M&S Professionals Domains, Skills, Knowledge, and Applications

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ABSTRACT

The U.S. House of Representatives passed House Resolution 487 in 2007 recognizing modeling and simulation (M&S) as a national critical technology. The niche technology of M&S applies mathematics and computer science to disciplines across academia, industry, and the government. The use and development of M&S depends on expertise in science, technology, engineering, and mathematics (STEM) as well as the specific disciplines to which the technology is applied. These disciplines include manufacturing, healthcare, medicine, instructional systems design, fluid dynamics, social science, and military science to name only a few. Uses of this technology include analysis and decision support; engineering and design; studies and experimentation; and training and education. The developed simulations might be live, virtual, or constructive; discrete event; process; agent-based; systems dynamics; another paradigm; or a combination of multiple paradigms. M&S expertise required includes services such as management and decision support on M&S use and application; support such as custom development and verification, validation, and accreditation; specialized support in the use of specific M&S; simulation development; and data support and integration to name a few. This wide range of discipline domains, uses, and specialized M&S expertise makes it difficult to simply describe the education, training, and job of the M&S professional. The development of the Certified Modeling and Simulation Professional (CMSP) and multiple efforts to compile an M&S Book of Knowledge and the launching of the National Modeling and Simulation Coalition have done little to clarify this. This paper examines what it means to be a professional in the field of M&S by providing an examination of the ecosystem comprised of M&S required skillsets, the subject matter required for its support, and its applications in order to provide a tighter bound on what it means to be a professional of M&S.

ABOUT THE AUTHORS

Lisa Jean Bair is the owner of Lisa Jean Bair Analytics LLC. She serves as a member of the National Modeling and Simulation (M&S) Coalition (NMSC) Community Outreach and Public Awareness committee. Her areas of expertise include M&S validation, social network analysis, Agent Based Simulation (ABS), Multiple Objective Decision Analysis (MODA), Multi-Attribute Utility Theory (MAUT), and analysis. Her experience includes concept development and experimentation; analyses of alternatives; complex decision problems; requirements evaluation; M&S planning use; test and evaluation; and validation for the DOD. Ms. Bair has conducted original research that established a comprehensive multi-agent system taxonomy and in the development of foundational principals and a framework for M&S validation. Ms. Bair is a PhD student in the M&S program at ODU and earned an MS in Operations Research from The College of William and Mary and a BS in Applied Mathematics from ODU.

James J. Jackson is leading SAIC's training and simulation service line. Mr. Jackson has supported a variety of programs ranging from the TIMED satellite, to the VIRGINIA Class Submarine and clients ranging from the US Joint Forces Command to the National Institute of Health. While at the Johns Hopkins University Applied Physics Lab, Mr. Jackson studied the shock and vibration effects on the Standard missile's IR guidance system. Mr. Jackson developed a novel concept for shock and acoustic isolation for the VIRGINIA Class Submarine using a simulation-based design approach. At SAIC Mr. Jackson led several training and simulation programs ranging from experimentation to collective training. Mr. Jackson has authored more than 16 technical papers and current research interests are the integration and application of disparate analytical, modeling, and simulation tools to solve complex warfighting issues. He is a member of the industry advisory board for the Virginia Modeling, Analysis, and Simulation Center (VMASC). Mr Jackson holds a BS Degree in Mechanical Engineering from Virginia Tech and an MBA from William and Mary. He is a member of Tau Beta Pi, the national engineering honor society.

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INTRODUCTION

Models and their simulations have been used to solve problems for centuries. One early simulation, the game Chaturanga, a predecessor to modern chess, simulated battlefield tactics in seventh century India. The Roman Empire used other, early wargame simulations during its expansion. Monte Carlo simulation, widely credited to George Louis Leclerc for Buffon's needle problem in the late eighteenth century, advanced simulation for solving complex problems. Further, mathematical models have been widely employed to describe and predict the physical world and used in determining theories as Kepler's Law of Planetary Motion in the seventeenth century. In the pre-computer era, simulation enabled investigation using mathematical models of physical, economic, and other phenomenon.

Over the last sixty years, advancements in computation have allowed expansion of mathematical modeling. The 1940's and 50's ushered in the use of computers to apply Monte Carlo methods to solve problems in mathematical physics. The 1960's saw the development of computer simulations for manufacturing and process analysis. It also saw the development of SIMSCRIPT, a simulation programming language for non-computer experts. The 1970's saw this expand into other modeling and analysis tools. Goldsman, Nance, and Wilson (2009) gives more details. In the late twentieth and early twenty-first centuries modeling and simulation (M&S) has enabled many of the most critical scientific endeavors such as space travel, national defense, and advances in healthcare and have seen simulation-supported advancements in weather prediction, climate change, the behavior of the earth's planet-core, and human biology to name a few. The need to solve increasingly complex problems has spurred further advances in M&S, but how important is M&S and what is critical to its future?

The Importance of M&S

Saying that M&S is important makes an understatement. Many fields and almost every scientific discipline use M&S. House Resolution 487, 16 July 2007, establishes M&S as a national critical technology. It highlights contributions of M&S to the end of World War II, our nation's security, the health and well-being of every citizen, and the improvement of our nation's infrastructure. In 2011, market analysis suggested that the U.S. military training and simulation market alone was worth $5 billion (Kimla, Pannu, Srimoolanathan, & Webb, 2012), and Virginia estimated that M&S directly contributes $1.7 billion and indirectly $3.1 billion to its economy in the defense, aerospace, and healthcare markets (Office of the Secretary of Technology, 2011). Florida estimated that in 2012 M&S contributed $4.8 billion to its economy with nearly $8 billion in state sales (Florida High Tech Corridor Council, 2012). If this alone did not establish the significance of M&S, the number of M&S-related industry groups, the growth of M&S academic programs, and the existence of multiple professional certification programs are other indicators.

M&S as an Industry

The U.S. government developed the North American Industry Classification System (NAICS) to enable it to collect, analyze, and publish data related to the U.S. economy. The codes developed within the standard are industry-based rather than product-based wherein the defined industries group businesses with respect to their similarity in processes used to produce goods or services. Intentionally, the NAICS codes avoid a market-focus that stretches across other industries (e.g., tourism touches airlines, hotels, and restaurants that provide the same services irrespective of whether their patrons are tourists, businessmen, or neither).[1] The two- through six-digit hierarchical system builds in increasing detail from economic sector, subsector, and industry group to NAICS industry, where comparability exists across all the North American countries, and national industry (U.S. Census Bureau, 2013).

[1] Interested readers can consult U.S. Census Bureau issue papers on benefits and limitations of this approach.

Every five years, the Economic Classification Policy Committee (ECPC) reviews NAICS codes for potential revisions necessary to reflect changes in the economy. The ECPC intends to solicit change proposals for the 2017 revision in early to mid-2014, review the proposals from mid-2014 to early-2015, give recommendations to the OMB in early-2015, and make notification of final decisions in May 2015. They will make the revised NAICS listing available in January 2017 (U.S. Census Bureau, n.d.). Despite its significance and although a proposal cosponsored by NTSA, Society for M&S International (SCS), Simulation Interoperability Standards Organization (SISO), National Center for Simulation, Alabama M&S Council, New England M&S Consortium, Mid-Atlantic Institute for Simulation and Analysis, and the Virginia Modeling, Analysis, and Simulation Center was submitted during the 2012 revision process, currently, there is no single NAICS code applicable to the M&S industry as a whole.

This failure to gain acceptance as an industry unto its own by the ECPC demonstrates the complexity and interdependency M&S has with other industries. M&S does not stand alone. Rather, it is applied in a discipline to allow for investigation of issues previously untouchable because of safety, mathematical theory, computational horsepower, or other limitations. For example, M&S can facilitate experiments that may be too dangerous, too expensive, or take too long to gain meaningful results. In all cases, M&S is an enabler, applied within the context of subject matter expertise, a scientific or engineering discipline, or a complex or indeterminate problem.

Modeling and Simulation Professional Certifications

Instituting professional certifications and their acceptance within the larger professional community is an important milestone in the maturation of a professional discipline. Professional certifications already exist for a range of disciplines, including aviation, law, medicine, project management, and finance. There are at least two M&S certifications. To ensure proper use, selection, and development of energy performance and economics models within the scope of the applicable physics, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) developed the Building Energy Modeling Professional certification (ASHRAE, 2012). Better known, is the Certified Modeling and Simulation Professional (CMSP) intended to identify individuals who have attained significant knowledge and experience in M&S. Similar to expectations from the project management community with the Project Management Professional (PMP) certification, the developers of the CMSP anticipate that as M&S matures as a discipline, agencies seeking M&S professionals will recognize and prefer those who have attained the CMSP designation (Modeling and Simulation Professional Certification Commission [M&SPCC], 2012).

The M&S Workforce

Developing and using M&S technology relies on professionals with unique job skills, professional education, and training in M&S careers. This M&S workforce commands above average salaries, benefits, and levels of training and education (NTSA, n.d.). While the M&S industry continues to grow in importance, providing well-paying jobs and bolstering the economy, the development of a qualified M&S workforce has been a challenge for industry, government, and academia. The wide application areas for M&S calls for a range of skills in practitioners – beyond mathematics, engineering, or computer science alone (Kincaid & Westerlund, 2009). This makes determining a clear educational course difficult. It also creates difficulties in establishing both an identity and a career path as an M&S professional. Moreover, this breadth of required expertise makes it challenging for companies, managers, human resource professionals, and customers to identify the M&S-specific products and services they need or even a categorically clear M&S-specific specialty skill set they require. To meet this need, several universities have developed curricula, certificate, and degree programs in M&S.

Paper Overview

Is M&S important to the world without NAICS codes (or some other form of standard classification) dedicated to the industry? The short answer is yes, but to fully answer the question, we must scrutinize the M&S profession and its work so that M&S may better define itself as a unique field of study and develop greater unanimity of what it means to be an M&S professional. To do this, this paper examines the ecosystem between M&S required skillsets and education, the supporting subject matter expertise required, and applications for which M&S could be used. First, it describes the M&S industry. Next, it describes areas of expertise common to M&S practice. Then, it gives an overview of the education available within M&S. Last, it discusses challenges and draws some conclusions and considerations that may help shape the future of our industry.

THE M&S INDUSTRY

Before writing about a discipline or an industry, it first helps to know what the subject under study is. For the scope of this paper, the M&S industry includes the development, use, and running of models and their simulations as well as the study of M&S itself as a discipline, irrespective of any application of use, development paradigm, or supporting domains of expertise required. In order to be agnostic to any specific industry domain or school of thought, this paper uses definitions for *model* and *simulation* adapted from the *Merriam-Webster Dictionary*:

> *Model*: a system of postulates, data, and inferences presented as a description[2] of an entity or state of affairs (m-w.com, 2013). *Modeling* is the process of developing a model. (c.f. Department of Defense, 1998)
>
> *Simulation*: the imitative representation of the functioning of a system or process, usually by representing a model of that system or process within a computer (m-w.com, 2013). A simulation often interchangeably refers both to the active result from the process of simulating, that is running the computer model, and to the computer model representation itself. (c.f. Department of Defense, 1998)

Industry Description

By the NAICS code itself and its defining characteristics; the U.S. government implicitly defines an *industry* as *a group of business endeavors having or using similar processes to produce goods or services*. It is worth comparing this de facto definition to that understood in common parlance:

> *Industry*: (2a) systematic labor especially for some useful purpose or the creation of something of value; (2b). a department or branch of a craft, art, business, or manufacture; especially, one that employs a large personnel and capital especially in manufacturing; (2c) a distinct group of productive or profit-making enterprises; (3) work devoted to the study of a particular subject or author (m-w.com, 2013)

The significance of industry as it relates to "similar processes to produce goods or services" as opposed to industry as a "craft, set of businesses, or subject worthy of study" is notable. This emphasis both provides a limiting boundary for what an industry might be and enables the generalization of industries according to methods. The ECPC understands the difficulties with this production-oriented schema for services industries both in describing the production output of the services and the need to expand the NAICS codes for services. An adopted solution, not unique to services, was to group both the supplying and using industries together for the purposes of the NAICS even though it creates some data collection and analysis issues (ECPC, 1993). M&S suffers from this accommodation.

The 2012 NAICS Proposal identifies several NAICS codes related to the M&S industry: 333319 [sic], teaching machines (e.g., flight simulators) manufacturing; 541711 and 541712, research and development in biotechnology and the physical, engineering, and life sciences respectively, that provide subject matter expertise to the M&S industry; 541511, custom computer programming services, and 541512, computer systems design services, that are industries similar to M&S; and 611310, colleges, universities, and professional schools, that provides essential human capital to the M&S industry. However, it is incumbent upon a nascent M&S industry not only to differentiate itself from these other NAICS-defined industries according to the implied definition for industry but also to expand its myopic view of M&S beyond those industry support-areas with which its sponsors are most familiar into the greater breadth of M&S's use. It is either that or explicitly recognize and define itself within a narrower, more specified domain of application such as that adopted by the ASHRAE.

The left side of Table 1 on the next page summarizes 18 April 2013 search results using the keywords "modeling" and "simulation" constrained to database opportunities classified as "awarded," "partially awarded," or "umbrella"

[2] The *Merriam-Webster Dictionary* specifies a "mathematical description." While this is trivially correct once a model is instantiated into computer code, not all model descriptions in practice are immediately, or always, relayed in explicit mathematical terms. It is not uncommon to see operational views from the Department of Defense Architecture Framework and SysUML diagrams used to provide a model's description. While the mathematical definition of a *graph* applies to these structures, it is not necessarily obvious to those less versed in mathematics that this is so. Hence, the term "mathematical description" seemed too restrictive for the purposes of this discussion and was removed. However, nothing is lost from the discussion were it retained.

from a popular government business intelligence service that resulted in 10,000 records. These were further reduced to those having an assigned NAICS code and unique opportunity ID (duplicates reflected multiple awards). The remaining 1980 records covered 38 NAICS industry-groups spanning from 1988 to 2013 with the vast majority of awards occurring since 2001 (right-bottom of Table 1, not all data was available for all records). This further illustrates the need to either focus on a specific subset for the M&S industry or develop a broader view. Furthermore, while the national industry level codes highlighted in the 2012 NAICS Proposal appear within the top 85% of the national industries included, as the right-top of Table 1 shows, only one of them appears within top five national industries listed.

While this result is from a keyword search (e.g., it includes anything with modeling in its description, such as data modeling, whether it conforms to the definition posed in this paper; and it includes anything offered by PEO STRI irrespective of its relationship to simulation as defined) so cannot serve as a definitive description of the M&S market or industry, it nevertheless illustrates the breadth encompassed by M&S across industries. Furthermore, this result would be expected from the definitional construct that drives the NAICS definitions themselves.

Industry Size and Scope

The cursory search of the business intelligence services database also enables an assessment of the size of the M&S industry. For the 10,000 opportunities resulting from the search, Figure 1 summarizes the reported contract award totals. While it should again be noted that this data cannot be deemed as definitive owing both the nature of its collection and reporting as well as to the nature of the search itself, it is sufficient to illustrate growth of the M&S market. This is true even removing upticks in procurement in 2001 and 2003 (red dotted-fill and dashed line) or other possible procurement boosts from 2006 to 2008 (green dot-dash line and cross-hatch). While the government M&S market may be arguably volatile, it has an increasing trend. Notably, this observation ignores other non-government-related M&S.

Surveying conferences dedicated to or with tracks in M&S gives an indication of the scope encompassed by the M&S industry. A casual internet search on "DOMAIN simulation conference" leads to many tens of choices. Some of these conferences are likely familiar to the bulk of this paper's audience; most of them are likely unfamiliar. Table 2 gives a sampling of this diverse selection of M&S related conferences advertised for 2013.

M&S PROFESSIONAL AREAS OF EXPERTISE

To claim that one is a M&S professional or that one is engaged in the practice of M&S does not convey the

Table 1. M&S-Related Opportunities by NAICS-Industry, NAICS National-Industry, and Time

Industry	Opps
115---	1
221---	2
236---	2
238---	3
314---	2
325---	3
332---	4
333---	**19**
334---	56
335---	4
336---	34
339---	5
421---	1
423---	1
444---	1
452---	1
488---	5
511---	7
512---	1
513---	20
514---	7
517---	16
518---	13
519---	5
524---	1
525---	1
531---	1
532---	1
541---	1619
561---	43
562---	6
611---	80
621---	4
622---	1
811---	3
813---	1
927---	4
928---	2
Total	**1980**

Industry	Opps
541330	345
541710	314
541712	**280**
541990	119
541611	86
541511	**69**
541512	**69**
541690	68
541519	60
541620	52
541720	39
334511	29
611512	26
541513	21
561210	19
611430	18
333319	**15**
541711	**15**
611710	15
541380	15
541618	15
Total	**1689**

Year	Opps
1988-97	22
1998-2K	71
2001	95
2002	114
2003	133
2004	151
2005	123
2006	160
2007	134
2008	113
2009	137
2010	179
2011	129
2012	108
Total	**1669**

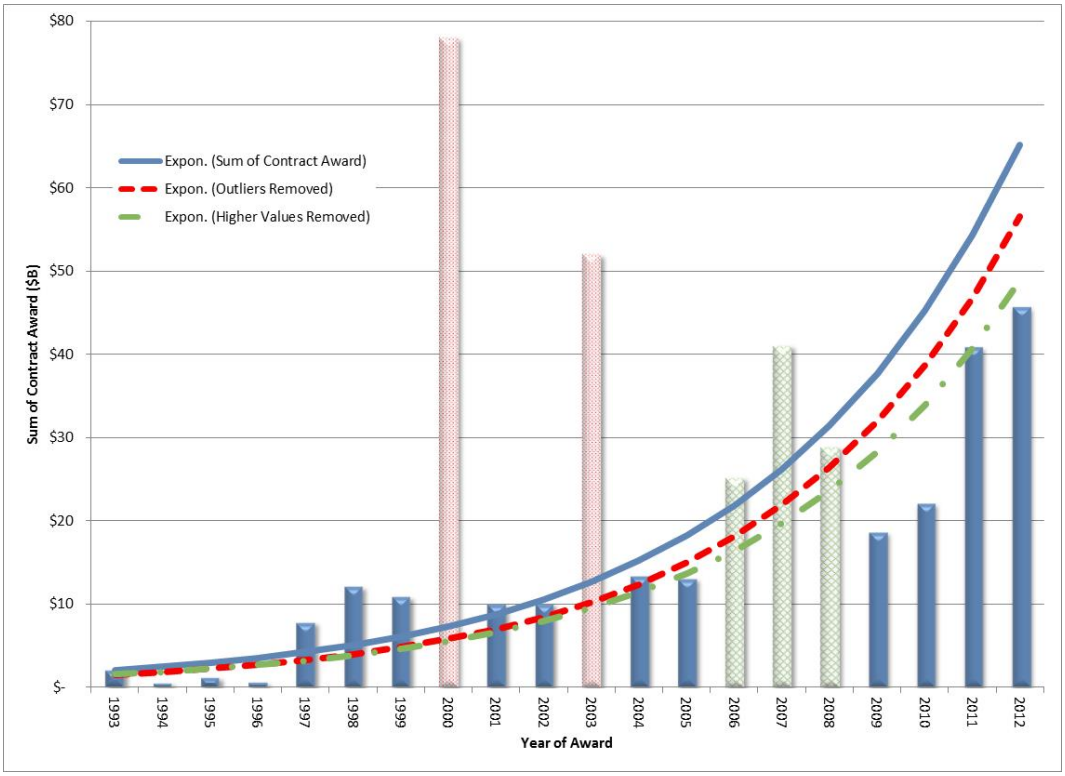

Figure 1. Reported Contract Value by Year of Award (Dollars Not Adjusted to a Base-Year)

Table 2. M&S-Related Conferences

I/ITSEC 2013
Summer Sim[n] Multi-Conf. (SummerSim '13)
European Sim[n] & Model[g] Conf. (ESM '13)
Int[l] Conf. on Comp[l] Model[g], Analysis & Sim[n] (ICCMAS 2013)
Int[l] Conf. on Advances in Comp[l] Model[g] & Sim[n] (ACMS 2013)
Int[l] Conf. on Mathematical/Analytical Model[g] & Computer Sim[n] (UKSim2013)
20th Int[l] Conf. on Analytical & Stochastic Model[g] Techniques & Applications (ASMTA 2013)
Congress on Model[g] & Sim[n] (EUROSIM 2013):
Portuguese Conf. on Artificial Intelligence (EPIA 2013): Social Sim[n] & Model[g] track
Complex Systems Model[g] & Sim[n] Workshop (CoSMoS 2013)
SIAM Conf. on Geometric & Physical Model[g] (GD/SPM13)
Int[l] Conf. on Modeling & Sim[n] in Engineering, Economics, & Management (MS'13CS)
Int[l] Conf. on Applied Mathematics, Sim[n], Model[g] (ASM '13)
34th Int[l] Conf. on Engineering Systems Model[g], Sim[n] & Analysis (ICESMSA 2013)
Int'l Conf. on Comp[l] Model[g] of Nanostructured Materials
Int[l] Conf. on Comp[l] Bioengineering (ICCB2013)

specifics of the work done, the expertise held, or the areas to which M&S is applied. In fact, this moniker conveys little beyond the idea of using computers to mimic (i.e., simulate) something else (i.e., what's modeled). It is both less sexy than saying one works in computer gaming and less descriptive than saying one is a computer scientist, while frequently, although not always, containing elements of both. A primary purpose for developing the CMSP was to provide a definitive description of the M&S profession, establish core knowledge required by practitioners, and distinguish those competent to practice (Lewis & Rowe, 2010). The exam topic index reflects diverse areas of application, domain, and methods. It includes M&S history, implementation, business practices, and related fields. Over time two tracks have evolved as the CMSP has matured. The first is a technical track suitable for engineers and developers; the second is a management track suitable for users or managers (M&SPCC, 2012). This evolution explicitly acknowledges the variety, diversity, and range of work in which an M&S professional could be engaged. Table 3 summarizes the areas covered by the CMSP examination.

Model Building

Building a simulation model requires more expertise than that found in a standard computer science or software engineering curriculum. Knowledge of standard computational languages, issues of computational complexity,

Table 3. CMSP Exam Topic Areas (M&SPCC, 2012)

M&S Domain-Specific Knowledge	
1. Concepts and context 1.1. Fundamental terms and concepts 1.2. Categories and paradigms 1.3. History of M&S	**7. Business and management of M&S** 7.1. Ethics and principles for M&S practitioners 7.2. Management of M&S projects and processes 7.3. M&S workforce development 7.4. M&S business practice and economics 7.5. M&S industrial development
6. Supporting tools, techniques, and resources 6.1. Major simulation infrastructures 6.2. M&S resource repositories 6.3. M&S organizations	
M&S-Specific Software-Engineering-Related Expertise	
5. Simulation implementation 5.1. Modeling and simulation life-cycle 5.2. Modeling and simulation standards 5.3. Development processes 5.4. Conceptual modeling 5.5. Specialized modeling and simulation languages 5.6. Verification, validation, and accreditation	5.7. Distributed simulation and interoperability 5.8. Virtual environments and virtual reality 5.9. Human-computer interaction and virtual environments 5.10. Semi-automated forces/computer generated forces 5.11. Stimulation
Areas of Specialized Expertise	
2. Applications of M&S 2.1. Training 2.2. Analysis 2.3. Experimentation	2.4. Acquisition 2.5. Engineering 2.6. Test and evaluation
4. Modeling methods 4.1. Stochastic modeling 4.2. Physics-based modeling 4.3. Structural modeling 4.4. Finite element modeling and computational fluid dynamics 4.5. Monte Carlo simulation 4.6. Discrete event simulation 4.7. Continuous simulation 4.8. Human behavior modeling 4.9. Multi-resolution simulation 4.10. Other modeling methods	**3. Domains of use of M&S** 3.1. Combat and military 3.2. Aerospace 3.3. Medicine and health care 3.4. Manufacturing and material handling 3.5. Logistics and supply chain 3.6. Transportation 3.7. Computer and communications systems 3.8. Environment and ecology 3.9. Business 3.10. Social science 3.11. Energy 3.12. Other domains of use
Domain Knowledge in Related Fields of Practice	
8. Related communities of practice and disciplines 8.1. Statistics and probability 8.2. Mathematics	8.3. Software engineering and development 8.4. Systems science and engineering

computer architectures, and data management are all necessary. Other necessary expertise may include computational expertise specific to the M&S-domain such as specialized simulation languages or numerical methods. These areas of expertise form an intersection between the software engineering and development field of practice and the Table 3 category of *M&S-Specific Software-Engineering-Related Expertise*. However, knowledge of and expertise in these software engineering practices, no matter how robust, is insufficient for the development of an appropriate model with an effective simulation. Crucial to this development and subsequent use is having expertise in the Table 3 category named *Areas of Specialized Expertise*. Model building occurs in the intersection between the *Applications of M&S*, *Domains of use of M&S*, and *Modeling methods* and requires specialized expertise in each. Expertise obtained in any two of these areas is not necessarily independent of and is often tailored to the choice in the third. The expertise areas found within *M&S-Specific Software-Engineering-Related Expertise* allows realization of those models within simulation software. The focused expertise-requirements for the ASHRAE certification explicitly reflect this interrelationship and the importance of subject matter expertise in the domain in which M&S is used.

Expertise in the *Domains of use of M&S* expresses the subject matter expertise in the applied science of interest (Weisel, 2011) (e.g., prevailing theoretical models; elements; required level of fidelity; etc.) gained by obtaining degrees specializing in these domain areas and direct career-experience in the field. Sound M&S use and development also requires application area expertise. For instance, analysis requires expertise in designs of experiments, statistics appropriate non-independent and identically distributed data, pseudo-random number generators, etc., and training and education requires expertise in instructional systems design. The last critical element is expertise in modeling methods appropriate for the domain and application. Many of these methods have long been taught in mathematics, operations research, and systems engineering curriculums or within the scientific field of study itself.

Effective M&S cannot be built without each of these three interrelated expertise areas coupled with sound software engineering practices. Implicitly embedded in this discussion is the need for expertise to decompose the domain and application areas into simulation requirements appropriate for or in order to determine the modeling method and to establish the development and testing requirements. This skill set often also falls within the fields of operations research, systems analysis, and systems engineering. Figure 2 shows a representation of these interrelationships.

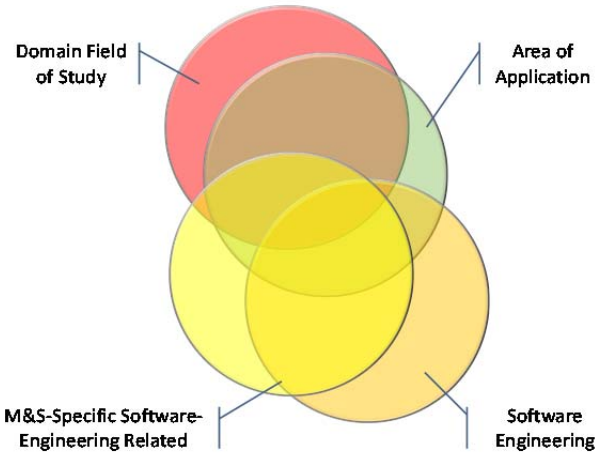

Figure 2. Areas of Necessary Expertise to Build an M&S

Model Use

The design and development of M&S is not the whole of the professional domain. If it were, it might perhaps be most appropriate to consider M&S primarily a sub-discipline of computer science and software engineering. Of at least equal importance is the use of developed M&S. This includes support to limited use-objectives, sometimes broadly referred to as intended use and other times more narrowly defined as a decision problem. This expertise goes beyond the general, higher-level expertise specific to *Applications of M&S* required for design and development. Rather, this is expertise tailored to a specific model, a given audience, a clearly identified set of objectives or problem, known risk area, etc. It may help to think of this as a limited run of a specified model used to achieve a clearly identified outcome.

There are a whole set of activities, with their own supporting professionals, required to use M&S: designing how the simulation model and results will be used, which may be an adjunct to other management and M&S selection activities; developing input data or validation data, often with the support of domain subject-matter-experts; running the model itself, which may require tailoring input data; and data analysis, which may require support from subject matter experts for interpretation. Additionally, M&S professional activities include addressing issues regarding simulation interoperability; simulation and simulation-component reuse; robust, multi-factor experimental designs; and validation of a model and its simulation to name a few. Moreover, these use-specific areas provide the fertile ground of leading edge M&S research. These go beyond solving a technical problem to build a better model or to improve the algorithmic or computation efficiency and get to the heart of M&S as a discipline, which may build upon the scientific advancement in other fields but primarily contributes to open questions specific to M&S.

The CMSP list of topic areas (Table 3) only briefly and peripherally references these areas of M&S-specific expertise, although they can be and are areas of specialization within the M&S domain. Furthermore, this list differs from the topics in the ASHRAE certification, which does not explicitly cover the simulation lifecycle as such, for instance. This specialization is not uncommon. In fact, for M&S, specialization may be the rule rather than the exception. For instance, an M&S professional may have generalized knowledge about all of the modeling methods but likely only has career experience in a small subset. In fact, someone may be a professional using M&S daily and have no experience in M&S methods other than semi-automated forces models, for example. Alternatively, a professional using M&S daily may never even have heard of that highly defense-specific term, specializing instead in other methods entirely (e.g., finite element methods). As an illustration, ASHRAE certification skill requirements do not include knowledge of the CMSP-listed modeling methods, referencing instead mathematical modeling methods, calculation methods, impact of model simplifications, and software tool evaluation and selection based on these considerations and the modeling study objectives (ASHRAE 2012).

EDUCATION AND TRAINING OF THE M&S PROFESSIONAL

Rogers, Zyda, Mykytka, Bartlett, and Bathe (1996 p. 1401) provides one of the first references for the need to educate simulation professionals to "discover, design and develop basic simulation principles and methodologies; design, develop, and manufacture simulation product[s]; apply and use simulation products to meet specified goals and objectives of an enterprise; manage and integrate simulation into projects enterprise wide development plans; and integrate simulation into the decision processes." Rogers et al. (1996) report that at the time most practitioners gained exposure to M&S through elective courses in related disciplines (e.g., industrial engineering, operations research, and computer science) and developed their skills on the job. They also identified early M&S education programs, primarily focused on providing skilled graduates for the defense industry.

In the intervening years, the Naval Post-graduate School launched its proposed Modeling, Simulation, and Virtual Environments program offering MS and PhD degrees in M&S as well as M&S certificates for U.S. federal and DOD employees engaged in the acquisition activities. Additionally, the graduate program at the University of Central Florida (UCF) has expanded into an interdisciplinary studies program offering a PhD and MS in M&S, an M&S Professional Science Masters in collaboration with its School of Business, and a M&S of Technical Systems Graduate Certificate having emphasis in [DOD] test and evaluation. Moreover, other institutions have developed programs offering degrees tailored toward M&S. Most of these programs are interdisciplinary. These include Old Dominion University (ODU): BS, ME, MS, PhD, DEng; University of Alabama – Huntsville (UAH): Certificate, MS, PhD; Arizona State University (ASU): MEng, PhD; Georgia Institute of Technology: Certificate; University of Pittsburgh (Pitt): PhD, Purdue University – Calumet: MS; and George Mason University: Certificate to name a few.

There is insufficient room to compare programs available to current or future M&S professionals exhaustively. The interested reader can consult the descriptions available at the referenced institutions' websites. However, given the aims of the CMSP, it is reasonable to presume that M&S curricula would reflect topics listed in Table 3, particularly *Modeling Methods* as they apply to *Applications of M&S* within some *Domain of Use* along with necessary *M&S-Specific Software-Engineering-Related Expertise*. Further, one could argue that *M&S Domain-Specific Knowledge*, other than topics related to M&S theory, can be obtained through practice and exposure rather than needing to be specifically taught. It would then be reasonable for one to expect some consistency in the degree-program offerings. However, a review of the course offerings and research programs of these institutions and their affiliated simulation centers demonstrates that they are as unique as the institutions themselves. Most of the required and elective courses reflect individual university research-interests and a multidisciplinary studies approach. For instance, one program emphasizes the subject domains and numerical methods for simulation within those domains (i.e., Pitt), another emphasizes data structures and computational frameworks (i.e., UAH), while another provides several potential focus areas such as quantitative aspects of simulation, simulation infrastructure, simulation management, computer visualization in M&S, and human systems in M&S (i.e., UCF). These inherent differences toward M&S underscore practical challenges for defining M&S as an industry and may also indicate philosophical differences.

CHALLENGES

What then can a current or future graduate expect to be qualified for upon graduating with a degree in M&S? Furthermore, what does an applicant having a degree in M&S mean to an employer? Having a degree in industrial engineering, operations research, computer science, physics, mathematics, biology, psychology, and many other fields is relatively self-explanatory to an employer and its human resources department. The variations are minor and the overlap significant between institutions. As has been demonstrated, the same cannot be claimed for M&S. What then does it mean to be an M&S professional? The answer to this question does not appear to be unique, but a review of some of the educational offerings implies some potential answers:

1. Pitt: An M&S professional has a detailed understanding in the application of numerical methods to solve real world problems with a strong educational foundation in a specific scientific field of study.

2. UAH: An M&S professional has strong foundational skills in computer data structures and software design with an application to systems engineering and simulation.

These proposed descriptions for the M&S professional developed from the course offerings of Pitt and UAH suggest that M&S is an adjunct capability to other core domains of expertise: a specific scientific field and software engi-

neering, respectively. One might go so far as to suggest that M&S, particularly numerical methods, is a tool of a science in the first description, and M&S is a sub-discipline or specialization within software engineering in the second. These inferred descriptions of an M&S professional illuminate that M&S is not a standalone discipline; rather, it requires subject matter expertise in the subject domain to be effective. Did space allow, it would be easy to derive alternative descriptions from the course offerings of ASU, ODU, UCF, and others. There is no doubt that the alternative descriptions would suggest other interpretations that define an M&S professional and his or her skills. It is equally certain that these would not obviate the conclusion that *effective M&S requires subject matter expertise outside the domain of M&S itself*. In fact, it may be that in domains where subject matter experts also have the necessary mathematical and computational expertise, M&S experts are not required; rather, M&S users, developers, and experts are comprised of the same population. Whereas, in domains lacking this mathematical and computational expertise, M&S experts are necessary to support M&S development and use. Table 2 suggests as much. This may explain the difficulty organizations such as the National M&S Coalition have had in gaining traction outside of the domains of aerospace, defense, and medical-training into domains such as manufacturing, infrastructure, and energy.

CONCLUSIONS AND WAY AHEAD

While the lack of consistency among academic programs may reflect the inherent utility of M&S to a variety of disciplines, the relative immaturity of M&S as a field may be at the heart of these inconsistencies. One does not see a similar divergence in the studies of physics, chemistry, biology, mathematics, computer science, or any of the natural sciences, except perhaps as specializations. However, despite the strong – one might go so far as to say necessary – influence of engineering, mathematics, and computer science within M&S, the M&S field does not itself offer the same rigor in the instruction of its future practitioners. Kincaid and Wusterland (2009 p. 277) reiterated observations initially made by Szczerbicka et al. (2000) that M&S lacks a "firm pedagogical foundation." If M&S is not a mature science, as these observations suggest, then the divergence in curricula across various program offerings is not surprising and might be expected. Kuhn's observations about a mature science further support this observation:

> At least in the mature sciences, answers (or full substitutes for answers) to questions like [What are the fundamental entities of which the universe is composed? How do these interact with each other and with the senses? What questions may legitimately be asked about such entities and what techniques employed in seeking solutions?] are ***firmly embedded in the educational initiation that prepares and licenses the student for professional practice*** [emphasis added]. Because that education is both rigorous and rigid, these answers come to exert a deep hold on the scientific mind. That they can do so does much to account both for the peculiar efficiency of the normal research activity and for the direction in which it proceeds at any given time. (Kuhn, 1970 p. 5)

If having a NAICS code dedicated to M&S is a necessary step for the economic growth of and the development of an identity for the M&S industry then it will be important for the next NAICS proposal to (1) acknowledge the expanse of the M&S industry as illustrated in this paper and (2) differentiate itself as a needed service-based commodity to the industrial bases and domains that it supports. (3) Acknowledging the salient differences between M&S as a tool, developed and used as part of a scientific endeavor with an existing computationally-savvy workforce, and M&S as a needed and valued service, provided to those without that same computational foundation by highly trained experts, will be highly beneficial to meeting this objective. With a narrowing of perspective and conciseness of thought comes precision and clarity. Future NAICS proposals will need to (4) discuss M&S's distinctive differences from other similar, related endeavors in computer science, operations research, etc. and (5) address M&S not as a market applicable to many industries but as a uniquely understood set of services bound by its own processes. Alternatively, the M&S industry can embrace its broad market applicability but advocate for many M&S-related NAICS codes identifying it as a specialized service within and across many industry sectors, dependent upon each.

If the M&S industry can better articulate who it is, what it does, and the expertise required, it will develop a basis from which to differentiate itself from other similar fields. By truly and clearly defining who we are, what we do, and who we support, the M&S industry will be able to not only establish an identity for itself but also enable an esprit de corps among its practitioners. Managers and human resource departments will better understand the skillsets and expertise required to carry out an M&S program and held by an M&S professional. Current and future M&S professionals will have better understanding of the scope of expertise encompassed by M&S. More importantly, by recognizing and acknowledging the breadth of scientific endeavors associated with M&S research and development and by establishing the bounds of our collective pedagogical interests, we, who associate ourselves with the M&S industry, can be informed by and benefit from those studying along parallel paths.

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