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RECOMMENDED PRACTICES FOR HOMELAND SECURITY MODELING AND SIMULATION

Sanjay Jain

The George Washington University
2201 G Street NW, Suite 415
Washington, DC 20052, USA

Charles R. McLean

National Institute of Standards and Technology
100 Bureau Drive, MS 8260
Gaithersburg, MD 20899, USA

ABSTRACT

This paper recommends practices for development and deployment of modeling, simulation, and analysis (MS&A) tools for homeland security applications. The proposed set of recommended practices applicable to any MS&A application includes: software engineering practice/ software reliability, modeling practice, model confidence/ verification, validation and accreditation, standards, interoperability, user friendliness and accessibility, performance, and innovative and unique elements. The recommended practices are discussed with respect to the MS&A application types for U.S. Department of Homeland Security (DHS) that include: analysis and decision support, systems engineering and acquisition, planning and operations, and training. The practices are also discussed with respect to MS&A application domains relevant to DHS.

1 INTRODUCTION

The objective of this paper is to define recommended practices for development and deployment of MS&A tools for homeland security applications and thus encourage increased and improved use of these technologies across this important area. The paper should also encourage development of infrastructure required for MS&A including availability of standards, guidelines, and data sets.

The recommended practices are defined with respect to MS&A tool development and deployment for homeland security relevant applications. Alternate ways of defining the practices could be from the perspective of U.S. Department of Homeland Security (DHS) for promoting the use of MS&A (e.g., through providing guidance on policies and procedures, standard data sets, accreditation process, identification of gaps to guide development efforts, avoiding duplication of efforts, etc.) or from the user perspective (e.g., input data analysis, data abstraction, ensuring right application of the model, user training, hardware & software availability such as for distributed parallel execution). These other perspectives are related to the perspective taken in this paper but are somewhat different.

The authors developed the set of recommended practices based on surveys and discussions during visits to organizations involved in the development and use of MS&A tools. The effort also built on the several decades of combined experience of the authors in MS&A development and application in general including over a decade of combined experience in applications relevant to homeland security. It should be noted that current best practices may not be the same as ideal practices. An ideal application would be the one that exceeds the expectations on all the recommended practices specified. A current best application may be one that does well on multiple recommended practices among those specified. An application that does notably well on one practice may also be highlighted as one to follow for that particular aspect. The set defined in this report aims to include ideal practices. It is understood that only a few projects may be able to follow the complete set of the applicable recommended practices and that the practices may be “followed” to different levels.

1.1 Study Methodology

The study team built on its knowledge of MS&A from its prior efforts in the area spanning several years since the first focused workshop on modeling and simulation for emergency response organized in 2003 (Jain and McLean 2003). This current study employed multiple ways of identifying MS&A tools that may be applied in the context of homeland security. These multiple ways included literature search, online search, participation in relevant workshops and conferences, discussions with DHS personnel, and visits to government and commercial organizations involved in the use, development, or support of MS&A tools. The intent of the visits was to review the tools and associated practices at organizations leading in developing and deploying MS&A tools for homeland security applications rather than conducting an exhaustive search. The information collected from these multiple sources was analyzed and used for defining the set of recommended practices in this paper. The survey of academic literature is captured in Jain and McLean (2008).

1.2 Organization of the Paper

The MS&A tools and their use may vary widely based on the application type. Some of the recommended practices may be implemented differently based on the application type and application domain. In the next section, a set of recommended practices are defined that are generally applicable across MS&A tools for all homeland security applications, indeed across all applications. The general recommended practices are discussed with respect to homeland security applications, where possible, in view of the objectives of this paper.

In section three, the recommended practices are discussed in reference to the four major application types, including analysis and decision support, planning and operations, systems engineering and acquisition, and training, exercises and performance measurement. It is noted that the applications objectives are not mutually exclusive. The same MS&A tools can be used for multiple application objectives. For example, a model can be used for training applications to show the effect of decisions made by trainees, and it can also be used for operations applications to select best action plans through evaluation of multiple alternatives using simulations. Additional recommended practices based on the application type are discussed where possible.

The fourth section discusses the recommended practices in reference to the seven major MS&A application domains, including social behavior, physical phenomena, environment, economic and financial, organizational, critical infrastructure and other systems, equipment and tools. The fifth and final section concludes the paper.

2 RECOMMENDED PRACTICES

A number of recommended practices are generally applicable, that is, they can be used across all MS&A for homeland security applications. Indeed, the practices discussed in this sub-section are applicable for all MS&A tools and not only those that are relevant for homeland security. The general recommended practices for MS&A are listed below and individually discussed following the list.

- Software engineering practices/ software reliability
- Modeling practice
- Model confidence/ verification, validation, and accreditation
- Standards
- Interoperability
- User friendliness and accessibility
- Performance
- Innovation

2.1 Software Engineering Practices/ Software Reliability

MS&A tools are a specialized kind of software and hence should be created using mature software engineering practices. Use of such practices will ensure that the MS&A tool has the required capabilities and it is reliable among other benefits. The effort should go through a full software development cycle including planning, requirements analysis, design, coding, unit testing, and acceptance testing. The process should include good software configuration management, development of information models and detailed documentation. The testing steps may overlap with verification, validation, and accreditation practice discussed later.

The overall software development process may follow an established model such as the waterfall, prototype, or spiral. The latter two may also be seen as part of the agile software development model. The waterfall development model is a linear development process with detailed planning for the full length of the project, while the agile approach is a combination of linear and iterative development processes with detailed planning for only the next increment. In case of agile model, each increment should follow a structured development cycle from requirements to testing. Agile approaches are recommended if the development team has close access to users, else a waterfall model may be more appropriate. The key idea is that a structured requirements-driven approach should be followed for development of MS&A tools. The specialized nature of MS&A tools should not be used as justification for informal unstructured development.

The software development processes used for developing MS&A tools should qualify among higher levels of the Capability Maturity Model Integration (CMMI) of the Software Engineering Institute (SEI). CMMI provides a process improvement approach for improving the maturity of the software development process using a structured approach and defined elements. It is based on earlier standards including the capability maturity model (CMM) from SEI and EIA-731 Systems Engineering. CMMI describes five distinct levels of maturity (Royce 2002):

- Level 1 – initial – unpredictable results
- Level 2 – managed – repeatable project performance
- Level 3 – defined – improving project performance within an organization
- Level 4 – quantitatively managed – improving organizational performance
- Level 5 – optimized – rapidly reconfigurable organizational performance as well as quantitative, continuous process improvement

A number of guidelines have been developed over the years for the software development process. The IEEE/EIA 12207 standard for software lifecycle processes subsumed earlier standards including ISO 12207 and J-STD-016, which in turn superseded MIL-STD-498 that superseded DoD-STD-2167 and DoD-STD-7935A. The IEEE/EIA 12207 defines software lifecycle processes including its industry implementation, life cycle data, and implementation considerations (IEEE 1996 and 1997). It has been adopted by the US Department of Defense (DoD) as a software development standard. The standard defines processes in three categories, primary life cycle processes, supporting life cycle processes, and organizational life cycle processes. It should be noted that the supporting life cycle processes include verification and validation processes that refer to qualification testing of the software. The verification and validation processes for MS&A tools are specialized and hence addressed separately in a practice later.

The recommended practice for MS&A tool development is to follow a structured software engineering process driven by requirements. The actual guidelines used (such as CMMI, or IEEE/EIA 12207) would depend on the developing and contracting organization, but it should follow a disciplined focus on requirements and a structured process to build and deliver to them. Balci (2004) recommends use of a tool like Evaluation Environment for collaborative application of a quality model and emphasizes the need for rigorous quality assessment of Modeling and Simulation (M&S) products including M&S requirement specification.

2.2 Modeling Practice

Modeling involves development of a conceptual model to represent the real life system. It requires proper abstraction, that is, identification of potential important factors in the real life to incorporate them in the conceptual model. It includes translation of the intended use(s) of the MS&A tool into the scope of the model, conceptual modeling, and selection of the modeling paradigm. It has been said that modeling is an art and not a science. It is hence hard to define a detailed specification to guide the modeling practice.

Good modeling practice builds on a deep understanding of the intended use of the model. The intended use should drive the determination of scope of the model. The assumptions made as part of the conceptualization and abstraction of the model should be unambiguously defined and documented.

There are some general guides available for the conceptual modeling activity. The languages for modeling such as the Unified Modeling Language (UML) and System Modeling Language (SysML) facilitate the development and documentation of conceptual models. Please see Object Management Group (OMG) standards (OMG 2009a and b) for further details. The Base Object Models (BOMs; SISO 2006) templates provide guidance for output of the conceptual modeling process. They serve as a foundation for the design of executable software code and integration of interoperable simulations. The BOMs include static description of real world in terms of conceptual entities and conceptual events. The BOMs also include interactions of the conceptual entities in terms of patterns of interplay and state machines to represent the corresponding real world relations. Together, the static and dynamic representations can be used as a basis for development of the simulation model by simulation software analysts. Similarly the Real-time Platform Reference Federation Object Model (RPRFOM; SISO 1999) is a reference model that helps in developing conceptual models for distributed simulation models based on the High Level Architecture (HLA).

A critical modeling decision is the identification of an appropriate modeling paradigm to represent the phenomena of interest. The two major paradigms are discrete event and continuous simulation with multiple implementation approaches within each such as system dynamics, cellular automata, and agent-based modeling. The phenomena of interest in the homeland security context include a wide variety such as dispersion of plumes, behavior of population following a major incident, movement and actions of emergency responders, and spread of wild-fire through forests and residential areas. It can be seen that the wide variety of phenomena may require different modeling paradigms for a suitable representation. For example, plume dispersions may be modeled using differential equations representing associated fluid dynamics in a continuous paradigm, behavior of population may be modeled using agent-based simulation in a discrete event paradigm, movements and actions of emergency responders may be modeled using discrete event simulation, and the spread of wild-fire may be modeled using cellular automata in discrete paradigm.

A modeling paradigm appropriate to the phenomena being modeled and the intended use should be selected for translating the conceptual model to an executable code. In fact, an early selection of the paradigm can also guide the selection of the method for conceptual modeling. For example, causal loop models are typically used to conceptualize the phenomena of interest for system dynamics modeling, one approach for continuous simulation. Process flow charts are typically used to conceptualize processes before developing discrete event models. Use cases documented in UML may also be employed for conceptual modeling of discrete event simulation models, though such use is not widely reported.

2.3 Model Confidence/ Verification, Validation and Accreditation Procedures

MS&A applications are of little value if there is not a high degree of confidence in their results. DHS decisions based on models and simulations must be reliable, they may involve national security, loss of human life, and/or large expenditures of public funds and other resources. It is critical that a model or a simulation and associated data are correct. Verification, validation, and Accreditation (VV&A) procedures are the mechanisms that are typically used to assure quality of outputs of M&S. VV&A helps provide confidence in simulation models. The Department of Defense has invested considerable resources in the establishment of VV&A procedures. VV&A terminology has been defined by the Department of Defense as follows: *Verification* is the process of determining that a model implementation accurately represents the developer's conceptual description and specifications (DoD 2007). *Validation* is the process of assessing whether a model or simulation is an accurate representation of the real world given its intended uses and establishing a confidence level for that assessment (DoD 2007). *Accreditation* is the formal certification that a model or simulation is acceptable for use for a specific purpose (DoD 1998). Accreditation is conferred by the organization best positioned to make the judgment that the model or simulation in question is acceptable. An accrediting organization may be an operational user, a program office, or a contractor, depending upon the purpose of the model or simulation.

The MS&A tools used for homeland security applications should go through structured VV&A procedures. It is understood that DHS is developing formal VV&A policies. Until the policies are developed, it is recommended that MS&A tools for homeland security applications go through a structured Verification and Validation (V&V) approach. Some of the available structured V&V procedures are discussed in this section. Formal accreditation should be carried out once the official DHS policy for VV&A is available.

The VV&A process should utilize a set of validated data. VV&A of a model cannot be decoupled from validation of data (DoD RPG 2006). A recommended practice should include validation of data as part of the VV&A procedures.

Over 100 V&V techniques exist (Balci 2004). V&V techniques applicable in different stages of M&S application development lifecycle have been identified (Balci 2003). DoD has a VV&A policy (DoD 2003) as well as significant guidance available on-line in the form of VV&A recommended practices guide (VV&A RPG; DoD 2006). The VV&A RPG provides guidance across a wide range of topics that allows a user to select the applicable sections. For example, it provides guidance for validating new models, legacy models, and simulation data. The RPG is a good source for VV&A guidance. Sargent (2008) also provides a recommended V&V procedure.

An associated concept is assessing and improving the maturity of the simulation process elements. Oberkampf et al (2007) present a predictive capability maturity model (PCMM) that should be used to ensure the maturity of the computation simulation process elements. They caution that the maturity of the process is not necessarily the same as predictive accuracy or the predictive adequacy required for a particular project. The PCMM defines four levels of maturity:

- Level 0
  - Little or no assessment of completeness and characterization
  - Individual judgment and experience
- Level 1
  - Some informal assessment of completeness and characterization
  - Some evidence of maturity
- Level 2
  - Some formal assessment of completeness and characterization
  - Significant evidence of maturity
  - Some assessments have been made by internal peer review
- Level 3
  - Formal assessment of completeness and characterization
  - Detailed and complete evidence of maturity
  - Essentially all assessment have been made by independent peer review

A structured VV&A process as part of the MS&A tool development life cycle is a recommended practice. Again, good sources are available for the VV&A process. One of the available processes should be used for V&V for MS&A tools for homeland security application until DHS issues its VV&A policies.

2.4 Standards

The use of standards for MS&A for a homeland security application, or for that matter, any software application, allows it to be employed for other similar purposes at a much lower cost than one that doesn't comply with standards. An excellent application that doesn't conform to standards may be less useful than a good application that does since the standards enable the good application to be rapidly deployed at multiple sites. The use of standards hence is an important recommended practice. Previous recommended practices referred to standards for software development, conceptual modeling and VV&A processes. The recommended practice discussed in this section concerns the compliance of the MS&A tools with all applicable standards other than those explicitly referenced in other recommended practices. In general, a tool that uses standards will be easier to integrate with other tools and systems that also comply with the same standards.

Standards help the homeland security community make more effective and efficient use of MS&A applications. The standards must support the design, development, and implementation of the MSA applications. Examples of major categories of standards that are relevant to MSA applications include *Architectures, General Purpose Integration Interfaces, Domain-specific Integration Interfaces, Equipment Specifications, Operational Guidelines, Document Formats,* and *Data* (McLean, Jain and Lee 2008).

Architectures support the overall design or structure of a system or system environment and interactions within a system of systems. An example includes the High Level Architecture that defines the interaction between distributed simulations, each representing a system. Integration interface standards facilitate the interoperation or data exchange between systems. *General Purpose Integration Interfaces* are used to integrate a wide variety of computer applications and are not specific to homeland security or related mission areas. Example interfaces include markup languages, image file formats, and database query languages. *Domain-specific Integration Interfaces* are specific to homeland security related areas, e.g., emergency communications message formats. *Equipment Specifications* define required capabilities, functional characteristics, or rules that ensure quality, safety, and health of users. *Operational Guidelines* define organizational structures, policies, procedures, and protocols. *Document Formats* specify layout and structure for documents in word processing, database, spreadsheet, graphics, presentation, print, and encoded formats.

The *Data* standards can be classified by the associated major data elements that are relevant for MS&A for homeland security applications. Jain et al (2007) identify thirteen major relevant data elements, namely, *Areas, Building-Structures, Chronology, Demographics, Environment, Hazard-Effects, Incident-Event, Infrastructure-Systems, Organizations, Policies-Procedures-and-Protocols, Response-Operations, Response-Resources,* and *Social-Behaviors*. Applicable standards are identified for each data element where available, for example, the *Areas* data can be defined using Content Standard for Digital Geospatial Metadata or the Governmental Unit Boundary Exchange Standard among others.

The use of standards enables wider use of the MS&A tools and hence is a recommended practice. At times there are multiple standards for the same purpose. In such a case, one has to select the standard that is used more often than others in the specific simulation domain. It is important though to use a standard rather than using a custom practice or development for the purpose at hand.

2.5 Interoperability

Homeland security applications cover a wide range of scenarios including man-made and natural disasters. A monolithic model to cover the wide range of scenarios is infeasible and would not be desirable for multiple reasons even it were feasible. Customized model for each scenario for each jurisdiction would be a highly inefficient way to use MS&A. The most efficient approach is to develop generic data driven component models that can be integrated in combinations required to represent a scenario of interest for a jurisdiction. This approach requires that component models be interoperable.

Interoperability among component models can be established from a low level focused on network connectivity, generally defined as integratability, to a high level focused on alignment of conceptual models, generally defined as composability. Turnista (2005) defines the following seven levels of conceptual interoperability: none, technical, syntactic, semantic, pragmatic, dynamic, and conceptual. The highest level is conceptual interoperability where the assumptions, constraints, and the abstracted conceptual models among components are aligned, independent of their implementation platforms. The description of the levels suggests that semantic and higher levels of interoperability may be domain specific. Domain independent standards are available for lower levels. Domain independent standards at the syntactic level include Distributed Interactive Simulation (DIS) and HLA. Even the available standards are evolving as indicated by the current Simulation Interoperability

Standards Organization (SISO) effort for DIS revision (SISO 2009). Ongoing DHS initiatives are expected to provide guidance on the available standards and lead to development efforts for additional standards. Meanwhile, MS&A development efforts for homeland security applications should agree on interoperability standards for models intended for integration.

Admittedly, the level of interoperability of an MS&A tool with other tools and systems will be largely influenced by its compliance to standards. Interoperability is addressed separately to highlight the need in the homeland security application context. A high level of interoperability with other commonly used tools and systems is an indicator that the system is not duplicating any functions and it utilizes commonly available capabilities of other tools and systems. This also includes the capability of the tools to configure using data describing the scenario of interest. This improves the possibility of its use at other sites that use a similar set of tools and systems.

Improving interoperability of homeland security applications requires the development of the necessary infrastructure by the involved community. This includes common reference models, data dictionaries, glossaries, taxonomies, ontologies and an architecture framework. DHS has sponsored work in this area and is beginning to develop a coordinated approach. Jain and McLean (2008) define a component based architecture framework for simulation and gaming for incident management. McLean, Jain and Lee (2008) provide a taxonomy for homeland security MS&A applications.

Development of interoperable components allows efficient use of resources and is a recommended practice. The homeland security MS&A community needs to work in a coordinated manner to develop the required infrastructure for achieving interoperability. Developers of MS&A for homeland security applications need to employ practices that support interoperability such as use of Extensible Markup Language (XML) interfaces, service-oriented architectures, and web services based on standards.

2.6 User Friendliness and Accessibility

The MS&A tools can be complex software applications and special attention needs to be placed on making them user friendly. The targeted users for such tools would have experience in emergency management and generally limited exposure to complex software applications. MS&A tools should be embedded within or seamlessly interfaced with operational systems commonly employed by the targeted users in their daily routine. The users should have easy mechanisms to trigger the MS&A tools and should have to input minimum number of decision parameters. The tools should be set to access all the input data automatically from available sources with control available to the user to modify data and sources for testing and experimentation. The use of earlier recommended practices on use of standards and interoperability will facilitate setting up automatic interfaces to data systems and to other models.

The outputs of MS&A tools can be complex and they have to be disseminated appropriately to the incident management organizations. The preferred dissemination mechanism for complex MS&A tools for operations application may be a reach-back center that provides expertise in deciphering the outputs for use by the incident management personnel. In other cases, user friendly interfaces may be built to ensure rapid and correct understanding of the MS&A tool outputs by the incident management personnel. The outputs should quantify the uncertainty associated with the results. The incident management personnel may look for a clear yes or no answer while the MS&A tools may provide answers with associated uncertainties and sensitivities. Ideally in an operations application, the decision makers should have had experience deciphering the outputs and the associated uncertainties based on several exercise cycles utilizing the specific MS&A tools. They should be able to incorporate the uncertainty and sensitivity information in their decision making. The results should be presented to the incident management organizations using visualizations and terminology familiar to them. MS&A tools should use geographic map displays for relevant outputs or interface with post processing tools that allow such displays. The dissemination of outputs thus would gain from use of standards and a high level of integration with other tools and systems.

MS&A tools should comply with section 508 of the Rehabilitation Act of 1973 (USGSA 2009). The act requires that information systems should be accessible to Federal employees with disabilities. The user interfaces for MS&A tools for homeland security applications should be developed with this consideration.

2.7 Performance

The performance of an MS&A tool can be judged on multiple aspects including the execution time, the response times to various queries, and the hardware platform requirements. A system that executes quickly, responds to users' queries promptly, and does not require unique and expensive hardware to execute allows wider use and is preferred. The performance requirements differ based on the application type, that is, for training, operations planning, trans-incident operational support, etc. The application needs to simulate phenomenon in real time for training applications, and faster than real time for trans-incident real time operations support applications. The execution time is generally not a constraint for planning applications, but an application executing over several hours may see limited use.

It should be noted that a combination of tools may be used to meet the time constraints. The National Atmospheric Release Advisory Center (NARAC) uses tools with short computation times to provide approximate predictions on plume dispersion within minutes following an incident and follows it with more accurate predictions based on outputs of tools that require longer computation times (LLNL, 2009).

2.8 Innovation

This practice refers to the use of innovative and unique elements in the MS&A tool that improves the possibility of its use through such features as those that lead to more accurate output in limited time, improved user experience, and lower requirements for infrastructure than others. CT-Analyst, a plume dispersion modeling application developed by the Naval Research Laboratory, provides a good example of innovation. Plume dispersion models using computational fluid dynamics provide accurate predictions of plume behavior in urban areas; however, they require large computation times and hence are limited in use for real-time operational support applications. CT-Analyst utilizes a novel approach to reduce the computation times to allow use in time constrained situations. It precomputes "dispersion nomografs™" for an identified area that can then be used to enable quick computation of plume dispersion following an incident (Patnaik and Boris 2007).

3 PRACTICES SPECIFIC TO MS&A APPLICATION TYPES

The implementation of recommended practices may differ by the four MS&A application types, namely, 1) analysis and decision support, 2) planning and operations, 3) systems engineering and acquisition, and 4) training, exercises and performance measurement. For example, it is a recommended practice to verify, validate and accredit MS&A tools. The verification, validation and accreditation (VV&A) procedures may be applied differently across the MS&A application types and domains. VV&A of MS&A tools for application in training, exercises and performance measurement does not need to be as rigorous as the VV&A of tools for application in planning and operations, that is, to support decision making in emergency response. Similarly, VV&A of MS&A tools in the social behavior domain is rather difficult and may be accomplished to a certain extent using data collected from past actual incidents. VV&A of physical phenomenon such as plume dispersion may be accomplished to a greater extent than in the social behavior domain due to the availability of data from tracer gas experiments.

The MS&A tools may fit multiple MS&A applications types. MS&A tools with training as the primary objective aim for running in real time and provide realism with a reduced emphasis on technical correctness. Tools for planning applications emphasize technical correctness and run time may not be a major concern, while tools for operations need both technical correctness and execution time that are much faster than real time. Clearly, the tools suitable for operations can be used for training and planning also. However, the tools with both technical correctness and execution times that are much faster than real time should generally be considered as primarily for supporting operations.

3.1 Analysis and Decision Support

MS&A can be used for analysis and decision support for homeland security applications through use of such tools as choice models, information control techniques, analysis and reasoning techniques, representation aids, and human judgment amplifying and refining techniques. These tools may be seen as focused on analysis rather than modeling and simulation (M&S). They may be integrated with M&S tools to process the simulation results with various applicable analyses. These analyses help the decision makers gain insights provided by the simulation results and use them to make decisions. These tools may also provide a decision support environment utilizing M&S tools. The environment may provide interfaces suitable for a decision maker for executing simulation runs and guiding the analyses. M&S tools in this group may be used for reconstructing past incidents for analysis and improved understanding of the involved phenomenon.

The recommended practices presented in section 2 will need to be applied with different emphasis for the analysis and decision support application type. The emphasis will primarily be on user friendliness and accessibility in particular of outputs since that is a key purpose for these tools. The other important practices for this type are standards, interoperability and performance. The VV&A criteria may be used differently based on the type of the tool. A VV&A methodology similar to that used for M&S tools may be used for the cases where the tool is an environment with an embedded M&S tool, or for an M&S tool primarily used for reconstructing and analyzing incidents after they have occurred. A different VV&A methodology may be used for analysis tools primarily to ensure that there is no error in the mathematical operations used to process the simulation outputs.

3.2 Planning and Operations

Planning and operations applications are a rich area for employing MS&A tools. In particular, MS&A tools can be and are widely used for pre-incident planning, evaluating alternate strategies, policies, and plans for response, recovery, and mitigation. MS&A tools are also used to provide trans-incident operations support, though to a much lesser extent than planning.

The pre-incident planning area is perhaps the most appropriate area for utilizing MS&A tools with the present state of supporting infrastructure. Planning applications include evaluation of impact of natural hazards and man-made incidents, and the response, recovery, and mitigation options to minimize the impact on the population and property from strategic to tactical levels. MS&A tools can be applied at a high level of abstraction and model long time periods in simulation to evaluate the strategic options, and they can be applied at detailed level modeling individual actions over a short time frame to evaluate tactical plans and procedures.

A large number of pre-incident planning applications of MS&A exist and perhaps a larger number are in various stages of development. The wide use of MS&A in this area is due to the current state of infrastructure required for their applications. MS&A tools typically require a large amount of data describing an incident and the location for modeling the impact and the response, recovery and mitigation options. At present, there is limited data that is readily available for MS&A. Use of an MS&A tool, thus, requires a substantial effort for collecting and cleaning up the data required. MS&A tools themselves need to go through VV&A process before they are used. The VV&A process itself can be time consuming and may require a few iterations. The planning applications allow the time to go through data collection and VV&A process for MS&A use. It is expected that as data sources and the MS&A tools mature, they will be increasingly used for trans-incident operational support applications.

The trans-incident operational support applications of MS&A include the tools that can be used to guide efforts during the response phase as the incident and/or its aftermath is unfolding. MS&A tools may be used for understanding the impact of an incident and to evaluate the response options. For example, MS&A tools may be used to estimate the areas that will be affected over time by a toxic plume emanating from an incident to guide the population evacuation efforts. They may be used to understand the impact of an incident on different infrastructure assets in the incident area and the cascading effect of the disruptions to guide the efforts to isolate and minimize such effects.

All the recommended practices identified in section 2 are applicable for the operations applications. The VV&A aspect is critical for operations applications since MS&A tool outputs may support decisions that may affect human lives. The incident management organizations have to have a high degree of confidence in the outputs of the tools and that may be provided through the use of rigorous VV&A process. Along with the model validity, the need to support critical decisions also demands that the data used as input to the models should be the best available and should be validated to the extent possible.

The user friendliness and accessibility to the incident management personnel is another critical aspect for operations applications of MS&A. The incident management decision makers should clearly understand the predictions provided by the model with the associated uncertainties before acting on them. Frequent exposure to MS&A tools output for operations applications will help the decision makers in their use of these tools for trans-incident operational support applications that provide limited time to absorb the data. Proper dissemination of MS&A tool outputs may require additional infrastructure than mentioned earlier for providing the required validated data to MS&A tools. The required infrastructure may include centers of expertise that can serve as reachback for the incident management team and advise them on the predicted outputs on impact of the incident and evaluation of proposed response strategies. It may include platforms, tools, and expertise available right in the emergency operations centers for such a role. It may also include handheld devices for the first responders for communication of results of MS&A tools such as the predicted path and affected areas for a toxic plume.

There are parallels in the use of MS&A for command and control of incident management operations and of battles at the tactical level. MS&A use for homeland security applications can gain from relevant advances in DoD simulation community. Daly and Tolk (2003) suggest use of applications traditionally found in the M&S community for defense command and control based on advanced information sharing and dissemination. Similar capabilities can be used to support command and control for emergency response efforts in reducing the risk of unintended consequences and efficient use of resources. M&S applications can be used to translate the volumes of data available into visual representations of current situation and potential scenarios. Such use of M&S applications requires high level of integration with other data systems, applications, and the command and control systems used for emergency response.

3.3 Systems Engineering and Acquisition

MS&A tools can be used to support the systems engineering and acquisition processes for homeland security similar to their successful use for the purpose in DoD. Such applications include use of MS&A tools for requirements definition, program management, design and engineering, efficient test planning, result prediction, supplement to actual test and evaluation, manufacturing, and logistics support. This application area primarily includes use of MS&A to evaluate systems and equipment through their design, development or manufacturing, and installation. The simulation models for evaluating performance of the system or equipment by itself are generally specific to the system or equipment being acquired and may not be data driven component models. These may include models of such aspects as mechanical strength and operation, chemical detection efficiencies, and electrical and electronic system operations. For example, the evaluation of a product design for detection of explosives in baggage would require modeling the physics of the process. On the other hand, models for evaluating the functioning of the system or equipment within the intended deployment environment may be component models. For example, the impact of the time taken for explosive detection system on the throughput of an airport security checkpoint may be done with component models developed for the purpose.

Among the recommended practices there may be a lower emphasis on performance since the systems engineering and acquisition applications would not be time constrained similar to operations support applications. Similarly there may be lower emphasis on the user friendliness and accessibility aspect since the primary users of the models for evaluation of product design may be subject matter experts familiar with the involved technology. The design evaluation models being custom developments may not need to emphasize compliance with interoperability requirements either. Most of the recommended practices would apply other than performance to the models used for evaluating the functioning of the system or equipment being acquired within the intended deployment environment.

3.4 Training, Exercises and Performance Measurement

Perhaps the best known applications of MS&A tools in homeland security domain are the training, exercises and performance measurement applications. Such an impression may have been formed based on widely available reports of intensive use of MS&A tools for war games and associated training applications used by the armed forces. MS&A tools allow creating realistic scenarios that a trainee may face in real life to test and improve his/her skills for executing his/her responsibilities. The responsibilities may be at the level of decision maker for directing preparedness, response, or recovery efforts or at the level of a first responder. The corresponding tools would vary from those that provide information from simulations regarding an unfolding incident to serious games offering first person interactions at the incident scene.

Some of the recommended practices discussed in Section 2 may be employed a bit differently for MS&A tools for homeland security training applications. The VV&A of the tool may be to a different level than used for other objectives. Ideally one would want to have the tools model the phenomena to the same level of detail and validate the outputs to the same level as for other objectives, but the requirement for real time responses to the trainee may override this desire. For example, simulation of the impact of a complex phenomenon like an explosion may require computation times much longer than the time it takes to occur in real life. The use of an explosion in a scenario for training hence has to be simulated with approximations to allow it to occur in realistic time durations or is pre-calculated off-line for use during the training. In first person serious games, “effects simulation” is used instead of simulation of the actual physics behind the phenomenon. Effects simulation consists of using approximate effects including visual impact (i.e., the explosion), and the resultant physical impact (i.e., the destruction and casualties). The approximations and effects simulations are used to allow as much reaction time to trainees as would be available to them in a real life incident and thus provide valuable training.

The interoperability practice includes the capability of a tool to automatically configure the model to data read in from other systems. For a training application, the MS&A tools will be more valuable if the model can be customized to locations that trainees may actually be called to for an emergency situation. Some of the training tools provide fixed fictitious locations with several fixed parameters that provide limited value to the trainees due to the impression of a “toy problem” or an unrealistic “game.” The integration level doesn’t have to be as high as for tools supporting operations since the training application does allow the luxury of time to configure the model to an actual location and scenario of interest. However, lower level of integration would result in a higher level of effort required to customize the scenario and thus higher expense for training.

Clearly user friendliness and accessibility practice is important for this application type. The applications and their outputs may be used by personnel with a wide variety of backgrounds and hence the user interfaces and features should be designed accordingly. The results should be presented to allow rapid understanding by the personnel involved in training, exercises and performance management applications.

The standards practice for training applications should include compliance to Sharable Content Object Reference Model (SCORM). SCORM is a collection of standards and specifications for e-learning based training applications. The standards include specifications for communications between the host system, called the run-time environment, and the client side content. The SCORM specification was developed under the sponsorship of the United States Secretary of Defense as part of the Advanced Distributed Learning initiative. Bohl et al (2002) provide a critical assessment of SCORM.

The training applications may provide a good opportunity to familiarize the incident management personnel with the outputs generated by MS&A tools. While the first responder personnel may primarily train through interaction with simulation and gaming technologies to improve their response skills, the management personnel should be familiarized with MS&A tool outputs that they may be using in future for decision making. The training applications may also provide a good opportunity for collecting feedback on the techniques used for dissemination of MS&A outputs.

A number of considerations other than the recommended practices presented in section 2 may be used to identify good training applications of MS&A. These include:

- realism of the visualizations
- the value of the learning delivered by the tool
- the features for verification of learning
- support for after action reviews
- the cost of access to the training and tools

4 PRACTICES SPECIFIC TO MS&A DOMAINS

The recommended practices may vary in implementation by MS&A domains too. McLean, Jain and Lee (2008) define the following MS&A domains for homeland security applications: social behavior, physical phenomena, environment, economic and financial, organizational, critical infrastructure and other systems, equipment and tools. The social behavior models are very difficult to validate due to the subject matter being human beings with their own individualities. A common approach to model social behavior is through agent based models. Computational considerations generally lead to defining behavior rules for large groups of populations. Even if large computation times are allowed and a large set of behavior rules defined, it is difficult to predict outcomes with significant level of confidence. The large computation times also limit execution performance and hence the applications.

Physical phenomena models are somewhat more predictable than social behavior models but still quite difficult to validate. In fact, one of the criteria to judge the validity of plume dispersion models is that their results agree with the tracer gas experiment results within a factor of 2, which would be considered a low accuracy in the realm of discrete event simulation models for manufacturing. Physical phenomena models are generally computation intensive and hence are limited in execution performance. Environment models are quite computation intensive, similar to physical phenomena models, and about as difficult to validate.

Economic and financial models share some of the characteristics of the social behavior models. A common criticism of economic models is that they assume rational behavior for all involved and that is not a good assumption. Hence similar to the social behavior models, they are hard to validate.

Organizational models are somewhat similar to social behavior models since they represent organizations comprised of humans. In fact, in addition to being subject to varying individual behavior, each organization has its own culture and perhaps multiple micro-cultures within its units, making them difficult to model and validate. These models may perform better for organizations with well defined processes. The organizations involved in homeland security have to follow guides such as the National Response Framework and the National Incident Management System that help develop the models with some consistency. The underlying assumption is that the organizations follow the defined guides and procedures rationally. The assumption may hold to a somewhat larger extent than the rational behaviors of individual in economic models.

The critical infrastructure models also face complexity in validation due to the multiple interconnections among the infrastructures they represent. Multiple paradigms have been used to model critical infrastructures including system dynamics, continuous simulations, and discrete event simulations. The use of multiple paradigms contributes to complexity of validation.

Models for other systems, equipment and tools share some of the concerns raised for models for evaluation of systems and equipment in the systems engineering and acquisition application type. These models may be customized to the system, equipment or tool they represent. However, they may need to be designed for interoperability in cases where they will be integrated into models of the environment they are deployed in.

5 CONCLUSION

This paper recommended practices for development and deployment of MS&A tools for homeland security applications. Several practices were recommended including software engineering practices, modeling practice, model confidence, standards, interoperability, user friendliness and accessibility, performance, and innovation. The practices may be implemented with different emphasis based on the application type, namely, analysis and decision support, planning and operations, system engineering and acquisition, and training, exercises and performance measurement. The paper identified such differences in emphasis for different MS&A application types and for various MS&A application domains.

Current and future proposed work includes an analysis of needs and requirements, a survey of tools, models and datasets, and an analysis of available standards and gaps for MS&A tools for homeland security applications. The analysis of needs and requirements will help the enhancement of existing tools and development of new tools where needed. The survey would help potential users of MS&A tools in identifying suitable applications and availability of data sets to help evaluate them. Analysis of available standards will guide the developers in ensuring compliance with applicable standards to follow and thus apply the recommended practice. Analysis of gaps in availability of standards will help guide the MS&A community interested in homeland security applications in identifying the critical needs and in mounting collaborative efforts for addressing them.

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DISCLAIMERS

Some software products may have been identified in the context of this paper. This does not imply a recommendation or endorsement of the software products by the authors or NIST, nor does it imply that such software products are necessarily the best available for the purpose.

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AUTHOR BIOGRAPHIES

SANJAY JAIN is an Assistant Professor in the Department of Decision Sciences, School of Business at the George Washington University. Before moving to academia, he accumulated over a dozen years of industrial R&D and consulting experience working at Accenture in Reston, VA, USA, Singapore Institute of Manufacturing Technology, Singapore and General Motors North American Operations Technical Center in Warren, MI, USA. He received a Bachelors of Engineering from Indian Institute of Technology (IIT)-Roorkee, India, a Post Graduate Diploma from National Institute of Industrial Engineering, Mumbai, India, and a Ph.D. in Engineering Science from Rensselaer Polytechnic Institute, Troy, New York. His email address is `<jain@gwu.edu>` and his webpage is available at `<http://home.gwu.edu/~jain>`.

CHARLES R. MCLEAN is a computer scientist and was the Group Leader of the Manufacturing Simulation and Modeling Group at the National Institute of Standards and Technology until his retirement in summer of 2009. He is currently a guest researcher at NIST. He managed research programs in manufacturing simulation, engineering tool integration, product data standards, and manufacturing automation at NIST since 1982. He has authored more than 50 technical papers on topics in these areas. He served on the Executive Board of the Winter Simulation Conference and the Editorial Board of the International Journal of Production, Planning, and Control. He is formerly the Vice Chairman of the International Federation of Information Processing (IFIP) Working Group on Production Management Systems (WG 5.7). He holds an M.S. in Information Engineering from University of Illinois at Chicago and a B.A. from Cornell University. His e-mail address is `<charles.mclean@nist.gov>`.