice, technical specification, product line [5]
7. *Governance type;* values: standards body, management group, closed
8. *Governance formality;* formality of process to change standard (discrete value definitions given later)
9. *Technical specificity;* degree to which the standard prescribes a compliant implementation (discrete value definitions given later)
10. *Success;* degree to which a standard is successful (detailed definition give later)

The "Success" attribute differs from the others in an important way; it is the desired "dependent variable", whereas the other attributes are potential independent variable(s) that may help to determine or predict success. An objective of this study was to determine which of the independent variables, i.e., the attributes, if any, actually predict success in a standard.

Two of the attributes, governance formality and technical specificity, were conjectured to positively correlate with success of a standard. They required special definitions for their data values. Neither an absolute numerical scale nor a discrete set of descriptive terms seemed to usefully represent the intended meaning and range of values of these attributes, so for each a 5-point Likert-type ordered response encoding scheme was defined and used [9].

Technical specificity was defined as "the degree to which the standard defines or provides content which is implementable or executable as written".

The attribute values used for technical specificity were:

1. Descriptive text
2. Mixture of descriptive text and technical specifications
3. Detailed technical specifications
4. Detailed technical specifications supplemented with some compilable/executable code
5. Universally used identical compilable/executable code

Governance formality was defined as "the degree to which the process of setting and changing the standard is controlled by formally prescribed processes". The attribute values used for governance formality were:

1. Arbitrary control by organization or individual with no procedural controls
2. Informal management group with no procedural controls
3. Organized management group with self-enforced procedures
4. Organized management group with semi-formal and transparent procedures, or standard pending with official standards body
5. Official standards body (e.g., IEEE or SISO) with fully formal procedures

Table 2 summarizes the 22 standards and the attribute values identified for them. Other attributes relating to standards in general, or military M&S standards in particular, were considered or suggested by members of the community, but were not used in this initial study. The reasons for their non-use included overlap with other attributes, actual or anticipated difficulty in securing reliable data, inconsistent definitions within the community, or perceived challenge to vested interests. Those additional non-used attributes included:

1. *Government investment;* total and annual spending to support the standard
2. *Industry investment;* total and annual spending to support the standard
3. *Size of user community;* number of potential users for the standard

[5] In this context, a technical "product line" is a set of technical specifications, common architectural frameworks, and reusable software modules that are intended to be used to develop multiple applications that are, by virtue of those applications' use of the product line assets, interoperable with each other. In addition to the product line standards described herein, the OneSAF semi-automated forces system employs a product line architecture [Courtemanche, 2002].

4. *Potential applications;* number and breadth of potential uses for the standard
5. *Utility;* usefulness and effectiveness of the standard
6. *Ubiquity;* proportion of actual use among potential users
7. *Technical complexity;* complexity of the standard with respect to its purpose [10]

Name	Category	Status	Year	Type	Form	Governance type	Governance formality	Governance specificity
Category	Status	Year	Type	Form	Governance	Closed	1	4
type	Governance	Inactive	1992	Unofficial	Technical specification	Architecture management group	3	4
formality	Technical	Active	1993	Official	Technical specification	Standards body	5	3
specificity	Distributed simulation	Active	1996	Official	Technical specification	Standards body	5	4
TENA	Distributed simulation	Active	1997	Unofficial	Product line	Architecture management group	3	5
XMSF	Distributed simulation	Inactive	2002	Unofficial	Technical specification	Architecture management group	2	3
MILES	Live training	Active	1980	Proprietary	Product line	Closed	1	5
CTIA	Live training	Active	2001	Unofficial	Product line	Architecture management group	3	5
RPR FOM	Object modeling	Active	1999	Official	Technical specification	Standards body	5	4
BOM	Object modeling	Active	2006	Official	Technical specification	Standards body	5	3
UML	Conceptual modeling	Active	1996	Unofficial	Technical specification	Architecture management group	3	2
DoDAF	Conceptual modeling	Active	2003	Official	Technical specification	Architecture management group	3	3
SDIS	Synthetic environment	Inactive	1987	Proprietary	Technical specification	Closed	1	3
SEDRIS	Synthetic environment	Active	1994	Official	Technical specification	Standards body	5	4
NFDD	Synthetic environment	Active	2005	Official	Technical specification	Standards body	4	3
FEDEP	Simulation development	Active	2003	Official	Recommended practice	Standards body	5	2
VV&A RPG	Simulation development	Active	2006	Unofficial	Recommended practice	Closed	2	2
VV&A Overlay	Simulation development	Active	2007	Official	Recommended practice	Standards body	5	2
DSEEP	Simulation development	Active	2010	Official	Recommended practice	Standards body	5	2
MSDL	Scenario definition	Active	2008	Official	Technical specification	Standards body	5	3
C-BML	Command and control	Pending	2006	Official	Technical specification	Standards body	5	3
DIS Enumerations	Enumerations	Active	1993	Official	Technical specification	Standards body	5	3

Table 2. Summary of attribute values for military M&S standards studied

Standard	VU	SU	NUNS	SS	VS	NR	Median	Mode	Range
MSDL	1	3	15	25	3	25	SS	SS	5
C-BML	1	4	17	15	9	26	SS	NUNS	5
NFDD	3	2	11	1	2	53	NUNS	NUNS	5
SDIS	1	2	11	3	2	53	NUNS	NUNS	5
SEDRIS	1	8	9	25	12	17	SS	SS	5
SIMNET		1	5	21	19	26	SS	SS	4
ALSP	1	6	9	18	8	30	SS	SS	5
DIS		2		14	52	4	VS	VS	4
HLA	1		2	21	45	3	VS	VS	5
TENA		1	2	30	24	15	SS	SS	4
XMSF	8	3	13	10	2	36	NUNS	NUNS	5
MILES		1	4	8	22	37	VS	VS	4
CTIA		4	15	8	6	39	NUNS	NUNS	4
RPR FOM			5	16	36	15	VS	VS	3
BOM	2	7	10	25	8	20	SS	SS	5
UML			5	18	41	8	VS	VS	3
DoDAF		4	8	28	20	12	SS	SS	4
FEDEP		2	8	27	21	14	SS	SS	4
DSEEP	1	1	15	22	4	29	SS	SS	5
VV&A Overlay	1	5	11	16	7	32	SS	SS	5
VV&A RPG		3	9	19	11	30	SS	SS	4
DIS Enumerations		1	2	21	30	18	VS	VS	4

Key

VU = Very Unsuccessful
SU = Somewhat Unsuccessful
SS = Somewhat Successful
VS = Very Successful
NR = No Response
NUNS = Neither Unsuccessful Nor Successful
Median = Half responses above, half responses below
Mode = Most frequent response
Range = Values from lowest response to highest response

Table 3. Responses to standards success assessment survey

8. *Timing;* relative earliness of introduction and existence of need [10]

9. *Competition;* quantity and quality of competing standards

10. *Application;* type(s) of applications which the standard supports

11. *Update frequency;* frequency with which the standard is revised and updated

Of course, the study methodology as described so far begs the question of how to define "success" with respect to a standard. Definitions are central to communication and research, and the definition of a key term (perhaps "the" key term) in this study could be contentious. For the purposes of this study, the following definition was used: "An M&S standard is successful if it largely meets its technical objectives and substantially benefits a class of users over a period of time proportional to the investment required to create it."

2.3 Data collection

An objective or quantifiable means of measuring the success of a standard was unavailable.[6] In lieu of such a metric, the standards' success was assessed by four groups of standards experts, totaling 72 persons. The experts were given the list of military M&S standards in Table 2 and asked to assess the success of each one on a 5-point Likert-type ordered response encoding scheme [9]; the values were: Very Unsuccessful (VU), Somewhat Unsuccessful (SU), Neither Unsuccessful Nor Successful (NUNS), Somewhat Successful (SS), and Very Successful (VS). The four groups of experts surveyed were:

1. A group of 18 persons selected for their known expertise in military M&S standards by the study author and sent a standards success survey instrument directly via electronic mail in September 2010 and May 2011.

2. A group of 21 persons who attended a workshop on M&S standards organized by Old Dominion University on May 11 2011.

[6]The author's attempts to develop and justify such a metric encountered a range of dauntingly problematic obstacles, including a lack of consensus on what constituted success and non-availability of reliable data for success-related measures, such as number of users. Creating such a metric remains an open research question.
[7]A group of 43 standards experts were actually sent the survey instrument; 18 experts responded.

3. A group of 25 persons who attended the System Life Cycle and he Distributed Simulation Process and Tools forums at the Fall 2011 Simulation Interoperability Workshop on September 21 2011.
4. A group of 8 persons who attended the U. S. Army RDECOM Modeling and Simulation Senior Working Group meeting on June 28 2012.

The informed opinions of the 72 experts regarding the success or lack thereof of military M&S standards are reported in Table 3.

3. Results

This section reports the results of the standards success survey and correlation analysis. The standards' attribute values for governance formality and technical specificity, which had been conjectured to correlate positively with standards success, were examined for correlation with the experts' assessments of success. Conventional correlation statistics (e.g., Pearson's correlation coefficient [11]) were not calculated because converting the discrete Likert assessment values into numerical scalars was considered methodologically questionable. Instead, a two-stage analysis of correlation was undertaken; the first was a qualitative correlation analysis and the second was a quantitative correlation analysis based on a correlation statistic suitable for the survey data.

3.1 Survey results

Table 2 summarizes the attribute values for the military M&S standards examined. Additional military M&S standards exist even beyond the standards in the table. However, the standards selected and summarized in the table include an important subset, and were selected to be representative of the set of military M&S standards.

Table 3 summarizes the results of the experts' assessments of the standards success. It shows the number of experts who selected each of the success values for each of the standards studied.

A naïve analysis of the results in Table 3 would have assigned numerical ratings to the response values (e.g., Very Unsuccessful = –2, Somewhat Unsuccessful = –1, Neither Unsuccessful Nor Successful = 0, Somewhat Successful = +1, Very Successful = +2) and then compute a numerical weighted mean of the responses using these ratings. However, this procedure is methodologically questionable in that any assignment of numerical ratings to the response values implicitly assumes some quantitative ratio between the values (e.g., "Very Successful" is 2x as good as "Somewhat Successful"); such ratios cannot be assumed to be an accurate reflection of the intentions of the experts' as they made their assessments. Consequently, the table does not report mean success.[8] Instead, it reports median (the response value with half the total responses below it and half above it) and mode (the most common response value) as measures of centrality.[9] The table also reports range, which is the number of response values from the lowest to the highest (inclusive) as an indicator of variance.

3.2 Qualitative correlation

The first stage of the correlation analysis was a categorical or qualitative correlation check. A band of corresponding values for each attribute were defined as correlating (e.g., high values for one attribute were considered to positively correlate with high values of the other attribute).[10] The proportion of standards from among those studied which met the categorical correlation definition was calculated, with a larger proportion interpreted as indicating overall correlation.

Tables 4, 5, and 6 summarize the qualitative correlation results for the 22 standards. The unshaded portions of the tables show values considered to correlate and the shaded portions show those that do not correlate.

As shown in Table 4, for 17 of the 22 standards, governance formality was found to positively correlate with standards success. As shown in Table 5, for 14 of the 22 standards, technical specificity was found to positively correlate with standards success. These two attributes were found to qualitatively correlate with success. A secondary conjecture was that range (as defined in Table 3) would correlate negatively with standards success.[11] As shown in Table

[8]The reader is invited to calculate the means as suggested if he or she does not share the authors' methological misgivings.
[9]Note that in all but one case, the mode response is the same as the median response; consequently, only the median response will be analyzed further.
[10]Specifically, as shown in the tables success value VS was assumed to qualitatively correlate with governance formality values 4 and 5, SS with 3, 4, and 5, NUNS with 2, 3, and 4, SU with 1, 2, and 3, and VU with 1 and 2. Similar assumptions were made for technical specificity.
[11]The idea behind the range conjecture was that successful standards would be widely recognized as such.

6, for only 1 of the 22 standards does range negatively correlate with standards success, i.e., range does not in fact negatively correlate as conjectured.

	1	2	3	4	5
VS	1		1		4
SS	1	1	3		7
NUNS	1	1	1	1	
SU					
VU					

Table 4. Qualitative correlation of governance formality and success median (17 of 22 positively correlated)

	1	2	3	4	5
VS		1	2	2	1
SS		4	4	3	1
NUNS			3		
SU					
VU					

Table 5. Qualitative correlation of technical specificity and success median (14 of 22 positively correlated)

	1	2	3	4	5
VS			2	3	1
SS				5	7
NUNS				1	3
SU					
VU					

Table 6. Qualitative correlation of range and success median (1 of 22 negatively correlated)

3.3 Gamma correlation

The second stage involved a statistical measure of correlation deemed appropriate for the standards success data. Goodman and Kruskal's gamma statistic is a nonparametric statistic used to evaluate the correlation between two variables.[12,13] While there are other possibly relevant statistics (e.g., Spearman's rho and Kendall's tau), the gamma statistic is preferred when there are multiple ties in the data, i.e., when two or more values for a given variable are equal, which was true in the standards survey data. Sample applications of the gamma statistic include pharmaceutical clinical trials [12] and financial investments [13].

Conceptually, the gamma statistic is evaluated by evaluating pairwise comparisons. For every possible pair of members of the sample, the rank order of the variables of interest on one member is compared to the rank order of the same variables on the other member. If the rank order of the variables is the same for the two members, they are considered a *concordant* pair and if the rank order is different they form a *discordant* pair. If either of the members have equal values for the two variables, the pair is dropped.

For example, SDIS has a governance formality value of 1 and a success value of NUNS, whereas SEDRIS has a governance formality value of 5 and a success value of SS. The rank order of SEDRIS is higher in both, making SDIS and SEDRIS a concordant pair. On the other hand, MILES has a governance formality value of 1 and a success value of VS, whereas CTIA has a governance formality value of 3 and a success value of NUNS. The rank order of the CTIA governance formality value is higher but the rank order of the MILES success value is higher, making MILES and CTIA a discordant pair.

The gamma statistic is calculated by subtracting the number of discordant pairs, denoted as D, from the number of concordant pairs, denoted as C, and then dividing by the sum of C and D:

$$\Gamma = \frac{C - D}{C + D}$$

The gamma statistic falls within the interval (1, –1), where 1 indicates a perfect positive correlation, –1 indicates a perfect negative correlation, and 0 indicates that there is no correlation and that the variables are independent.

In this analysis, every possible pair of standards was considered.[14] For technical specificity, if the rank order of technical specificity and success on one standard matched that of the other standard, the pair was concordant; if the order was reversed, the pair was discordant. The same applies to governance formality.

[12]The statistic is sometimes denoted γ instead of gamma.
[13]Nonparametric statistics are used when no assumptions can be made about a population's distribution [Brase, 2009].

Given C and D, Γ for governance formality is calculated as follows:

$$\Gamma = \frac{C - D}{C + D} = \frac{75 - 30}{75 + 30} \approx 0.0667$$

In evaluating the correlation of governance formality with standards success, a gamma value of $\Gamma = 0.4286$ suggests that there is moderate positive correlation between governance formality and the success of a standard.

Given C and D, Γ for technical specificity is calculated as follows:

$$\Gamma = \frac{C - D}{C + D} = \frac{56 - 49}{56 + 49} \approx 0.0667$$

In evaluating the correlation of technical specificity with standards success, a gamma value of $\Gamma = 0.0667$. This suggests that there is essentially no relationship between technical specificity and the success of a standard.

4. Discussion, conclusions, and future work

This section includes a discussion of issues and resolutions in the study methodology, a statement of conclusions, and a list of possible future work.

4.1 Discussion

It is possible for a study of this form to be inadvertently influenced by unintentional observational bias. Here we discuss three related forms of observational bias that could affect this study or studies like it. First, it is generally only the successful standards that are readily identifiable, well documented, and widely familiar to experts. Unsuccessful standards are generally more obscure, poorly documented, and generally less well known in the M&S community. Thus, unsuccessful standards would presumably tend to get a larger number of No Response responses than successful standards. To compensate for this bias, it might be reasonable to treat "No Response" responses as indicating that a standard was unsuccessful. As can be seen in Table 3, such an adjustment would certainly affect the results. However, no methodologically defensible means of doing so was identified and that adjustment was not performed.

Second, because unsuccessful standards are less well known, they are less likely to be nominated for study by members of the community. Without sufficient awareness of this effect, and considerable effort to overcome it by seeking out unsuccessful standards to include in the study, only successful standards might be included in the study. The result would then be potential difficulty in identifying any standards attribute values that predict success because if all of the studied standards are successful than all attribute values appear to predict success. To compensate for this bias, attention was given and effort was expended to include unsuccessful standards in this study.

Finally, few people find it easy to admit that a standard that they themselves or a respected colleague contributed to was in fact unsuccessful. There is even some reluctance among people to characterize any standard as unsuccessful, for fear of harming a professional or personal relationship or the professional reputation of those persons who contributed to the standard. This bias might tend to produce overly successful assessments of the standards. However, no attempt was made to compensate for this bias.

Clearly causation and correlation could become confused in a study of this type. If standards with a given set of attribute values tend to be more successful, is it because those attributes values cause success, success causes those attributes, or both those attribute values and success are caused by a third unidentified factor? Careful analysis and further study would likely be required to distinguish cause from effect. For this study, simply identifying a correlation of standards attributes values and success was deemed sufficient.

The most significant methodological difficulty encountered was in objectively measuring success in a standard. As discussed earlier, the seemingly best objective measures of success in a standard are among those standards attributes for which reliable data is most difficult to acquire. After much unproductive effort to overcome this difficulty, the solution chosen was to assess success in standards subjectively rather than objectively, in the form of the survey of experts reported earlier.

4.2 Conclusions

The qualitative correlation results suggest that governance formality and technical specificity are positively correlated with standards success. The gamma statistic supports that

[14]With 22 standards in the study, there are (22·21)/2 = 231 possible pairs of standards.

conclusion for governance formality but appears to contradict it for technical specificity. Additional data, which is being sought, may lead to stronger conclusions.

4.3 Future work

This study could be enhanced and expanded in any or all the following ways:

1. Secure additional responses from community experts for the standard success survey.
2. Identify and add additional categories of military M&S standards.
3. Identify and study additional standards within the current and new categories.
4. Select additional standards attributes from among the non-used attributes listed earlier and collect data for them for the studied standards.
5. Include non-U. S. standards in the study.
6. Develop and validate a numerical measure of standards success and repeat the correlation analysis.

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Authors' biographies

Dr. Mikel D. Petty

Mikel D. Petty is Director of the University of Alabama in Huntsville's Center for Modeling, Simulation, and Analysis, an Associate Professor in the Computer Science department, and a Research Professor in the Industrial and Systems Engineering and Engineering Management departments. Prior to joining UAH, he was Chief Scientist at Old Dominion University's Virginia Modeling, Analysis, and Simulation Center and Assistant Director at the University of Central Florida's Institute for Simulation and Training. He received a Ph.D. in Computer Science from the University of Central Florida in 1997. Dr. Petty has worked in modeling and simulation research and development since 1990 in areas that include simulation interoperability and composability, human behavior modeling, multi-resolution simulation, and applications of theory to simulation. He has published over 170 research papers and has been awarded over $14 million in research funding. He served on a National Research Council committee on modeling and simulation, is a Certified Modeling and Simulation Professional, and is an editor of the journals SIMULATION and Journal of Defense Modeling and Simulation. While at Old Dominion University he was the dissertation advisor to the first and third students in the world to receive Ph.D.s in Modeling and Simulation and is currently coordinator of the M&S degree program at UAHuntsville.

Ms. Retonya L. Dunning

Retonya L. Dunning is a Graduate Research Assistant at the University of Alabama in Huntsville's Center for Modeling, Simulation, and Analysis. She earned a B.S. in Mathematics from Alabama Agricultural and Mechanical University in 2009 and a M.S. in Modeling and Simulation at the University of Alabama in Huntsville in 2012.

Dr. Andrew J. Collins

Andrew J. Collins is a Research Assistant Professor at the Virginia Modeling, Analysis and Simulation Center which is part of Old Dominion University. He received a Ph.D. from the University of Southampton, UK in 2009 for applying reinforcement learning to an airline pricing game simulation. Previous to pursuing an academic career, Dr. Collins worked for the UK's Ministry of Defence (MoD) as an operational analyst where he was worked on peace-support operations simulations and the application of game theory to terrorism issues. Dr. Collins holds a B.A. in Mathematical Sciences from University of Oxford.

The Importance of Establishing Common Methods and Terminologies in Data Mappings

AUTHORS

Dr. Robert Cox
PEO STRI, PM ITTS/IMO
rob.m.cox@us.army.mil

Mr. Paul Dumanoir
Joint Training Integration & Evaluation Center
paul.dumanoir@us.army.mil

Dr. Louis Hembree
Naval Research Laboratory Monterey
louis.hembree@nrlmry.navy.mil

Mr. Farid Mamaghani
SEDRIS
farid@sedris.org

Mr. Kevin Trott
Northrop Grumman Information Systems
kevin.trott@ngc.com

Ms. Michele Worley
SAIC
michele.l.worley@saic.com

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Abstract

DATA PROVIDERS HAVE METHODOLOGIES FOR IDENTIFYING AND DEFINING THE CONTENT IN THEIR DATA PRODUCTS. OFTEN THESE METHODOLOGIES ARE BASED ON FORMAL DICTIONARIES OR CATALOGUES OF TERMS/CONCEPTS, WHICH MAY OR MAY NOT BE UNIQUE TO A PARTICULAR DATA PRODUCT OR A SPECIFIC DATA MODEL. MOST DATA USERS COMBINE PRODUCTS FROM DIFFERENT DATA PROVIDERS AND DATA SOURCES, REQUIRING DATA TO BE ALIGNED, CORRECTED, AND CORRELATED. THIS REQUIRES A PROCESS THAT INVOLVES VALUE ADDING TO EXISTING DATA BY COMBINING, ADJUDICATING, CONFLATING, MERGING, THINNING, ORGANIZING, AND ADDING DETAIL TO THE FINAL DATA FROM VARIOUS SOURCES. SUCH DATA INTEGRATION DEMANDS THE USE OF A SINGLE CONSISTENT METHODOLOGY FOR IDENTIFYING AND DEFINING THE CONTENT. INTEROPERABILITY BETWEEN SYSTEMS USING DIFFERENT METHODOLOGIES REQUIRES THE DEVELOPMENT OF CONSISTENT AND LOGICAL EXCHANGE MECHANISMS THAT MUST TAKE INTO ACCOUNT DATA SYNTAX, SEMANTICS AND ORGANIZATION. AN IMPORTANT COMPONENT OF DEVELOPING SUCH DATA EXCHANGE MECHANISMS IS THE ESTABLISHMENT AND USE OF FORMAL MAPPINGS BETWEEN DIFFERENT DICTIONARIES WITHIN THE CONTEXT OF THEIR RESPECTIVE DATA MODELS. TO ESTABLISH THESE MAPPINGS IT IS CRITICAL TO EMPLOY A COMMON APPROACH AND TERMINOLOGY THAT ADDRESSES THE VARIATIONS AND TYPES IN MAPPING OF CONCEPTS. THIS PAPER DISCUSSES METHODS AND TERMINOLOGIES THAT CAN FACILITATE THE DEVELOPMENT OF MAPPINGS BETWEEN DICTIONARIES AND/OR BETWEEN DATA MODELS USED IN THE ENVIRONMENTAL DOMAIN. THE PAPER HIGHLIGHTS WHY THE USE OF SUCH METHODS AND TERMINOLOGIES IS CRITICAL IN ESTABLISHING RELIABLE AND PRACTICAL MAPPINGS BETWEEN SYSTEMS, AND, THROUGH SPECIFIC EXAMPLES, DISCUSSES THE TYPES OF PROBLEMS THAT CAN OCCUR IN MAPPING.

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1. Introduction

Successful data interoperability between systems or applications depends on several factors. These include a solid understanding of how the systems or applications use the data, which in turn requires an understanding of data semantics, data organization, and data constructs. To successfully interoperate between systems, the software components involved in data conversion or translation usually rely on a design that heavily depends on understanding these data constructs and requirements. Therefore, developing a robust mapping between the relevant data elements used in different systems becomes a critical step in fulfilling interoperability. In the modeling and simulation (M&S) domain this mapping task becomes even more complex and critical, since usually many diverse systems are involved in networked M&S applications. This means data communication requirements, which often involve data translation or conversion, demand a solid foundation for a common data mapping between many diverse systems or applications. In addition, for many models or simulations, data is often brought in from a variety of sources, then integrated and fused before being utilized in the system. Therefore, similar to the interoperation requirements between systems, a consistent and common approach to data mapping from different sources to the internal data requirements of a given system becomes a natural part of the data integration process. To incorporate a reliable data mapping approach, whether for interoperation of heterogeneous systems or integration of data from diverse sources, the establishment and use of common mapping terminologies becomes an inherent part of the mapping process.

This paper draws from lessons learned in practical application of mapping methodologies and terminologies and discusses why such steps are important. The paper focuses on mappings related to environmental data, and discusses the importance of establishing standard terminology and approach for use in the development of mappings between environmental concept dictionaries and/or between data models or products. However, despite this specific focus, the same issues and principles will easily find application in other (non-environmental) data mapping efforts.

2. Background

In dealing with environmental data (such as ocean, terrain, atmosphere, or space data) many systems, databases, or data products employ their own dictionaries of terms or concepts in their data models, formats, or schemas. These systems often do not interoperate well together in part due to their diverse concept dictionaries, data models, or their use. The creation of a mapping between the concept dictionaries, data models, or products is a necessary, but not sufficient, step in developing applications that convert or translate data between systems.

Categorization, the process of classifying objects into categories, is fundamental to human reasoning and communication. The formal study of this topic dates back centuries, and plays a central role in philosophy, language, logic, mathematics, and many other areas. Classifying objects into categories is usually dependent on how the uses, functions, characteristics, and/or applications of those objects are viewed. This context-specific nature of categorization makes it difficult, if not impossible, to apply a single categorization for all purposes. How objects are organized within a given context can be completely different from how those same objects are thought of within a different context. Categorization is also critical to communication and interoperability between information systems. It is commonly necessary to translate data from the format(s) used by a given information system, to the format(s) used by another. Categorization plays a critical role in the creation of the mappings that allow such automated data translation to be performed. The process of creating such mappings, establishing a set of terminology to describe such mappings, and why this is an important process is the subject of this paper.

Development and use of such mappings may apply to a broad range of data encapsulations and at various levels of data abstraction. These range from dictionaries, to data/information models, to physical data products, and any number of derivatives in-between these. The process of how such mappings are developed can be generalized to apply at any of these levels of abstraction. However, there are enough variations in creating the mappings that the details of an approach often become critical to understanding the mapping. As a result, it is important to first

establish a baseline for what is meant by each of these data abstraction levels, and only then define the mapping approach and the corresponding terminology in accordance with that baseline.

3. Data abstraction

Defining data semantics and data specifications can be organized into several broad categories. Each of these can also be thought of as a model of the data at some level of abstraction. Some of the relevant and key categories are noted in this section. The DoD Architecture Framework (DoDAF) version 2.0 also defines similar required artifacts for system architectures.

Dictionaries – A dictionary simply consists of a collection of terms and their definitions that are used within a particular domain and context. There are variations in the scope of how a dictionary may be applied. These will be further highlighted. DoDAF requires that every system architecture description include an Integrated Dictionary (AV-2) that defines the terms used in the architecture to ensure semantic understanding across the enterprise.

Logical Data Models – A logical data model defines the various kinds of classes (also referred to as concepts, items, objects, or entities) that are of interest within a domain, the attributes that describe those classes, and the relationships among those classes. A logical data model is not particularly concerned with how information may be implemented or manifested in specific form or media. DoDAF requires a Logical Data Model (DIV-2) to document system data requirements and structural business process rules.

Physical Data Models – A physical data model adds the details of how information about each kind of object is to be stored, transmitted, and manipulated by hardware and software. This includes the specific data types to be used to represent each attribute, and the details of how each relationship and operation is to be implemented. DoDAF requires a Physical Data Model (DIV-3) to specify how a Logical Data Model is to be implemented in terms of message formats, file structures, and physical database schemas.

Based on the amount of detail that they may contain, data models cover a very broad range, from highly abstract or conceptual data models to detailed physical data models. Since a dictionary can be assumed to reflect a model of the data at some abstract level, it can be considered to form one extreme of the overall range of data models, providing the minimum amount of information necessary to start developing a mapping between different domains. At the other extreme, physical data models provide the necessary detailed information that allows automated data translation to be performed.

Whether formally identified or not, dictionaries play a fundamental role in the development of specifications and in the production of content for information systems. For example, for the standards developed by the International Organization for Standardization (ISO), the Shorter Oxford English Dictionary (SOED) [3] is the default dictionary for all terms that are used, but not explicitly defined.

In the context of expressing semantics of environmental data, and in particular in this paper, the terms defined in a dictionary denote concepts, which can include:

- Objects – Also known as classes, entities, things, and, in the geospatial community, features. These terms refer to objects of interest within the domain addressed by the dictionary. They are generally nouns, or noun phrases, that are used as the subjects and/or direct or indirect objects in declarative statements.
- Attributes – Also known as properties, characteristics, etc. These terms are used in describing objects, either qualitatively or quantitatively. They, or their associated values, are used as adjectives, or in other forms of descriptive phrases.

In practice, a dictionary is not a data model. However, its definitions may implicitly specify the basic relationship information from which a data model can be developed, for a given context. General-purpose dictionaries, sometimes referred to as concept dictionaries, can be used, in part or whole, as building blocks in the development of specific data models for specific applications or products. Once a data model has been developed, the collection of specific terms (classes or entities, and associated attributes) used in that data model form an associated dictionary specific to that data model. Such a dictionary is called a *data dictionary*. However, the term data dictionary is often incorrectly used to refer to concept dictionaries, catalogs, feature/attribute lists, and dictionaries of terms.

In concept dictionaries, attributes are defined generically, independent of how they may be used to describe specific objects. Concepts such as length or color can be used to describe many different types of objects. Defining these terms in a generic manner facilitates their consistent use when applied to different objects. By contrast, data models usually require, and define, specific pairings between objects and attributes. Additional constraints are provided in data models to meet specific application or product needs. As a result data dictionaries (dictionaries associated with a given data model) contain only those terms required for that data model.

As noted earlier, a concept dictionary is not a logical data model, let alone a physical data model. However, the definitions in a concept dictionary play a key role in identifying the attributes and relationships that are (or can be) associated with the concepts in the data models. Many definitions follow a pattern: they typically relate a concept to a more general concept, and then use descriptive phrases to further specify what differentiates this concept from all others within that more general concept. For example, in the definition: "A barn is an agricultural building that is designed to house animals and related equipment," "building" is the more general concept, while the phrases "agricultural" and "designed to house animals and related equipment" specify how a "barn" is distinguished, from other kinds of buildings, with respect to its form, function, and/or use.

4. Why mapping between dictionaries is important

To illustrate why mapping between dictionaries becomes an important step in the data conversion or translation process, it is useful to examine a few simple examples of how concepts are defined and provided in different dictionaries. We will use three dictionaries to illustrate this. These dictionaries have evolved over time and generally share similar lineage, but differ in approach, style, and content.

Within the geographic information community, the objects of interest are referred to as "features". The ISO Technical Committee 211 family of International Standards defines concepts and conceptual models for geographic information. ISO 19126:2009, Geographic Information – Feature concept dictionaries and registers, defines a "feature concept dictionary" to be a "dictionary that contains definitions of and related descriptive information about concepts that may be specified in detail in a feature catalogue". ISO 19110:2005/DAmd 1, Geographic Information – Methodology for feature cataloguing, Amendment 1, defines a "feature catalogue" as a "catalogue containing definitions and descriptions of the feature types, feature attributes, and feature relationships occurring in one or more sets of geographic data, together with any feature operations that may be applied. Thus, a feature catalogue, in general, should be expected to provide more of a data model than a feature concept dictionary.

These concepts have evolved over time, and are continuing to evolve. For example, most traditional NGA products were based on definitions of features and attributes contained in the Defence Geospatial Information Working Group (DGIWG) Feature and Attribute Coding Catalogue (FACC) [1]. Note the use of the term "catalogue" in its title. Earlier versions of FACC related attributes to features, but in the final version (Edition 2.1, Sep 2000, and the subsequent baseline maintenance releases, ending with BL 2003-4) these relationships were dropped.

The Environmental Data Coding Specification (EDCS) [6], ISO/IEC 18025:2005, is composed of nine related concept dictionaries, and is one of the SEDRIS technology components. Lessons learned from use of FACC were instrumental in the development of EDCS; however, because of requirements in SEDRIS the scope and level of detail in EDCS was broader than FACC. In addition, EDCS introduced a set of refinements in the logical decomposition of concept definitions. These included separating units of measure and scale from attributes; placing units and scale definitions in their own dictionaries; explicitly relating a given concept to other concepts in EDCS; and providing citations and references for concept definitions. The standard also allows the extension of its content through an online registration process.

The DGIWG Feature Data Dictionary (DFDD) [2] is the successor to FACC, and is derived from both FACC and EDCS, incorporating concepts such as separating units of measure from definitions, as well as utilizing an online registry. However, DFDD does not explicitly relate definitions.

To illustrate why consistent mapping methodologies are important, we briefly examine several related concepts in these three dictionaries.

FACC 2.1 defined the feature concept "Building" (AL015) as: "A relatively permanent structure, roofed and usually walled and designed for some particular use." FACC did not define specific kinds of buildings. Instead, it provided an attribute called "Building Function Category" (BFC), defined as: "Type or purpose of the building", with a list of coded values. One of these values was BFC 125, "Barn/ Machinery Shed".

EDCS defines a "Building" as: "A fixed, relatively permanent <STRUCTURE> with a <ROOF> and usually with <WALL>(s) that is designed for use and occupancy by <HUMAN>s; a building." Note the links and reuse of other related concepts, denoted by brackets and all-cap identifiers. The linked items explicitly refer to other existing concepts in the EDCS. EDCS also defines a "Barn" as: "A <FARM_BUILDING> that is used to store hay, grain, and implements and/or to house <NON_HUMAN_ANIMAL>s; a barn [SOED, "barn", A.1] [SOED, "barn", A.2]." And the concept of "Farm Building", used in the definition of "Barn", is defined as: "A <BUILDING> located on a <FARM>." Similar to FACC, EDCS also includes a "Building Function" attribute, defined as "The function of a <BUILDING>", which includes a value "Barn". EDCS also defines many components of buildings, including roof, wall, door, window, etc.

DFDD defines the feature concept "General Building" (AL015) as: "A relatively permanent structure, roofed and usually walled and designed for some particular use." DFDD also defines the feature concept "Building" (AL013) as: "A free-standing self-supporting construction that is roofed, usually walled, and is intended for human occupancy (for example: a place of work or recreation) and/or habitation." As in EDCS, since the DFDD definition of building is more specifically oriented toward human occupancy, DFDD also defines the feature concept "Barn" (AJ085) as: "A roofed farm building designed for sheltering harvested crops (for example: hay), livestock (for example: cattle), and/or farm machinery (for example: tractors and plows)." DFDD does not include a general building function attribute. Instead, it provides a collection of more specific "Facility Type" attributes, including "Agricultural Facility Type", which has values that include "Barn" and "Farm Building".

It is clear that different dictionaries, even those that share a common heritage, vary significantly in how they deal with hierarchical concepts. In some cases, feature concepts are defined at multiple levels of specialization; in other cases, attributes are used to further specialize a feature concept. It is not uncommon for these two approaches to be combined within a single dictionary.

In M&S applications, data is received from legacy sources (such as those products based on FACC) or new sources (such as those based on DFDD). It becomes important to provide a consistent and common mapping approach and terminology to capture which concept (or concept combination) in a given source dictionary can or should map to which concept (or concept combination) in a target dictionary. The mapping product must be clear in its terms and semantics of the mapping, and be provided as a software library that can be easily incorporated into a converter or translation application.

To facilitate data interoperability between systems that use different data products based on different dictionaries, it is clear that establishing a mapping between corresponding concept dictionaries, data dictionaries, and data models is critical and necessary, however, it may still be insufficient. Because many data products can use the same dictionary, once such mappings between dictionaries are established the designer of data conversion applications can start with those established mappings, take into account the specific data model of the format or product, and further design a mapping that completes the full mapping of data, including not only the dictionary mappings but also the data structure and data organization mappings.

During data model mapping a specialized mapping of the concepts may be needed that is a refinement of the original concept dictionary. Mappings of data dictionaries often use concept dictionary mappings in whole or part. Therefore, a data model or product mapping will rely not only on the mappings between data dictionaries, but also the mappings of data structures and organizational constructs between data models or products.

Therefore, a concept dictionary mapping is a mapping independent of any data model or product. A data model, catalogue, or other nonconcept dictionary mapping is a mapping between corresponding constructs. Such mappings may use concept dictionary mappings modified by the associated data structures and rules.

5. Mapping approach

A mapping between concepts begins by analyzing a single concept entry in the source dictionary and determining whether an equivalent concept exists in the destination dictionary, either as another single entry or as a combination of several entries. If such a semantic equal can be identified in the destination, then there is a mapping between those concepts, from source to destination. Otherwise, the single entry in the source dictionary has no equivalent concept in the destination dictionary. This same approach is often used in mapping data models or other similar products. However, in addition to starting with a single concept in the source, it may be necessary to combine multiple concepts to meet specific data model requirements.

Since in practice at any given point in time data translation or data movement is in one direction, we consider mapping from a concept in the source to a concept in the destination as a single one-directional mapping. The mapping from the destination concept back to the source concept is considered to be another, separate, one-way mapping. A complete two-way mapping is therefore composed of two one-way mappings. Often the two one-way mappings between concepts are inverses of each other, but for a variety of practical reasons this is not guaranteed for all concepts or instances.

Independent of whether mapping is being done between concept dictionaries, data dictionaries or data models, when developing mappings for use in data conversion applications, the end result for a given concept is either that a mapping exists for that concept or there is no mapping. This principle is particularly important to application designers when using a given mapping product for two concept dictionaries, since declaring a partial or potential mapping is not useful to the designer, unless explicit conditions can be established clearly so there is no ambiguity in how a mapping is to be applied. However, during the development of a mapping, some instances may be marked as "unresolved" (along with appropriate explanation) until these are further reviewed and then resolved (in the final product) to either having a specific mapping or marked as having no mapping.

During the development of a mapping and in particular during the analysis phase, there are often cases when it is possible to map a given concept in the source to more than one semantically equal concept in the destination. In such cases, the final mapping product should identify only the best, most logical, and most practical of those mappings.

There are a number of mapping types and subtypes. These usually involve additional information, special conditions, or a collection of concepts in order to provide the same semantics in the destination. For all mapping types and sub-types, additional explanation, rationale, or analysis may be provided to help the end user (as well as the reviewers, during the development of mappings) to better understand why a certain type of mapping has been designated for a given concept. These supplemental data often can be binned into one of several specific categories of rationale or analysis, and can be used with a number of mapping types. This supplemental information is captured in a separate field, adjacent to the mapping type.

6. Terminology for mappings

Different terminologies are needed for different stages or categories of mappings. To establish a mapping for environmental data, a developer may produce mapping products between concept dictionaries or between data models (or specific data products). During the development of such mapping products there is considerable analysis that will take place to search and analyze the concepts in both the source and destination material. Therefore, it is important to be able to identify, through a shorthand notation, the type of analysis as well as the type of mapping associated with a given mapping.

Specific notation, definition of types, and examples of how different categories and types of terminology can be applied have been developed by the authors, but inclusion of that detail will make this paper unnecessarily lengthy. Therefore, detailed listing of types of terminology for each category, and examples for each case, are not included

in this paper, however, a brief description of the various mapping categories and terminology types is provided in the following sections.

7. Analysis terminology

During the analysis phase appropriate terminology, and associated shorthand identifiers, are needed to concisely express the reasoning for a specified mapping. This analysis terminology is distinct from the formal mapping terminology and should be captured in a separate field associated with a given mapping. This allows formal mapping cases to be clearly delineated, and after the mapping is completed, the retained analysis information in conjunction with other comments can be helpful in understanding why the specified mapping was chosen. Such information is not necessary for the end use of the mapping product and need not become part of the mapping library that will be used to look up the mapping for a given concept, but is useful both during the analysis and review phase as well as in retaining a trace of the rationale for a given mapping for future revisions or reviews.

Analysis terminology is used to describe the relationship between the source and destination concepts. Examples of these terminologies include such relationships as aggregate component relationship, specific concept to general concept, inverse of these, concept does not have an equal, concept cannot be mapped, concept has an equal, concept is identical to destination concept, etc.

Given a definition in a dictionary, a set of real object instances should exist that conform to that definition. Furthermore, given a pair of definitions in two different dictionaries, two sets of real object instances should exist, conforming to each of those two definitions. For example, given the respective EDCS and DFDD definitions of "Barn", a set of real (farm/agricultural) buildings exist that conform to each of those definitions.

One way of determining the relationship between the two concepts is to consider the relationship between those two sets of object instances. There are only five possible relationships between those two sets. Which relationship applies in a given case can be determined by asking three yes-or-no questions:

- Q1) Are there instances that conform to both definitions?
- Q2) Are there instances that conform to the first definition, but not to the second definition?
- Q3) Are there instances that conform to the second definition, but not to the first definition?

The relationship between the two sets, and therefore between the two concepts, is then given in table 1:

Q1	Q2	Q3	Result	Graphic
Y	N	N	Concepts are identical	
Y	Y	N	First concept includes second concept	
Y	N	Y	Second concept includes first concept	
Y	Y	Y	Concepts overlap	
N	-	-	Concepts are disjoint	

Table 1. Relationship between sets and concepts

In addition, there are other kinds of relationships, such as component and functional relationships, which also may need to be identified and documented as part of the analysis process.

8. Mapping terminology for concept dictionaries

The key to creating mappings between different concept dictionaries is to determine that a given concept definition in the source corresponds to a particular concept in the destination. Furthermore within a dictionary of concepts it is only necessary that definitions be unique and unambiguous, not that they be "normalized" such that no two concepts overlap within a dictionary. As a result, terminologies used in the development of mapping products between concept dictionaries may also be used in the development of mapping products between data models.

Mapping terminology is used to identify how a concept maps to a destination concept. Examples of mapping terminologies include identifications such as: a concept maps directly to a specific destination concept; there is no mapping for a given concept; there is a mapping, however the main concept in the destination dictionary is qualified by one or more attributes from the destination dictionary; there is a mapping between attributes, but a data type change is required; there is a mapping, but a change in unit

of measure is needed; there is an intermediate mapping that requires additional determination at data conversion; there is an attribute mapping, but the concept's enumerants are specifically split into multiple attribute enumerant combination concepts in the destination dictionary; etc.

9. Mapping terminology for data models

When the mapping involves more than the isolated entries between two concept dictionaries, and includes the specific context of a data model or a product that uses a source dictionary, and is being mapped to another data model or product that uses a separate destination dictionary, additional terminology may be applied to better identify the mapping between such data models or products.

Typically, in such cases, the mapping process begins with the results of the formal concept dictionary mappings (if they exist), and uses those defined mappings (through the terminology specified in the earlier sections) to apply additional constraints imposed by the source and/or destination data models or product structures.

When mapping data models or products, some of the concept dictionary terminologies can be used, however, these will cover the complexities associated with data model mapping cases. Specific data model mapping terminology is required to express those types of mappings that occur when data models or products are involved. Examples of data model mapping terminology include: the source concept is qualified with other concepts and the combination has an equal (single) concept in the destination dictionary; the source concept may be mapped, if a given condition is met in the source data; the source concept, qualified with other concepts in the source dictionary, has an equal in the destination which itself is qualified by other concepts in the destination dictionary.

10. Summary

Enabling interoperability between M&S systems, and allowing coherent data integration from multiple sources, requires a consistent and common approach to handling, converting, and adjudicating the data. Data providers and system developers have their internal and often unique methodologies for identifying and defining the content in their data. These are based on formal (and sometimes informal) dictionaries of terms/concepts, whether they are concept dictionaries that are used in a variety of data models, or specific data dictionaries associated with a particular data model or data product. Since most M&S systems, in particular networked M&S systems, combine data used by different systems or integrate data from various data sources, having a consistent methodology and terminology for providing mapping between these data becomes critical. Such mapping products are in turn used in data conversion or translation applications. While data exchange between applications must take into account data syntax, semantics and organization, establishment and use of a common mapping terminology and a consistent mapping methodology is a significant factor in increasing the interoperability of systems and applications, and reducing development cost of converters.

This paper has described an overview of the issues and principles that are involved in establishing such mapping methodology and terminology, and has highlighted various categories of terminology and mapping stages, and why utilizing a common and consistent mapping approach and terminology is important. Many of the concepts discussed in this paper are the results of past and on-going mapping experiences, including mapping work, dating back to late 90's, between FACC and EDCS, more recent experiences in establishing mappings between DFDD and EDCS, as well as the on-going mapping efforts between the National Geospatial and Intelligence Agency's NFDD, which is based on (but not identical to) the DGIWG DFDD, and EDCS. Although the concepts described in this paper are based on examples from use of environmental data, the same principles are applicable to other data interoperability challenges in M&S applications.

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Authors' Biographies

Dr. Robert Cox

Rob Cox has held many positions in industry and the U.S. military. Currently, he is a member of the US Army PEO STRI Engineering Directorate supporting PM Instrumentation Target and Threats Simulators (ITTS) and is responsible for the engineering design and testing of full motion and tracking simulators. Prior to joining PM ITTS, he was a member of the Future Combat System (FCS) Lead System Integrator (LSI) Training IPT. His primary responsibility was the development of the common environmental representation for FCS. He led the SAIC Synthetic Natural Environment (SNE) Research and Development team developing core SNE technologies to include the US Army OneSAF Environmental Runtime Component (ERC) and the SEDRIS project. Prior to joining SAIC, Dr. Cox was a member of the USAF where he held Program Manager Positions at the Defense Threat Reduction Agency (DTRA), the National Defense University (NDU), and with Air Force Weather (AFWA). Dr. Cox has an earned Doctorate from Texas A&M University.

Paul Dumanoir

Paul Dumanoir is the project manager for DoD Modeling & Simulation (M&S) Standards at U.S. Joint Training Integration and Evaluation Center (JTIEC). In coordination with the DoD Modeling and Simulation Coordination Office (M&SCO) he is responsible for providing acquisition, technical, and program management support for a wide range of DoD M&S Standards requirements. He has 22 years of experience working in DoD simulation and training programs as product manager, project director and systems/software engineer. His current interests include component-based product-line engineering, and standards based acquisition. He earned his B.S. in Electrical Engineering from the University of South Alabama in 1987 and his M.S. in Computer Systems from the University of Central Florida in 1991.

Dr. Louis Hembree

Louis Hembree has held jobs in industry, academia, and DoD. He is currently a Research Meteorologist at the Naval Research Laboratory Marine Meteorology Division, Monterey, CA. He has and is serving as a metrological and oceanographic environment subject matter expert for the SEDRIS development and maintenance, and as the co-editor of the EDCS standard. He is also developing atmospheric data sets for the Fleet Synthetic Training program. He was the lead for the Master Environmental Library and has developed atmospheric tactical decision aids.

Mr. Farid Mamaghani

Farid Mamaghani has worked in the field of interactive networked simulation since 1984. He is one of the original designers of the Defense Advanced Research Projects Agency (DARPA) Simulation Networking (SIMNET) computer image generation system, and over the years has worked as systems engineer or project manager on a variety of networked simulation projects. He is one of the people responsible for the establishment of the SEDRIS project, and provides management oversight and technical direction for the project. He is also involved in a number of other simulation and training programs and has extensive background in the design, development, and management of large software and simulation projects.

Mr. Kevin Trott

Kevin Trott has been a contributor to the SEDRIS technologies for the past fifteen years. He is an editor of the Spatial Reference Model (SRM) standard, and has contributed to multiple ISO TC 211 geographic information standards. He is a senior software engineer with Northrop Grumman Corporation.

Ms. Michele L. Worley

Michele L. Worley has been a member of the SEDRIS core team at Science Applications International Corporation for the past 12 years. She is an editor of the Environmental Data Coding Specification and coordinates work on the Data Representation Model. Ms. Worley has a Bachelor of Science degree in Computer Science from the University of Central Florida.

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