Enabling Homeland Security with Modeling & Simulation (M&S)

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ABSTRACT

Homeland security stakeholders, who acquire and use M&S capabilities, include all the major components of the U. S. Department of Homeland Security (DHS): Customs and Border Protection (CBP), Citizenship and Immigration Services (CIS), Federal Emergency Management Agency (FEMA), Immigration and Custom Enforcement (ICE), Transportation Security Agency (TSA), U.S. Coast Guard (USCG), and U.S. Secret Service (USSS). Other developers and users of M&S tools and data include state, tribal, and local homeland security agencies, homeland security training facilities, exercise participants, systems and tool developers, and academic researchers. Other stakeholders include non-governmental organizations (NGOs) and international organizations with homeland security missions or concerns. This paper describes a meta-model for analyzing natural and man-made threats and hazards, which considers integration of capabilities from multiple consortiums of public and private sector organizations. The social and physical impacts of natural and man-made disasters can be analyzed using irregular warfare modeling capabilities to provide insights on political, military, economic, society, information, infrastructure (PMESII) domains to support problem solving, decision making, and training at multiple levels of the enterprise. This meta-model provides a framework for assessing current capabilities to identify needs and advance the state-of-the-art of M&S for homeland security.

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INTRODUCTION

Modeling and simulation (M&S) capabilities are a critical enabler in science, engineering, operations research, and training and education, which is emphasized in numerous studies and reports. For example, the National Research Council (NRC, 2002) identified modeling, simulation, and analysis tools as one of its top priority areas:

> *Systems analysis and modeling tools are required for threat assessment; identification of infrastructure vulnerabilities and interdependencies; and planning and decision making (particularly for threat detection, identification and response coordination) …Modeling and simulation also have great value for training first responders and supporting research on preparing for, and responding to, biological, chemical and other terrorist attacks.*

Reference [NRC, (2007)] states:

> *Simulation systems provide one useful tool for decision makers to test potential resource allocation and planning options in a virtual environment. They can provide a vehicle to promote understanding and dialogue on actions and issues related to the development of an effective preparedness and response plan, and serve as a forum and basis for mutual understanding between agencies and disaster management practitioners. Further advances in simulation environments promise to provide comprehensive modeling frameworks that integrate both inverse and forward points of view, applicable at multiple levels of analysis in diverse fields of study, in a structured manner.*

A President's Information Technology Advisory Committee report (PITAC, 2005) states:

> *Modeling and simulation techniques are increasingly being applied to complex, large-scale systems that have an impact on people or are affected by people in real time. The ability to simulate, for example, the spread of a disease epidemic over time or the daily traffic patterns across a metropolitan transportation system is providing public health officials and emergency response coordinators with a powerful new planning tool that provides visual representations of the interactions of complex data. Seeing the "big picture" of what might transpire during a crisis helps planners anticipate and address issues in advance, such as which hospitals and how many hospital beds would be needed at what points during the spread of an epidemic.*

There are multiple consortia engaged in homeland security related analyses and support, which include both governmental and private sector organizations. Some examples of these consortia include:

- The United Nations
- World Bank – Disaster Risk Management Institute (DRMI)
- U. S. Department of Homeland Security (DHS)
- U. S. Geological Survey (USGS)
- National Oceanic and Atmospheric Administration (NOAA)
- Florida Commission on Hurricane Loss Projection Methodology (FCHLPM)
- Institute for Business and Home Safety (IBHS)
- National Earthquake Hazard Reduction Program (NEHRP)
- Earthquake Engineering Research Institute (EERI)
- International Association of Earthquake Engineering (IAEE)

Many of these organizations are using or developing M&S tools and capabilities to support predictions, planning, mitigation, and response to threats and hazards; however, there has been limited collaboration or sharing of tools and analytical approaches and capabilities across these consortia.

In DHS, the Science and Technology (S&T) Directorate supports and array of capabilities, such as:

- M&S capabilities for analyzing structures survivability to explosive threats
- Group Violent Intent Modeling
- Foreign Animal Disease Modeling
- Secure Borders Initiative System Engineering Tool

These are typically developed in an *ad hoc* way to address specific problem areas for S&T "customers", including DHS Components and first responders, but there is limited coordination or collaboration across DHS enterprise to integrate analytical tools and data, to address gaps in capabilities, and advance the state-of-the-art of these capabilities.

Despite studies and reports indicating the value of M&S, DHS does not have an enterprise approach or policy to develop, evaluate, and use M&S capabilities for homeland security. DHS also needs to create a vision and strategic plan to:

- Support collection of critical data for analysis and model development;
- Fully integrate M&S and computational science capabilities throughout homeland security enterprise, and;
- Address critical technical challenges for further model and M&S development.

This would include working with the consortia and organizations developing and using M&S capabilities for homeland security applications.

To support the advancement of M&S for homeland security, this paper describes a framework for analysis of multiple threats and hazards. The framework describes how DHS might integrate a full range of analytical tools and capabilities to evaluate threats and hazards, assess their impacts, and assist officials and decision makers with homeland security planning, operations, and training. The framework is approached from a "systems thinking" perspective. First, we define and provide an overview of homeland security threats and hazards, including some historic information as background. Then we define "model" and "simulation" and describe how different types of M&S capabilities are used to support analysis and decision making. Next, we describe the meta-model for analyzing threats and hazards and show how this can support DHS activities. We conclude with a discussion of some challenges to be overcome for better enabling homeland security with M&S.

OVERVIEW OF HOMELAND SECURITY THREATS AND HAZARDS

To understand the breadth of homeland security phenomena likely to be faced, a taxonomy of the threats and hazards is useful. We define a threat or hazard as any substantial phenomena which cause physical, economic and/or other harm to communities, regions, or the nation. The Hazards-US Multi-hazards (HAZUS-MH) risk assessment program [FEMA, (2004)] defines a hazard as:

> *A source of potential danger or adverse conditions…A natural event is a hazard when it has the potential to harm people or property.*

Threatening phenomena can broadly be classified as either natural or man-made. Table 1 lists threats and

Table 1: Natural Threats and Hazards

Domain	Phenomena
Atmospheric	Climate Change
	Drought
	Hurricane
	Storms (Snow, Electrical, Hail, Ice, Rain, Wind)
	Temperature Extremes
	Tornado
Biological	Animals (Destructive Insects, Locust, Rodents, Invasive Species)
	Bacteria
	Fungus
	Plants (Invasive Species)
	Viruses
Ocean	Tsunami
	Sea Level Changes
	Waves
Space	Impacts (Asteroid, Meteor)
	Solar Flare
Terrestrial	Earthquake
	Flood
	Fire (Wildfire, Forrest)
	Landslide/Avalanche
	Volcano

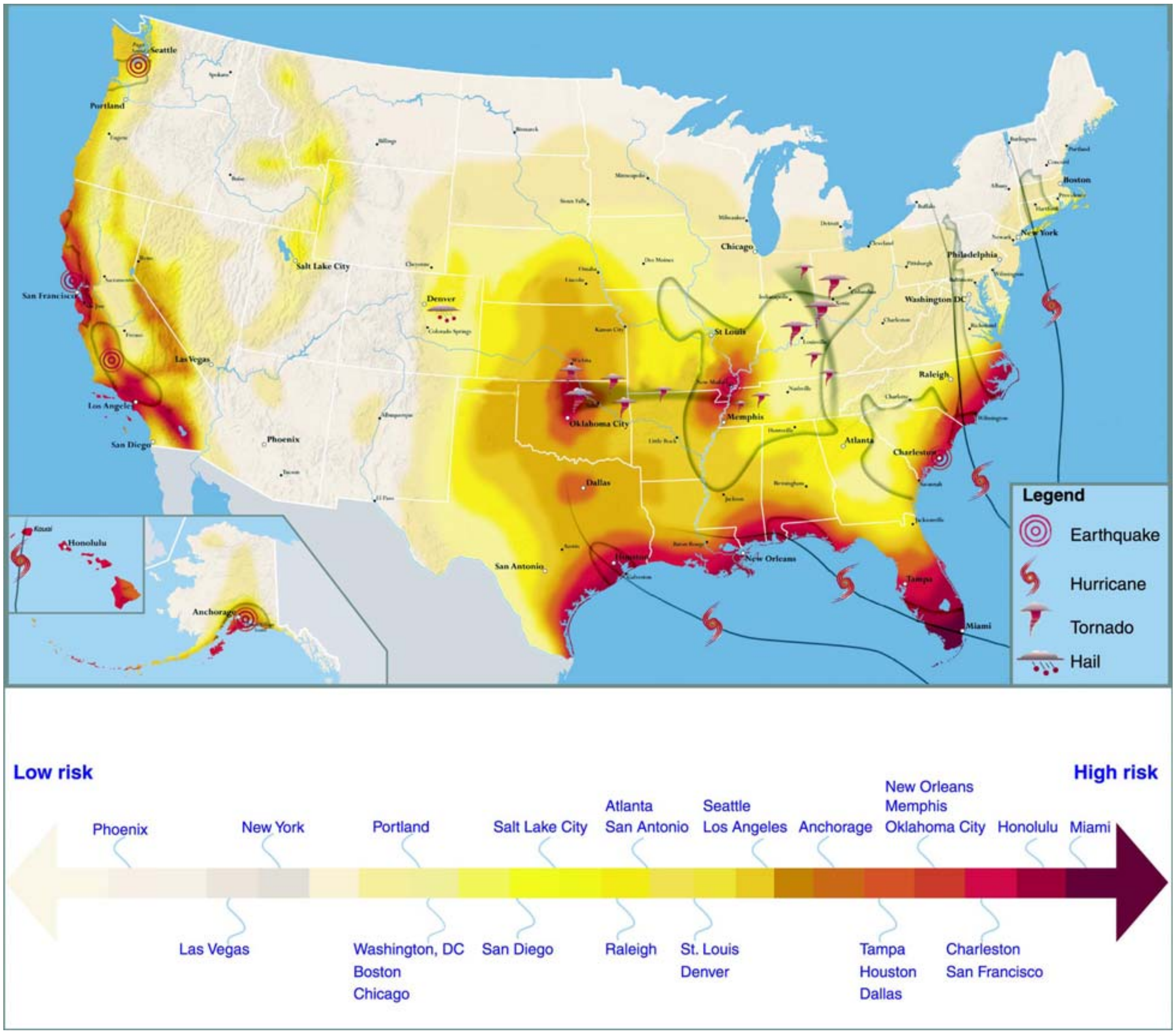

Figure 1: Catastrophic Risk in the United States: Earthquake, Hurricane, Tornado, and Hail [GAO 2002]

hazards encountered in the natural environment. Table 1 includes phenomena identified by FEMA in the HAZUS-MH program:

- Earthquakes
- Floods (Coastal and Riverine)
- Hurricanes
- Landslides
- Tornadoes
- Tsunamis
- Wildfires
- Other Hazards

DRMI has developed a process for risk management that includes the identification of natural and man-made disasters for application worldwide [Schiegg, (2001)]. Under natural disasters, they include:

- Radiation
- Ozone
- Climate (CO2)
- Hurricane
- Lightning Stroke
- Hail
- Snow
- Rain
- Avalanches
- Floods
- Waves
- Droughts
- Volcanism
- Earthquakes
- Debris Flow
- Landslides

Table 2. Man-Made Threats and Hazards

Domain	Phenomena
Biological	Agent Release
	Disease Vector
Chemical	Release/Contamination
	Fire/Arson
	Plumes
	Spills
Criminal	Cyber
	Counterfeiting
	Disinformation
	Extortion
	Fraud
	Espionage
	Identity Theft
Electromagnetic	Electromagnetic Pulse
	Jamming
	Laser
Kinetic	Explosion (Nuclear, Conventional)
	Projectiles (Firearms, Missiles, Other)
	Particle Beams
Nuclear	Release/Contamination
Physical	Assault
	Crowd/Mob Violence
	Hostile Takeover
	Illegal Immigration
	Individual Violence
	Kidnap/Hostage Taking
	Malicious Destruction
	Murder/Assassination
	Piracy/Hijacking
	Smuggling/Drug Trafficking
	Theft/Looting

- Settlement
- Sinking
- ANIMALS
  - Vectors
  - Locust
- PLANTS
  - Fire
  - Forest Dying

Many natural phenomena such as hurricanes, tornadoes, and earthquakes are not uncommon events. Figure 1 shows the combined relative risk of earthquakes, hurricanes, tornadoes, and hail across the United States based on property-casualty insurance data.

Table 2 includes man-made domains and related threat phenomena due to accidents, crime, and terrorism. The phenomenology associated with man-made threats could be accidental, criminal related, or terror related. Characteristics, relationships, and *modus operandi* of criminal groups, gangs, and terrorist organizations have been studied by others [e.g. see Wilson et al., (2007)]. Figure 2 shows FBI statistics of phenomena related to terrorism between 1980 and 2005. These figures include all types of terrorism both domestic and international. It is clear that bombings have been the primary weapon of choice for terrorism.

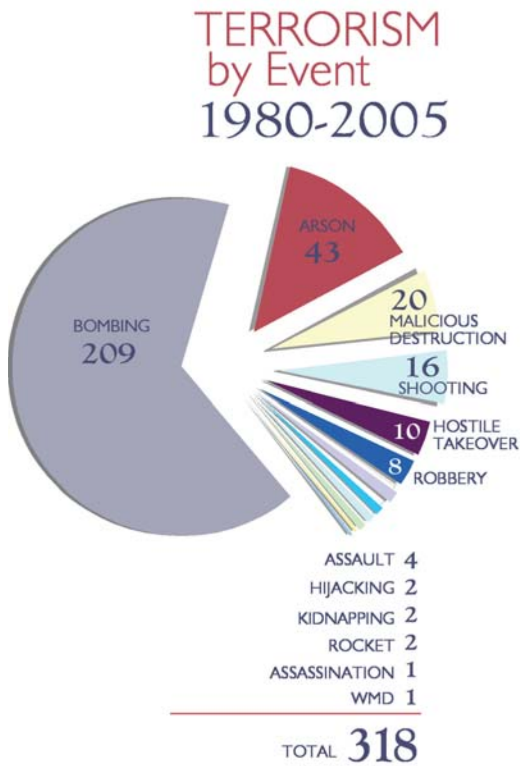

Figure 2: FBI Statistics on Terrorism Events from 1980 – 2005 [FBI, (2006)]

According to the DRMI analytical scheme, which is rooted in systems thinking (cybernetics), natural disasters involve only matter (e.g., tidal surge) and energy (e.g., lightning) transfer in a system while man-made disasters involve matter and energy (e.g., explosions), and/or information exchange (e.g., cyber terrorism).

Together, Tables 1 and 2 describe a comprehensive set of threats and hazards, which concern the homeland security community. Some of these phenomena can, to an extent, be predicted using analytical capabilities, such as hurricane track forecasting. Given this diverse set of hazardous phenomena, homeland security problems would best be addressed with an understanding of both the physical and social impacts of these phenomena to mitigate damage, to prepare for future incidents, and effectively respond to adverse events that have occurred. Since we cannot create disasters and catastrophes at will for experimentation and study, science-based simulations and M&S capabilities are essential to understand physical phenomena, their damage mechanisms, and their impacts on communities. This understanding would support analysis, planning, operations, and training.

META-MODEL FOR ANALYZING THREATS AND HAZARDS

Homeland security M&S capabilities have been catalogued and reviewed (e.g., see Jain and McLean, 2003; Agrait, R, et al., 2004; and Jain and McLean, 2008). These support a range of application such as planning, vulnerability analysis, identification and detection of hazards, systems testing, and real-time response. Real-time response capabilities usually provide first responders with quick estimates of hazards to assist controlling the situation after an event has occurred. After a chemical spill for example, information from chemical plume modeling helps first responders evacuate the area down-wind of the spill and assists them with rescue and recovery of the victims where the chemical concentration is estimated to be toxic.

For this paper, we use the following definitions for model and simulation [IEEE, (1989)]:

> ***Model.*** *An approximation, representation, or idealization of selected aspects of the structure, behavior, operation, or other characteristics of a real-world process, concept, or system.*
>
> ***Simulation.*** *A model that behaves or operates like a given system when provided a set of controlled inputs.*

Models and simulations require data and information for development, evaluation, and use. The quality of M&S results will necessarily be limited by the quality and quantity of data and information used to create and run the M&S capability.

M&S results typically serve one of three purposes:

- Simulating experiences, environments, or objects (e.g., video games, training simulators, exercises).
- Providing analytical insights for studies, research, concept exploration, and system development, (e.g., “low fidelity”, first approximations).
- Providing predictive capabilities; e.g., future performance of a given system in a specified environment or scenario (e.g., “high fidelity”, computational science models for operations analysis, systems engineering, etc.).

M&S and data provide a range of analytical capabilities for problem solving and decision making. At one extreme, they provide analytical insights and a means for thinking about complex systems for complex, intractable problems, also known as messes or “wicked” problems. At the other extreme, M&S capabilities provide predictive capabilities and tools for routine decision making to evaluate alternatives for well defined problems.

“Model”, “simulation”, and “data” mean different things to different communities, and it is important to recognize this when dealing with a wide range of models and modelers from different disciplines. For example, the physical science community views data objectively, which is typically acquired from sensors or instruments that provide readings which are observer independent. This community then develops models which capture the behavior of physical systems based on measured data, and validation of models is an assessment of how well the simulated or calculated values of a physical system correspond to measurements given uncertainty. We shall refer to this type of M&S capability as “hard” M&S adapting an approach by Pidd for classifying operations research [Pidd, (2003) and Pidd, (2004)]. M&S capabilities which provide predictions are typically considered “hard” M&S; e.g., equations of motion for missile targeting or calculating the orbits of satellites.

For the social science communities, data is often more subjective, and researchers typically form consensus on what a set or sets of data represent. These communities use models to organize thinking and to study complex phenomena or systems. Validation is usually a check of consistency, plausibility, and whether or not the results make sense given what is understood of the phenomena or system of interest.

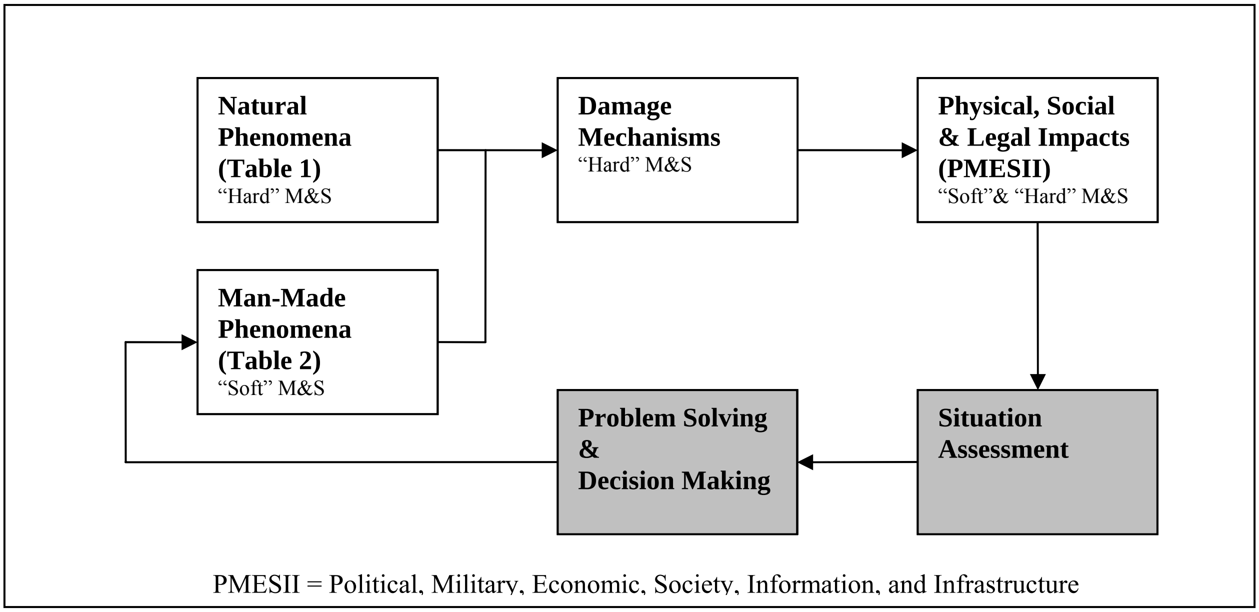

Figure 3: Meta-Model for Threats and Hazards

We shall refer to this type of M&S capability as "soft" M&S. "Soft" M&S capabilities generally provide insights to analysts on very complex systems with significant variability or uncertainty; e.g., economic projections for the Gross National Product or individual human behavior in response to a threat.

For homeland security analysis, problem solving, and decision making, analysts at all levels should take advantage of the full range of M&S tools and capabilities from all the sciences (behavioral, biological, management, physical, and social) to understand how communities at various levels (national, regional, state, and local) function normally and how these communities are stressed during a catastrophic event or disaster. With a "big picture" perspective and sound M&S capabilities, decision makers can make informed choices and respond quickly to contain damage and promote resiliency after any disaster.

Figure 3 shows a meta-model for integrating a range of M&S capabilities to evaluate phenomena and their impacts for situation assessment, problem solving, and decision making for homeland security. This approach is similar to that used by the insurance industry to analyze risks and establish insurance premiums. It starts by identifying and evaluating potential risks, addressing the question: What phenomena cause damage? Natural phenomena such as hurricanes have several damage mechanisms which result in damage to buildings and infrastructure such as high wind, rain, large waves, and tidal surge.

The damage mechanisms due to phenomena can be assessed and evaluated using physics-based M&S capabilities to understand how damage occurs to a system or systems of interest (e.g., location, area, or institution, etc.). Man-made phenomena, such as explosions, also cause physical damage which can be assessed and evaluated using physics-based M&S capabilities. The results of damage assessments create a basis for mitigation measures and response planning.

Although less well understood than physical phenomena, social phenomena are important factors in responding to a disaster, and these should be integral to situation assessment, problem solving, and decision making as shown in Figure 3. These capabilities need to be developed for the homeland security community.

In the U. S. Department of Defense (DoD) planners are increasingly focusing on Effects Based Operations (EBO) to plan future campaigns. This includes analyzing diplomatic, information, military, and economic (DIME) options for achieving national objectives. The outcome of particular DIME actions are evaluated using social and cultural models to assess the impacts of these actions in political, military, economic, society, information, and infrastructure (PMESII) domains [NRC, (2006) and NRC, (2008)].

PMESII analysis includes an array of M&S capabilities, such as regular military force,

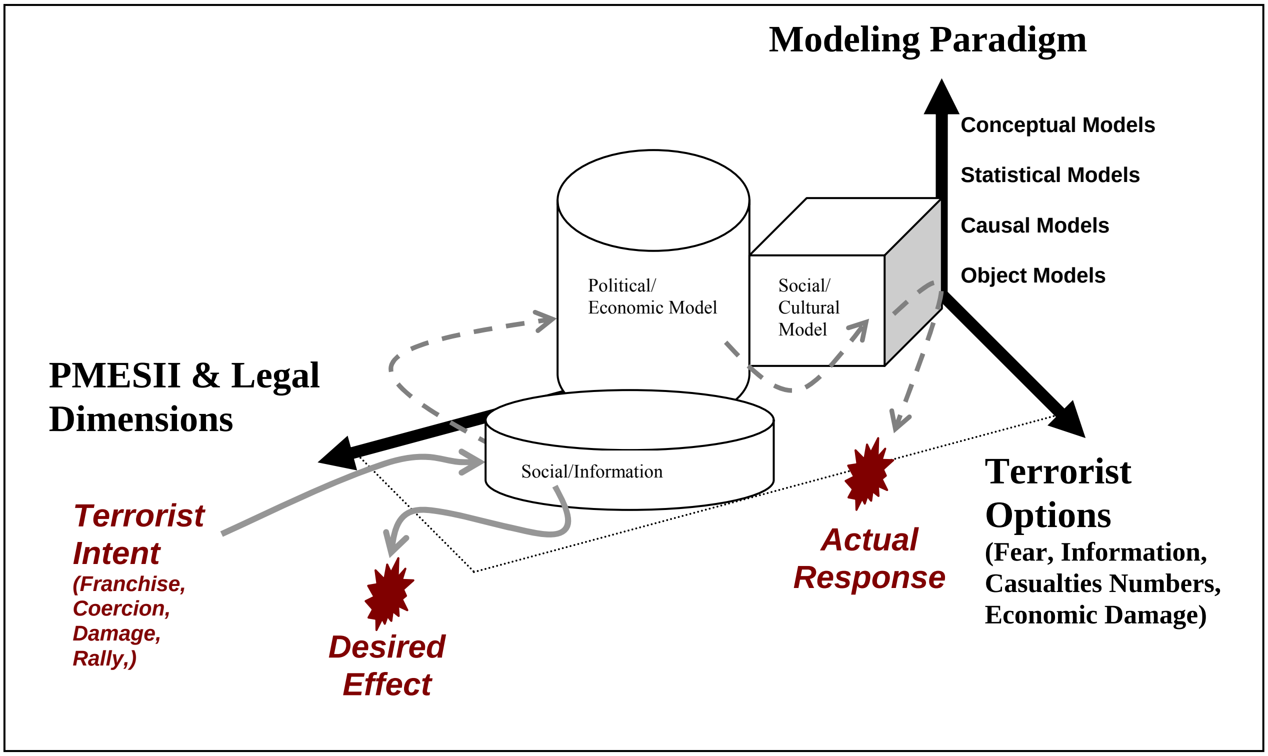

Figure 4: Terrorism Modeling Space [Adapted from Figure 2-3 in NRC, (2008)]

political/religious, political/economic, social information, and social/cultural models using a variety of modeling techniques such as:

- Concept maps
- Concept Graphs
- Social Networks
- Causal Graphs
- Systems Dynamics Models
- Neural Networks
- Situation Theory

The DIME/PMESII approach provides a useful paradigm for analyzing and planning for Homeland Defense and Irregular Warfare. DoD is funding research and development in these analytical tools and capabilities and establishing requirements for models. For DHS, the DIME/PMESII approach and some of the models are good candidates for analyzing homeland security impacts and issues due to natural and man-made threats and hazards.

Figure 3 includes feedback from the Problem Solving and Decision Making phases to Man-Made Phenomena. This assumes that rational enemies/terrorists will critically examine homeland defense actions and adapt their tactics and actions according to what they learn from the response to a given incident, based on their intentions.

Homeland security analysts could consider EBO from a terrorist perspective to assist with managing risks due to terrorist or extremist groups. Instead of DIME options, terrorist groups might consider fear, information, casualty numbers, and economic damage to promote an agenda, which might include a number of motives or intentions. Libicki, et al., (2007) describe several hypotheses regarding the intentions and motivation of al Qaeda including:

- Franchise operations
- Coercion
- Damage
- Rally support

The analytical space defined by terrorist options, PMESII & Legal dimensions, and modeling paradigms is shown schematically in Figure 4. Although a terror incident or campaign may be aimed at a desired effect, the national or cultural response may be vastly different than intended due to complex cultural, social, and political interactions. Sound PMESII type capabilities could help analysts anticipate potential terrorist actions and potentially mitigate the impacts given their desired effects. The Group Violent Intent Modeling project being sponsored by the DHS S&T Directorate is focused on this problem.

Natural disasters also have PMESII type and legal impacts demonstrated during Hurricane Katrina, which had impacts and fallout in each PMESII domain. Development of capabilities to evaluate and assess the physical, social, and legal impacts of any adverse event would enable homeland security problem solving and decision making and promote systems thinking with science-based analytical tools.

APPLICATION OF THE META-MODEL

We have described a set of phenomena of interest for homeland security and a meta-model for developing tools and analytical capabilities for addressing threats and hazards. We now give two examples of how this framework could be applied in DHS.

The Federal Emergency Management Agency (FEMA) established a National Exercise Simulation Center (NESC) early in 2009 as a national resource for M&S capabilities related to homeland security, focusing on training and exercise support. The NESC uses virtual reality tools to study how to prepare for and coordinate training events to work out problems prior to initiating a live event. NESC can also model emergency operations centers at other locations using virtual reality and gaming technology to provide participants different perspectives on various aspects of the exercise or training event.

NESC is currently a hub for simulation which makes use of capabilities developed by other users, and efforts are underway to catalogue what M&S tools are available from the community at large to support training and exercise scenarios.

DHS officials and others gain experience and insights into incident management through "board games", exercises using established scenarios, or through dealing with real-life incidents. For training and exercises, few analytical capabilities exist to provide feedback to exercise participants on the physical and social impacts of their decisions to promote learning and improve disaster response. The meta-model described above provides a framework for development of a comprehensive set of M&S tools and capabilities to improve the quality of training evolutions and exercises.

Incident response typically starts at a local level and escalates as additional resources are required. First responders are first at the scene, and higher level involvement from the state, regional, or national levels is determined by the magnitude of an event and the assets needed to effectively deal with the situation. The National Incident Management Systems (NIMS [DHS, (2004)]), guides the response to incidents at multiple levels and serves to:

> *…provide a core set of doctrine, concepts, principles, terminology, and organizational processes to enable effective, efficient, and collaborative incident management at all levels.*

To support budgetary planning, contingency planning, and training and exercises, DHS has developed a number of National Planning Scenarios (NPS) [DHS, (2006)]. There are 15 different NPS focusing on a variety of both natural and man-made threats, and these are representative of the range of possible threats and hazards that face the nation. The NPS scenarios are generic and all follow the same general outline, which includes:

- Scenario Overview
  - General Description
  - Detailed (Attack) Scenario
- Planning Considerations
  - Geographical Considerations/Description
  - Timeline/Event Dynamics
  - Meteorological Conditions (where applicable)
  - Assumptions
  - Mission Areas Activated
- Implications
  - Secondary Hazards/Events
  - Fatalities/Injuries
  - Property Damage
  - Service Disruption
  - Economic Impact
  - Long-Term Health Issues

The importance of fully understanding all the implications and impacts due to a disaster were shown by lessons learned from Hurricane Katrina [White House, (2006); GAO, (2006)]. Although one NPS includes a major hurricane scenario and exercises had been conducted prior to Hurricane Katrina, many of the impacts of Hurricane Katrina were not anticipated. Training, exercises, and planning for events without realistic analysis and understanding of all the issues are of limited value. Analytical and M&S capabilities developed using the meta-model as a framework would allow these scenarios to be realistically tailored to communities or regions and improve the quality of the scenarios for planning and exercises.

CONCLUSION

We have described a taxonomy of natural and man-made threats and hazards of interest for homeland security, which include phenomena noted by others. Natural threats occur with some regularity and their impacts vary in type and degree of severity. Man-made threats are unpredictable and have typically included the use of explosives or other lethal methods, which have the potential to be catastrophic. We described a meta-model for incorporating threats and hazards into an analytical framework, which could include a broad spectrum of M&S tools and capabilities to support homeland security problem solving and decision making. Our approach includes assessing the damage from all threats and hazards and providing insights on their physical, social, and legal impacts. Science-based M&S capabilities can enable protection, prevention, mitigation, response, and recovery actions by providing decision makers a comprehensive, "big picture" understanding of an array of complex, multifaceted homeland security issues.

Analytical modeling for homeland security has primarily focused on the physical infrastructure sectors, and the National Infrastructure Simulation and Analysis Center (NISAC) was established in DHS by the Homeland Security Act of 2002. NISAC employs over 100 analysts at Sandia and Los Alamos National Laboratories and has acquired data and developed models for many of the infrastructure sectors, which supports analyses and understanding of the physical and economic impacts to these sectors during a disaster such as an earthquake or hurricane.

NISAC analysts also performs studies, for example, examining the impacts on population, critical infrastructure, and the economy due to an outbreak of pandemic influenza [NISAC, (2007)], which included an assessment of various mitigation strategies.

Homeland security readiness and DHS management and operations, in general, would benefit by establishing in-house, analytical capabilities to study and understand all related impacts of disasters and catastrophic events. For example, a DHS center for homeland security information and analysis could establish homeland security measures of effectiveness and metrics to guide Departmental actions and coordinate the collection, quality control, and management of critical homeland security data. This center could support development of a full range of multi-disciplinary simulation capabilities, and foster analytical capabilities and a competency for homeland security analysts. This would both complement and support NISAC capabilities.

Several areas need to be addressed for development of M&S capabilities. From a technical perspective, DHS needs data and a better understanding of all the PMESII domains and legal impacts both prior to and after a catastrophic event to develop and evaluate models. Some of this information may be available in historical documents, reports, and lessons learned of previous disasters; however, this data is often incomplete. Mechanisms or approaches are needed to better acquire and warehouse data and information that will enhance our information and understanding of systems at all levels (national, regional, state, tribal, and local) in both normal and adverse conditions.

Strategic planning is needed to support capabilities development and the homeland security M&S infrastructure. A strategic plan should identify key gap areas, promote research and development to advance capabilities, and support development of analytical and M&S competency in homeland security enterprise.

The development and use of a variety of M&S capabilities will require guidelines and standards for integration and interoperability of tools and capabilities. DHS leadership in this area would help focus homeland security M&S efforts in other government agencies and the commercial and private sectors. Additionally, policies and guidelines are needed for the evaluation of capabilities to ensure that uncertainties and errors are quantified to promote the credibility of M&S results. This is a significant challenge for all types of M&S capabilities and an active area of research. Sensitivity analysis and the quantification of M&S uncertainty would provide analysts and decision makers with deeper insight into the credibility of M&S results and better enable the sound application of these tools and capabilities.

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