Practical Considerations for Implementing Homeland Security Models & Simulations

Dr. Charles W. Hutchings
U. S. Department of Homeland Security
Washington, DC
Charles.hutchings1@hq.dhs.gov

Dr. Sanjay Jain
George Washington University
Washington, DC
jain@email.gwu.edu

Y. Tina Lee
National Institute of Standards and Technology
Gaithersburg, MD
yung-tsun.lee@nist.gov

Charles McLean
McLean Software Consultants
Derwood, MD
crmclean@comcast.net

Modeling and simulation (M&S) capabilities support reasoning in many domains and can provide powerful tools for homeland security analytical needs. These capabilities are particularly valuable in exploring systems that are inaccessible for direct observation and study or that involve significant complexity. Uncertainty and risk play a significant part in many homeland security problems, and computer models and simulations can be used to check assumptions and study variability in the performance of a system, process, or policy. The sound and effective use of M&S capabilities in solving problems requires an understanding of the issues being addressed (i.e., cost), the M&S methodology, and the capabilities and limitations of the information that the technology can provide. Although the U. S. Department of Homeland Security executives and program managers frequently address problems of all sorts, relatively few understand the advantages, disadvantages, and cost and benefits of using M&S as an analytical tool. This paper provides some practical guidance for executives and program managers to consider when deciding to use M&S as an analytical tool.
Keywords: Guidelines, Logic Model, framework, standards, program managers.

DISCLAIMER

The findings, recommendations, and viewpoints described in this paper are those of the authors and do not represent the official position of U. S. Department of Homeland Security (DHS), its Components, or the National Institute of Standards and Technology (NIST). Any references to tools or services are not endorsements by DHS or NIST, nor does it reflect the tools and services mentioned are necessarily the best for the purpose.

1. INTRODUCTION

Models and modeling are important for homeland security and are described in both law and policy. For example, references [1-10] mandate or describe the use of modeling in DHS components and related organizations to support homeland security. Per U.S. Code [3], the Chief Financial Officer is required to provide leadership in developing and promoting improved analytical tools and methods for analyzing homeland security planning and the allocation of resources. Homeland Security Presidential Directive #7 (HSPD-7) [7] states that, "The Secretary will utilize existing, and develop new, capabilities as needed to model comprehensively the potential implications of terrorist exploitation of vulnerabilities in critical infrastructure and key resources." HSPD-18 and HSPD-21 [8, 9] cite the need for high-level modeling of Weapons of Mass Destruction (WMD) scenarios and a model-based assessment of public health preparedness. A memorandum from U.S. Office of Management and Budget [10] requires agencies to explain the basis for significant assumptions,

data, and models used or relied upon in risk-related assessments or decisions. The intent of much of the legislation is for DHS to coordinate development and use of homeland security modeling capabilities with other federal agency partners and the private sector. It also highlights the importance of model applications, especially for assessing risks to critical infrastructure and responding to damage from natural and man-made disasters and catastrophes.

Homeland security officials, executives, and program managers (PMs) face a variety of problem situations in securing the nation. These types of problem situations can be multifaceted. They can be static or dynamic. They can be simple in nature or complex and "messy." They can involve physical systems as well as organizations and human beings. They can be routine or unprecedented as with several recent catastrophes like the Deepwater Horizon oil spill in the Gulf of Mexico or the Fukushima nuclear disaster. Decision making to resolve a problem situation can be done by individuals or groups using different types of decision models and can be structured or unstructured. Computational models and M&S capabilities offer enormous potential as analytical tools to support the spectrum of problems faced by homeland security officials in predicting, preventing, responding, and/or recovering from man-made and natural threats and hazards.

Unfortunately, DHS executives and PMs typically do not have analytical or technical backgrounds in M&S and are not familiar with M&S capabilities and limitations. They rely on Federally Funded Research and Development Centers (FFRDCs), the National Laboratories, other federal agencies, and contractors to develop and manage M&S capabilities to provide needed results to inform reasoning and decision making. Furthermore, the skills and knowledge to develop and use computer models and simulations require domain-specific knowledge associated with the problem situation and the availability of relevant data or theory to characterize the phenomena of interest to effectively provide simulation results. Computer and information technology is rapidly evolving, so M&S developers and analysts not only need domain knowledge but also knowledge of capabilities and limitations of existing computing technology. This mismatch of competencies between executives and PMs on the one hand and the analytical and M&S communities on the other, present barriers for better integrating M&S capabilities into homeland security problem solving.

Although M&S capabilities can be powerful analytical tools to support problem solving, these capabilities can also pose risks if they are not properly developed, or managed, or the results are misused. This paper provides some guidance for executives and PMs who may not be familiar with M&S on whether or not to use M&S capabilities to address their analytical needs and requirements. Relevant research literature to this paper is briefly reviewed in Section 2. Section 3 provides an overview of general needs related to homeland security M&S defined in several recent workshops. Section 4 surveys available guidelines and resources for homeland security applications of M&S. Section 5 describes a logic model for using M&S in problem solving. The paper concludes with an organizational perspective to frame the cost and benefits of M&S for mission support.

2. RELEVANT RESEARCH LITERATURE

Several efforts reported in the literature deal with issues relevant to those discussed in this paper. A few of the efforts are briefly discussed here.

M&S capabilities developed for large homeland security incidents are often complex and involve two or more interacting agencies and multiple types and configurations of M&S capabilities. They also have to comprehend complicating external factors caused by natural and man-made incidents that affect the general public. The best approach to deal with large scale M&S applications is modularization or decomposition achieved using a structured approach to M&S life cycle [11].

Modeling human and social behavior continues to be a challenge. Similar to military missions, a commander's success in a homeland security mission depends on the vital ability to process intent and effect to coordinate with all involved agencies and organizations. Efforts to model intents and effects such as in [12] are relatively recent. Another modeling challenge is the sudden changes in human behavior that may occur in emergency situations, such as from fear to aggression. Such sudden changes have been defined as chaotic jump discontinuity of behavior, and needs to be explored more deeply for simulation studies of homeland security [13].

Large homeland security incidents, such as a major hurricane and its effects, can be modeled as complex systems of systems (SoS) that requires SoS simulations. A survey level introduction of relationships between SoS, complexity, and M&S is available in the context of military applications [14]. It includes discussion of metrics of complexity of SoS simulations and reports on approaches to improve the associated systems engineering process. Again, application of the SoS concept in the context of homeland security applications is warranted.

The use of M&S to support decision making has been a topic of interest given the complexity of M&S applications and the evolving underlying science. It has been recognized that supporting decision makers using M&S in complex environments requires a self-critical reflection of simulation results [15]. It is suggested that in some cases proportional reduction in error (PRE) measures can help support the predictive validity of simulation. Further discussions are invited on the topic of simulation-supported decision

making. The risk of decision making based on a small number of simulated scenarios unrepresentative of real world conditions has also been identified [16]. An integrative engineering approach is presented to support sound decision making. Both approaches [15, 16] are discussed in the context of military applications and their use for homeland security applications needs to be explored.

Enterprise activities or offices dedicated to supporting use of M&S in organizations have been reported. The role of the Modeling and Simulation Information Analysis Center (MSIAC) in supporting M&S within the U.S. Department of Defense (DoD) described in [17] is instructive. The MSIAC coordinates efforts at scientific, technical and operational support levels to support effective development, maintenance, and application of M&S. A similar coordinating center for DHS has been proposed to complement other DHS sponsored centers such as the National Infrastructure Simulation and Analysis Center [18].

Overall, the brief review of literature suggests that homeland security applications of M&S are complex and would benefit by structured and coordinated approaches for development and management. It also suggests that support should be provided to decision makers on developing M&S applications and using M&S results.

3. HOMELAND SECURITY M&S CHALLENGES

Several DHS workshops have documented findings and recommendations for improving the application of M&S for a spectrum of homeland security concerns. In 2008, a DHS workshop on Future Directions in Critical Infrastructure Modeling and Simulation [18] identified existing issues and made recommendations for improving the use of M&S capabilities to support infrastructure protection:

- Initiate studies on improving the design of organizational structures to produce, assess, and disseminate M&S products and methodologies most effectively to DHS and the homeland security community.
- Develop interoperable model architectures.
- Improve communication and collaboration within the modeling community.
- Define and pursue opportunities to leverage infrastructure and related models for untapped clients and users.
- Investigate the approaches, testing methods, and metrics that the private sector and other government entities are using for model verification and validation.
- Develop and regularly update a master compendium of available models and related research from labs, academia, and industry.

A recent workshop on M&S for homeland security sponsored by DHS [20] brought together a wide range of experts from both government and private sectors to exchange information and benchmark knowledge on M&S and M&S-related issues for securing the homeland. Securing the homeland was identified to include an array of activities to prevent, protect, respond, and/or recover from both man-made and natural threats and hazards. Workshop participants identified a number of challenges for better implementation of M&S including:

- Identification of appropriate models, simulations, tools, and databases to address homeland security needs.
- Identification and development of common models, simulations, tools, and databases that can be shared with the user community.
- Development of a central repository, directory, or authoritative source for models and tools with related information such as guidance on use and quality.
- Integration among models and simulations implemented for different technical domains as well as with other homeland security software applications and databases.
- Ensuring an adequate return on investment to stakeholders and sponsors for research projects.

The two workshops identified some common themes for M&S needs and challenges from the perspectives of infrastructure protection and homeland security more broadly; i.e., infrastructure protection, incident management, health care systems, and hazardous material releases.

Although workshops and papers describe needs and challenges for homeland security M&S, the identified needs focus primarily on M&S needs to support DHS operations. They do not focus on the needs and requirements of those who would use the results such as executives and PMs in DHS or other homeland security organizations. For example, [20] focused on four areas in which homeland security M&S capabilities tend to be concentrated:

- Incident Management
- Critical Infrastructure Protection
- Hazardous Material Releases
- Health Care Systems

M&S capabilities are seldom used in DHS for management related problem solving and decision making such as strategic planning, acquisition program management, and systems engineering even though these capabilities are widely used for similar functions in business, product development, and manufacturing.

DHS spends a majority of its resources on just managing homeland security core functions like screening, securing the border, and administering benefits. M&S and

other analytical capabilities offer a means to improve planning and execution of these core management functions but are not typically used to support analysis of DHS resources, processes, and enterprise operations. This is another significant challenge that has not been formally identified. Reasons for lack of use of M&S capabilities reflect a general lack of analytics by DHS executives, PMs, and their staff members. Other reasons may be due to limited knowledge of how to manage and use M&S capabilities, the analytical power they offer, or the trustworthiness of M&S results. The next section provides a survey of available guidelines on some technical aspects for specifying, developing, evaluating, and managing homeland security M&S capabilities that may be helpful.

4. SURVEY OF EXISTING GUIDELINES

This section briefly surveys the technical aspects of the M&S selection and use process discussed in the previous section. In recent years, DHS sponsored efforts have developed resources and guidance for PMs interested in utilizing M&S for homeland security applications. Relevant efforts in selected aspects of the structured approach mentioned above are discussed below.

4.1. M&S Application Process Guidance

The guidance for the M&S application process should help DHS PMs in understanding the major stages involved in requirements, development, validation, and implementation of M&S solutions. In many instances the DHS PMs engage contractors for development of M&S applications. The guidance hence should also assist the PMs in specifying requirements that can be used for contract award, management, and evaluation. It should provide the necessary background to PMs to assess the use of best practices by the contractor. In addition, guidance is also needed for archiving and configuration management of M&S applications to allow their use and/or modification for other purposes that are similar to original intent.

In response to the identified needs, DHS-sponsored efforts have led to developing multiple guidance documents [21-23]. Technical guidance on specifying and developing homeland security simulation applications has been provided [21]. It is intended to help develop better technical specifications for homeland security M&S applications. Examples of topics that are addressed in this report include:

- User needs analysis and system requirements specification
- Conceptual and data modeling of the specified application
- M&S technologies and their appropriateness to different problem domains
- Use of commercial M&S tools
- Project team/developer qualifications
- Targeted users and user interfaces
- Inputs and test case data
- Output reports
- Documentation
- Verification, validation, and accreditation (VV&A)
- System performance
- Computing platforms
- Security
- Communications
- Databases and database management systems
- Exchange files
- Standards

For each topic, the following information is provided: a brief definition/discussion of the topic and explanation of its significance to M&S. Additional information includes ideas of what the PM should expect with respect to development issues, M&S deliverables, possible role of standards, selected references, and if appropriate and available, technical examples.

Best practices for development and deployment of M&S applications have been identified [22] to guide PMs' assessment of approaches being proposed by contractors. The set of best practices includes:

1. Conceptual modeling practice
2. Innovative approaches
3. Software engineering practice
4. Model confidence/ VV&A
5. Use of standards
6. Interoperability
7. Execution performance
8. User friendliness and accessibility

Each of these practices is discussed using a common outline that includes: practice introduction, available guidance, recommended implementation, use for legacy vs. new applications, roles and responsibilities, costs/benefits, and metrics. Available guidance for the best practices ranges from a few research publications to many standards and policy documents. The recommended implementation identifies the guidance to follow for the cases where there are several competing options. The case for use of the best practices is supported by cost and benefits information where possible since limited documentation is available in literature on these aspects.

Technical guidance on archiving and configuration management of homeland security M&S applications has also been developed [23]. The general guidance is designed to help DHS PMs who may have limited expertise in simulation to better understand the technologies used to

maintain and support homeland security M&S applications. Examples of topics (within the context of simulation) that are addressed in this report include:

- Archiving of simulation applications, associated software, and test data
- Configuration management of simulations, models, associated software, and test data

For each topic, the following information is provided: a brief definition/discussion of the topic, explanation of its significance, definitions of key terminology, and identification of relevant standards. Examples of subtopics include policies and planning, procedures, and tools. Additional information on subtopics includes a discussion of issues, recommendations and guidelines, and sources of further information.

Together the three documents [21-23] help DHS PMs develop basic knowledge in M&S and provide guidance for managing contracts for development of M&S applications.

4.2. M&S Reference Resources

Availability of reference resources can significantly encourage M&S applications in an organization. DHS-sponsored efforts have also studied the use of reference resources and have developed some resources. Approaches used in several federal agencies for managing and using M&S capabilities for mission support have been identified and general characteristics of an organizational infrastructure to support M&S applications that could be adopted by DHS to improve M&S management have been described [24].

A knowledge-sharing framework has been proposed to support development and implementation of M&S applications [25]. It would define the needs and requirements based on input from the subject matter experts, researchers and users and ensure the best use of constrained resources that are required for developing useful M&S tools. Currently available tools, ongoing projects, and facilities would be identified to avoid duplication of efforts. Best practices would be shared to allow all to learn from experiences of others. Known research, development, and implementation issues would be captured and shared. Current and needed standards would be identified to ensure interoperability of developed M&S tools.

It has been recognized that homeland security includes a wide range of applications. Hence, the knowledge assets need to be organized by major domain areas within homeland security. The knowledge assets with inputs from experts in four major domains: incident management, critical infrastructure systems, hazardous material releases, and healthcare systems have been compiled [19]. For each of the domain, the report discusses: 1) needs and requirements; 2) M&S resources; 3) best practices; 4) limitations, cautions, and warnings; and 5) research and development, standards, and implementation issues.

4.3. Selected M&S Tools for DHS Use

DHS has made a concerted effort on selecting M&S tools in the incident management domain for organization-wide use. The effort has been implemented through the National Exercise Simulation Center (NESC). In addition to identified tools, NESC and the DHS Science and Technology directorate have worked with Sandia National Laboratories to develop the Standard Unified Modeling, Mapping and Integration Toolkit (SUMMIT) for integration of M&S tools and data sources [26]. SUMMIT has been used to support exercises ranging from small to large scale including the National Level Exercise 2012 [27].

5. LOGIC MODEL FOR USING M&S

Section 3 focused on challenges for homeland security M&S and suggested that these capabilities are not being used to their full potential. Section 4 described a number of resources and guidelines to help M&S applications in DHS with one of them [20] providing broad guidelines for M&S applications in four major domains within homeland security. However, support is needed to address the question of whether to employ M&S in general for any problem faced by the organization. This section provides a framework for addressing this question at a non-technical level.

Problem solving begins with a question or questions at hand that need to be addressed. Problem solvers bring to this process the available data and background information regarding the perceived situation as well as their expertise, knowledge, and wisdom. The problem solver's body of knowledge will strongly influence the way in which the problem is characterized and the approaches used to satisfactorily resolve the problem situation and implement a solution. The body of knowledge will also influence what expertise may be required and what analytical processes, methods, and tools, including M&S capabilities, can be brought to bear in the analysis and resolution of the problem situation. Figure 1 shows a conceptual process model for identifying the course of action for problem resolution. In this model, M&S capabilities are one of the analytical tools that may be available to support a problem solving methodology. For example, it may be possible to evaluate uncertainties in data or knowledge associated with a particular problem situation using M&S capabilities to assess risks in various courses of action to resolve the situation. How can a DHS executive or PM decide whether or not to use M&S capabilities?

Logic models are widely used in developing program performance measures, in guiding program evaluations for

non-profit programs, and for analyzing government policies [28]. Logic models show the reasoning and logic underlying a given program or policy by considering what the desired outcome or impacts are, what activity outputs generate the desired outcome, what activities are necessary to generate the essential outputs, and what inputs to these activities are required to support the program or policy. If M&S capabilities development are considered as a program for addressing a given problem situation, a logic model may be useful to executives or PMs in deciding whether or not to invest in development and use.

Figure 2 presents a logic model for problem solving supported by M&S. The figure shows the path from inputs to the desired outcomes. A decision maker motivated to achieve the desired outcomes may consider investing in M&S capabilities with the understanding provided by the logic model. The input to the model includes the question or questions to be addressed and the body of knowledge associated with the problem situation elicited by the analyst or M&S developer. The analytical activities associated with using M&S include developing the M&S capability. M&S development occurs in distinct phases that include specification and development of the capability, evaluation of the capability to understand its reliability, processing and presentation of results, and management of the capability and associated data. M&S and data management will be particularly important if the M&S capability and data will be reused or shared within the organization, either as an individual tool supporting a single application or as part of a federation of other M&S capabilities. The guidelines surveyed in section 3 describe issues that support these sorts of activities.

It is important to remember that M&S generated data do not generate novel information to address problem solving and decision making, instead they evaluate proposed approaches for such purposes. M&S capabilities generate inferences based on deduction, i.e., the results are a function of the assumptions and data used to build and run the model as well as the software and custom programming used to construct the M&S capability. The power that M&S capabilities provide is an array of inferences to address specific areas of interest that may provide new insights into outcomes or courses of action. Not all M&S generated inferences are valid; therefore, it's necessary to carefully test the results and ensure adequacy to support decision making. This evaluation of results is typically known as verification and validation.

The M&S development process itself is informed by an analysis of requirements and the available M&S controls and enablers. For example, the generated results are required within the constraints of time, cost, and analytical needs. The M&S process is supported by available hardware and software for building the analytical tool, the skills of the M&S developer in creating the capability, and the M&S body of knowledge supporting the development. The success of the M&S process is largely influenced by the organizational M&S infrastructure supporting creation and use of M&S capabilities. Due to complexity or the limits of computational science, some analytical problems are not tractable using M&S and will not yield meaningful results.

The logic model includes organizational assets that support analysis using M&S. These types of assets include knowledgeable personnel who can support each of the activities in M&S development, use, and management. In the U. S. Department of Defense (DoD), the Modeling and Simulation Coordination Office (MSCO) provides M&S expertise, guidance, and best practices to support the DoD mission. Other organizational assets might include M&S policies, guidelines, and standards to facilitate development and use. For example, the National Aeronautics and Space Administration (NASA) developed a standard for M&S [29] to improve M&S use in development of spacecraft and other systems to support the NASA mission.

The direct outputs of an analysis using M&S are generated results and the analytical understanding and insights that these results provide to the problem solving and decision making process. The intended outcome and impact of the M&S activities and their results should be informed decision making based on sound analysis and reasoning. There are often significant assumptions or uncertainties associated with analyzing and addressing problem situation and these uncertainties may cloud what the best course of action might be for resolution. M&S capabilities offer a means to explore these uncertainties and evaluate the risks associated with courses of action to improve decision making. M&S outputs and outcomes are typically limited by external factors such as available funding and time that constrain M&S development and evaluation activities.

The logic model also provides a framework for evaluating the efficiency and effectiveness of an M&S investment. Efficiency is a comparison of the output of the M&S activities to the input. For example, resources (typically funding and information) are required to develop and evaluate the M&S capability that will generate results of value. If the results can be obtained by other, less costly means, then the M&S capability is not the most efficient option to address the needs of the sponsor. Similarly, effectiveness of the M&S activity is a comparison of the required resources to the outcomes or impact of the M&S capability on resolution of the problem situation.

The logic model shows the potential value of developing an enterprise infrastructure to support M&S capabilities as 'tools' – M&S capabilities reused to address commonly occurring problems for the enterprise. For these sorts of problems, it may be strategically advantageous to develop a single tool rather than creating a number of independent tools for the same purpose. Similarly, the

enterprise may find investing in common software capabilities or a hardware infrastructure to support M&S capabilities development and use to be advantageous. Development of an M&S competent workforce in the organization would also better enable M&S activities.

6. CONCLUSION

A survey of M&S guidance and the decision model presented above strongly suggest there needs to be a coordinated organization-wide effort to raise the maturity with respect to the use of M&S for problem solving. Such an organization-wide effort will need to follow a structured approach that includes:

1. Development of policies supporting use of M&S
2. Allocation of budgets on a sustained basis to support use of M&S for problem solving
3. Development of M&S expertise
4. Provision of M&S application process guidance
5. Provision of reference resources
6. Development of organization standard tools for common M&S problems
7. Monitoring the development and use of M&S applications
8. Measuring and highlighting the benefits realized

DHS has advanced on a number of these aspects. A number of policy documents discussed in section 1 support the use of M&S. DHS-sponsored efforts have led to development of guidance documents and resources that address items 4 and 5 in the above list. DHS has also made advances with respect to item 6 by selecting M&S tools for organization-wide use. It is anticipated that DHS will continue to move forward in all the aspects of a structured approach.

The surveyed guidelines and resources address a number of practical considerations for using M&S. The presented logic model provides an initial step to support the non-technical community in assessing when M&S capabilities should be employed to support analytical and problem-solving needs. Logic models provide a promising option for supporting DHS executives and PMs and should be explored further for such purposes.

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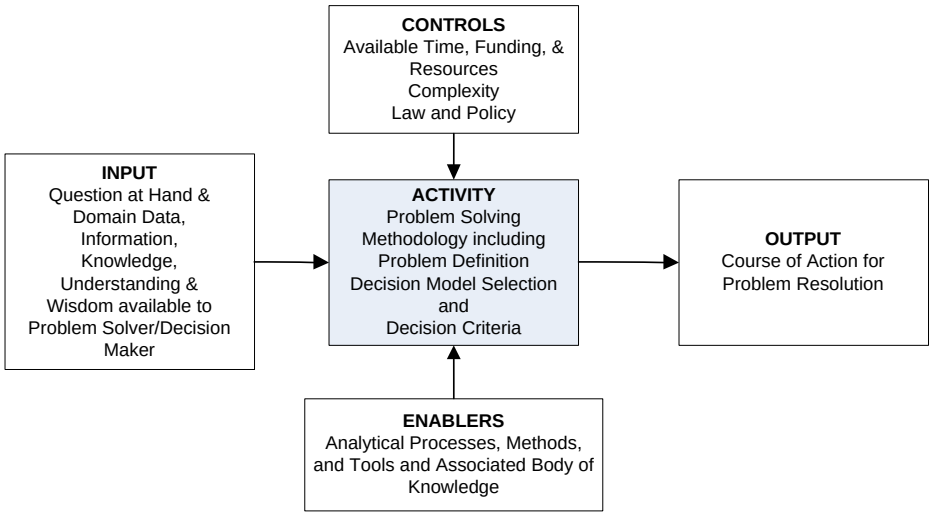

Figure 1. Selection of Problem Resolution Approach

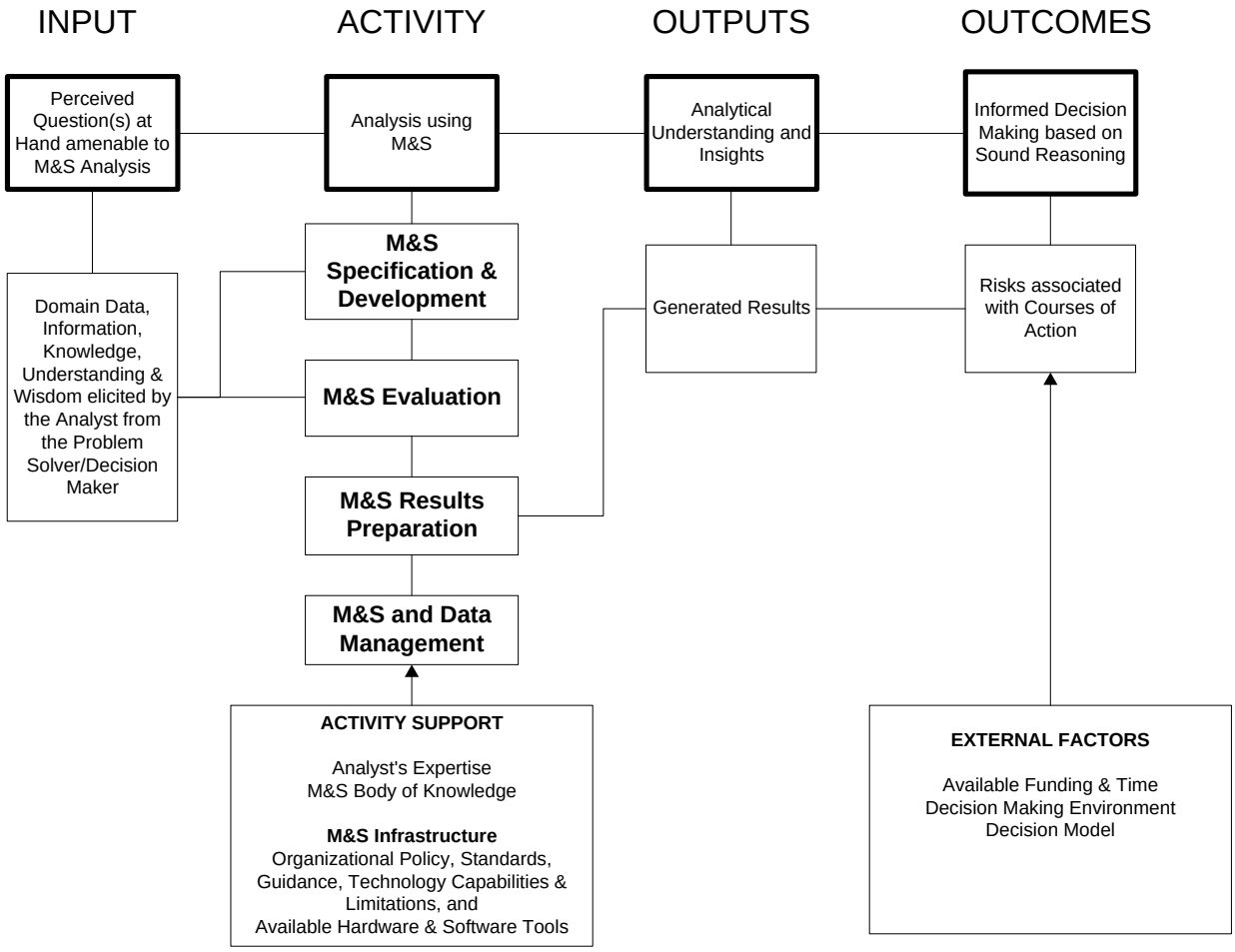

Figure 2. Logic Model for Using M&S in Problem Solving