Homeland Security Simulation Domain – A Needs Analysis Overview

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ABSTRACT: *The effective use of modeling, simulation, and analysis (MSA) applications could greatly enhance our nation's ability to achieve homeland security goals. The development of MSA applications has been conducted largely on an ad hoc and piecemeal basis. There is very little, if any, coordination of MSA development activities across government agencies, the research community, the commercial software sector, and various standards organizations. Without coordination and appropriate standards, there is little possibility of software re-use or the establishment of reference data sets that meet homeland security needs. A needs analysis for MSA applications is the first step to the identification of standards requirements. NIST is conducting a needs analysis for the Department of Homeland Security in this area. This paper provides a high level overview of a needs analysis for the homeland security simulation-modeling domain. The modeling domain gives an indication about what is being simulated or the dynamics of the simulation, i.e., the ways in which real world behaviors, processes, phenomena, or effects are generated. Major groupings of modeling domains for categorizing simulations include Social Behavior; Physical Phenomenon; Environment; Economic; Organization; Infrastructure System; and Other System, Equipment, and Tool. The paper briefly describes needs for each of these MSA domains.*

1. Introduction

The Department of Homeland Security (DHS) Science and Technology (S&T) Directorate has recognized that there is a critical need to establish order and appropriate standards for the homeland security modeling and simulation domain. NIST has been tasked with coordinating the identification of standards that are needed to improve the efficiency of modeling, simulation, and analysis (MSA) application development and the utilization of homeland security MSA products. The first steps in the NIST plan to improve the effectiveness of homeland security MSA applications is to establish mechanisms that will help track what simulation technology is currently available, identify needs, and determine best practices that are employed by simulation developers. Longer-term objectives include the identification of standards gaps that need to be filled and recommendation of verification, validation, and accreditation (VVA) procedures for MSA.

1.1 Homeland Security MSA Taxonomy

The initial task in establishing guidance for homeland security MSA applications was to develop a taxonomy for categorizing homeland security MSA applications by various key characteristics. The proposed taxonomy, rationale for the classification scheme, and descriptions of some of the characteristics is contained in [1]. The intention of the taxonomy was to develop a classification scheme that will hopefully stand the test of time and not require frequent modification, as needs change and new applications are developed. The taxonomy document is not focused on evaluating or defending particular uses of modeling and simulation, but rather providing a scheme for classifying applications, recognizing the fact that these applications already exist, are currently in development, or may be developed in the future.

The proposed MSA taxonomy has four major classification categories: objectives, target user organizations, simulation contexts, and implementation characteristics. Objectives define the reason why the MSA application was developed. Target user organizations define who the application was designed to serve. Simulation contexts define what was modeled and what the capabilities are contained within the simulation. Implementation characteristics define how the application was built.

An MSA application is often developed to satisfy a single major objective, for example the training of incident management personnel. This characteristic identifies the primary purpose of an MSA application. Application objectives are likely to be mutually exclusive, e.g., a training system would probably not be used for systems engineering and vice versa. Potential users looking for systems that are available to meet a specific need will typically want to search for an application based on its defined objective or original intended use. The major categories of objectives that have been identified are:

- Decision support
- Planning levels and domains
- Intelligence and risk analysis
- Systems engineering
- Training and performance measurement
- Component module

A particular implementation of a simulation may be used to support any or possibly all of these objectives. For example, a traffic simulation may be used in many ways. It may be used as a planning and decisions-support tool to make resource allocation decisions for evacuations or as a systems engineering tool to evaluate the effectiveness of traffic control systems. It also may be used as part of a training system to predict travel times in response operations or as a risk analysis tool to evaluate the vehicles that may be trapped in traffic during a disaster evacuation. Some simulators may be built as component modules and assembled into larger applications to satisfy one of the other objectives outlined above. For example, a weather simulation may be utilized in conjunction with a plume simulation model to estimate the exposure of a population to a toxic agent. In such a case the objective of building the weather model is to support the primary models. Models of phenomenon, agencies and functions that are not directly involved in homeland security may be built as component modules that may be used by one or more other MSA applications. It is beyond the scope of this paper to describe how each type of simulation might support a particular objective.

1.2 MSA Simulation Domain and Data Sets

A modeling domain defines the type or types of behaviors, phenomena, processes, effects, etc. that are simulated within the application. Actual simulation implementations may model all or part of a single domain or multiple domains. For example, a traffic simulation might be considered a basic or homogenous simulation since it would focus on closely related elements, i.e., vehicles, roadways, traffic controls, and transportation support services. An evacuation simulation, on the other hand, might be considered a hybrid or heterogeneous simulation, as it might contain models of traffic, crowds, public transportation systems, and various organizations involved in coordinating the evacuation. In this document modeling domains will be described as basic simulations, rather than hybrids, as there are potentially infinite combinations of hybrid simulations that may be envisioned.

With respect to data sets, MSA applications need to access many different types of homeland security-related information that originate from various sources and in various formats. The required information, such as weather, population, terrain, traffic, resources, and infrastructure data, may be stored as plain text files, structured interchange files, or remote databases. The format of this data may be based on standards or proprietary formats of information providers. In some cases, simulations may generate data in those same formats. The distribution of timely and accurate information is a key to enhancing the ability to manage all phases of homeland security planning, incident management, routine security operations, and emergency response. Examples of major categories of data sets include *Incidents, Environment, Resources, Controlling Documents, Spatial, Demographic and Behavioral, Investigative Intelligence, Training, Systems Engineering,* and *Simulation Support.*

Incidents data includes incident summaries, chronologies, response operations, models, message logs, media files, reports and other records, and after action reviews. *Environment* data includes climate, weather, societal, political, economic, biosphere, and chemical properties/hazard effects data. *Resources* data includes organizations, funds, facilities, personnel, systems, vehicles, other equipment, communications channels, document media, and consumable supplies. *Controlling Documents* data includes policies, plans, protocols, and procedures. *Spatial* data includes definitions of geographical regions, buildings and other areas, maps, layouts, and models. *Demographic and Behavioral* data includes population characteristics and social behavioral data. *Investigative Intelligence* includes crime scene forensics as well as various databases that are mined to gather intelligence for combating terrorism including locations, facilities, organizations, individuals, components, documents, money, weapons, vehicles, and drugs. *Training* data includes course syllabi, lesson plans, instructional materials, tests, exercises, and references. *Systems Engineering* data includes requirements analyses, design specifications, system documentation, test plans and procedures, and test data sets. *Simulation Support* data includes software assets, statistical distributions, and programming scripts.

1.3 Overview of the Paper

This paper represents an abbreviated version of a draft NIST technical report that more fully identifies needs for homeland security MSA applications. Wherever possible and appropriate, established DHS terminology is used to define MSA needs. The focus on this paper is the identification of needs that are associated with the "what" aspect of homeland security MSA applications.

Major groupings of modeling domains for categorizing simulations and the sections in which they are discussed include: Section 2 Social Behavior; Section 3 Physical Phenomenon; Section 4 Environment; Section 5 Economic; Section 6 Organization; Section 7 Infrastructure System; and Section 8 Other System, Equipment, and Tool. These simulation groupings, simulator types, and a brief summary of needs for each of the simulator types are described in the sections that follow. For each simulation grouping there is a statement of purpose, a brief list of functions, and a short discussion of data requirements that are most relevant to each type of simulation. Example implementations of each type of simulation are also referenced. Functional and data requirements presented in this paper are high level ones, more comprehensive requirements will be provided in a NIST technical report. *Training* data sets, *Systems Engineering* data sets, and *Simulation Support* data sets are general needs for all simulators and are not domain specific, thus these data sets are not identified in the data requirements list in this paper. Section 9 presents conclusions. The last section of the document provides references.

The authors welcome comments or feedback on the high level needs analysis. Review workshops are planned to obtain expert feedback from the homeland security community. Instructions for submitting comments may be found at www.nist.gov/simresponse.

2. Social Behavior Simulators

Purpose: To model the individual and collective behaviors, movements, and social interactions between people at various locations of interest that are engaging in normal day-to-day activities or responding to an incident. Some examples of social behaviors that may be modeled include pedestrians in crowds, attendees at a public event, vehicle operators in traffic, carriers and transmitters of communicable diseases in public places, and consumers in stores. Some applications of this type of simulation include planning incident response operations (e.g., evacuations) or training incident management personnel.

Functions:

- *Create the model* – Provide development capabilities to create simulation models that predict pedestrian and crowd movements, traffic flow, spread of communicable diseases through social interactions, and consumer activity at stores and supply depots under various incident conditions.
- *Set initial conditions* – Establish the demographic attributes; locations of individuals, vehicles, and their status; environmental parameters; response resources; etc.
- *Execute the model* – Update the mental perspectives, decisions, actions, location, and status of individuals and groups over time based upon their demographic characteristics, knowledge, behavioral models, incident data, and actions of first responders.
- *Interact with other simulations* – Obtain input data from other simulations such as the effects of physical phenomena, changing environmental conditions, and organizational actions; provide output data on locations and actions of individuals to physical phenomenon, organization, economic, and infrastructure systems simulations.
- *Analyze the results* – Determine number of casualties and/or injuries for different scenarios, resources required to deal with a scenario, time to evacuate an area, rate of spread of a disease, availability of goods in stores.

Data Requirements:

- *Incident* data sets may be used to define an incident and its initial conditions, specify the stimuli that may be used to provoke human behaviors, and to capture the results of the execution of the model.
- *Environment* data sets specify the climate, weather, societal, political, and economic conditions within the environment where the incidents take place.
- *Resources* identifies organizations, facilities, personnel (e.g., public safety individuals directing pedestrians or traffic), and systems that may affect the behavior of individuals involved in an incident.
- *Controlling Documents* specify the policies and procedures that will be followed to manage crowds, control traffic, issue supplies, manage epidemics, etc. when an incident occurs.
- *Spatial* data sets are used to define the indoor and/or outdoor settings where the human behavior is being modeled. It may include terrain, streets, sidewalks, pathways, stairs, gates, fences, obstacles, or locations of crowd control agents.
- *Demographic and Behavioral* data sets are used to define the characteristics of the people who are being modeled and determine how they are expected to act under various circumstances that may arise during the execution of the model.

Examples: Some prior implementations of social behavior simulators include crowds [2], vehicular traffic [3], epidemics [4], and consumer behavior [5].

3. Physical Phenomenon Simulators

Purpose: To model the origin, propagation, and mitigation of various physical phenomena associated with emergency incidents. Examples of physical phenomena that may be modeled include earthquakes; explosions; fires; chemical, biological or radiological plumes; spread of airborne or waterborne disease and bio-agents; and biotic agents. These simulators may be used to support planning, training, as well as system engineering activities.

Functions:

- *Create the model* – Provide capabilities to model how a physical phenomenon propagates; causes casualties or injuries to the populations; damages or affects the functioning of resources, buildings, and infrastructure systems.
- *Set initial conditions* – Establish the initial locations of population, pre-incident environmental conditions, locations of resources, etc.
- *Execute the model* – Update the location of plumes, damage, casualties, etc. as the physical phenomenon propagates.
- *Interact with other simulations* – Obtain changes in environmental data from the environmental simulator, changes in location of population and vehicles from social behavior simulators, etc. Provide hazard effects data for social behaviors, organization, infrastructure systems, and other system, equipment, and tool simulators.
- *Analyze the results* – Determine the location, toxicity of hazards, extent of damage, effects of precautionary measures and mitigation strategies.

Data Requirements:

- *Incidents* data sets contain information on real and simulated incidents resulting from physical phenomena, such as the location, type and chronology of incidents; propagation characteristics; responder operations; and effects of those operations on incident parameters.
- *Environment* data contains information that may affect the propagation of the physical phenomena, such as the direction and dispersion of a plume.
- *Resources* data sets identify facilities, vehicles, and equipment that may be damaged or otherwise affected by an incident.
- *Spatial* data provides information on the geographical region and building structures in the area of the incident.
- *Demographic and Behavioral* data sets provide information on the location and characteristics of the population affected by an incident.
- *Investigative Intelligence* forensic data may be generated by simulated incidents resulting from criminal activities.

Examples: A number physical phenomenon simulators have been implemented: earthquakes [6]; explosions [7]; fires [8]; chemical, biological or radiological plumes [9]; disease and bio-agents [10]; and biotic agents [11].

4. Environment Simulators

Purpose: To model the internal and external environments that may be impacted by the occurrence of an emergency incident, propagate incident effects, and/or serve as the focus for response operations. Environments include the earth's atmosphere; watersheds and landmasses; ecosystems; indoor areas; and other confined spaces within and around man-made structures. These simulators may be used to support planning, training, as well as system engineering activities.

Functions:

- *Create the model* – Provide development capabilities to define initial environmental conditions and determine how environmental conditions will evolve over time due to climate, weather phenomena, water movement over terrain, etc.
- *Set initial conditions* – Establish the state of the environment before the incident occurs, e.g., level of pollutants in air, land, and water; water levels in various bodies of water; status of ecosystems.
- *Execute the model* – Update the movement of air indoors and outdoors, flow of water in watershed systems, temperatures, wind conditions, land contamination, status of ecosystems as a function of time and in response to an incident, where appropriate.
- *Interact with other simulations* – Feed environmental data to drive the evolution of all other simulation models, e.g., physical phenomena – plume spread, social behavior – weather conditions, infrastructure systems – wind and water damage, organization – recovery needs; acquire outputs from other simulators such as results of mitigation actions from organization simulators (e.g. a levy built by army corps to prevent flooding or movement of contaminated water into a watershed system).
- *Analyze the results* – Determine the spread and extent of contaminants in land, water, and air; impact on ecosystems; and the effects of recovery operations of environmental conditions.

Data Requirements:

- *Incidents* data sets provide information on real and simulated incidents resulting from natural or man made causes that may affect the environment on a long term basis.

- *Environment* data sets provide weather history data for incidents under study, models of watershed systems, information on pollution and contaminant levels, and nature and status of ecosystems.
- *Resources* data sets provide information on resources that may be affected by environmental conditions or used to control the affects of hazards on watersheds, the land, or ecosystems.
- *Spatial* contains information on geography of the region of interest including terrain, soil conditions, vegetation characteristics, ecosystems, and building models.

Examples – Some implementations of environmental simulators include weather [12], watershed system [13], land contamination [14], indoor climate [15], and ecosystems [16].

5. Economic Simulators

Purpose: To model the economic impact of an incident or policy at various levels including local, regional and national, and over various time horizons. Some examples of economic impact that may be modeled include exposure of the insurance industry to different disaster scenarios or estimating the effects of an incident on a local economy, and the time and resources required to recover to normal levels. Major applications of economic simulators include decision support, planning, and risk analysis.

Functions:

- *Create the model* – Provide mechanisms for implementing economic models using substance flow analysis, life cycle assessment, partial economic equilibrium analysis, macro and/or micro-economic analysis techniques. Provide sector specific models for understanding the impact of incidents and policy changes on relevant economic variables such as demand and supply of goods within the sector.
- *Set initial conditions* – Establish the initial state of societal, political, and economic factors. Set up the parameters that determine the initial impact and evolution of impact on the economic activity.
- *Execute the model* – Update economic activities and measures as a function of time as incident unfolds, effects propagate, behavior of population is affected, and recovery operations occur.
- *Interact with other simulations* – Acquire relevant inputs generated by other simulators such as the functioning of organizations, the status of facilities and other resources, and public morale levels following an incident.
- *Analyze the results* – Determine economic impact in terms of damage to buildings, capital equipment, loss of wages, costs to restore facilities, and services and effectiveness of different policies, mitigation strategies, etc.

Data Requirements:

- *Incidents* data sets provide information on real and simulated incidents that may cause financial losses, impact markets, or affect the operation of local businesses.
- *Environment* data sets contain information on the initial state of societal, political, and economic factors.
- *Resources* data sets provide information on organizations, funds, facilities, and personnel related to economic activity.
- *Controlling Documents* data sets provide information on economic policies, plans, protocols, and procedures that determine the impact of an incident on an economy, recovery, and mitigation strategies.
- *Spatial* data sets provide information on geographical boundaries of economic regions of interest.
- *Demographic and Behavioral* data sets provide information about factors affecting the supply and demand for products and services in the area directly affected by the incident and in the surrounding areas.

Examples – Simulations have been used to study impact of incidents on economic activity including: an econometric model to estimate the economic impact of war and terrorist incident on tourism in Israel [17] and a macro level model to predict the impact of September 11 incidents on the Australian economy [18].

6. Organization Simulators

Purpose: To model the policies and procedures; activities and operations; decision processes, communications and control mechanisms; and information flows for various organizations and their members. Organizations of interest include those that perform incident management, support functions, or are impacted by incidents. Examples of organizations that may be modeled include fire departments, law enforcement agencies, health care institutions, government agencies, military units, businesses, voluntary assistance, and terrorist cells. Organizational models may be used for planning and risk analysis to evaluate effectiveness of organizations in dealing with various types of incidents. They also may be used to automate organizational operations in training simulations so as minimize staff required to conduct exercises.

Functions:

- *Create the model* – Provide capabilities to dynamically model an organization's business operations; decision-making processes; communication channels and information flows; resource availabilities, allocation strategies, and consumption rates; time delays associated with its activities; etc.
- *Set initial conditions* – Identify readiness state of an organization, its initial resources, pre-incident status of infrastructure systems, environmental conditions, etc.
- *Execute the model* – Update an organization's actions, status, effects on areas of responsibility, remaining resources based on the incident characteristics and possible associated physical phenomena, changing environmental conditions, social behaviors, infrastructure damage, etc.
- *Interact with other simulations* – Obtain social behaviors, physical phenomena, environmental, infrastructure systems data from associated simulators, e.g., damage, casualty, and injury data; provide output data on organizational actions that affect social behaviors, environment-related damage, economy, the state of infrastructure systems, the state of other systems, equipment, and tools, and the functioning of other organizational simulations.
- *Analyze the results* – determine the amount of resources used in response operations; time to restore facilities and services; effects on reduction of casualties, injuries, and damage based upon different operational strategies.

Data Requirements:

- *Incidents* data sets provide information on the events that organizations need respond to, their response operations, as well as serving as a repository of results of organizational simulations.
- *Environment* data sets provide information on the state of the environment in which an organization's response operations occur, e.g., hurricane weather conditions delay rescue operations until winds subside.
- *Resources* provides key information on the assets of organizations for response operations including funds, facilities, personnel, systems, vehicles, other equipment, communications channels, document media, and consumable supplies.
- *Controlling Documents* data sets specify policies, plans, protocols, and procedures of the involved organizations.
- *Spatial* data sets provide information on the regions in which organizations operate, e.g., jurisdictional boundaries.
- *Demographic and Behavioral* data sets provide information on the populations that organizations serve.
- *Investigative Intelligence* data sets may provide source information that drive processes for some organizations, e.g., forensics data for criminal investigations by law enforcement agencies or arson investigations by fire departments.

Examples – Simulations have been built to study and analyze the incident response by organizations including: wild fire firefighting [19], crowd control by police [20], hospital's emergency department [21], disaster management by multiple government agencies [22], military force deployments [23], impact of natural disasters on business [24], relief organizations [25], and terrorist organizations [26].

7. Infrastructure System Simulators

Purpose: To model infrastructure systems, the impact of incidents on system elements, the propagation of incident effects on other interconnected, related, or nearby infrastructure elements, and the restoration of these systems after an incident. Examples of infrastructure systems include energy distribution systems, water supply, transportation networks, food supply chains, and communications networks The most significant applications for this type of simulation are analysis of the risks associated with various types of disasters and planning of mitigation/recovery strategies.

Functions:

- *Create the model* – Define infrastructure systems, their functioning, their relationships to each other, and their vulnerabilities.
- *Set initial conditions* – Establish the initial condition of infrastructure systems before an incident occurs.
- *Execute the model* – Update the status of infrastructure systems as incidents occur, environmental conditions change, and response operations attempt to restore functionality of those systems.
- *Interact with other simulations* – Obtain social behavior, environment, and physical phenomenon impact data from associated simulators, repair operations from organizational simulators; provide loss of services data for economic and organization simulators, etc.
- *Analyze the results* – Determine the impact on infrastructure systems of incidents, time to restore services, resources required, cost of repairs, identify vulnerabilities, etc.

Data Requirements:

- *Incidents* data sets provide information on incidents that impact the operation of infrastructure systems, e.g., the nature and extent of damage.

- *Environment* data sets provide the information on the range of environmental conditions during the incident scenario.
- *Resources* data sets provide information on facilities, vehicles, staff, and equipment used to maintain/restore infrastructure systems.
- *Controlling Documents* define how infrastructure systems operate and are restored following an incident.
- *Spatial* data sets define the location of infrastructure systems and their relationships to each other regionally and within building spaces.
- *Demographic and Behavioral* data sets provide information on a population supported by infrastructure systems and expected behaviors when infrastructure systems operations are lost or affected.
- *Investigative Intelligence* data sets may be used to provide information for investigations where criminal activity resulted in the loss of infrastructure systems or to increase security when attacks are expected.

Examples: Recent implementations of infrastructure simulations include food supply chain [27], energy distribution [28], water supply [29], transportation networks [30], and communications networks [31].

8. Other System, Equipment, and Tool Simulators

Purpose: To model the detailed operation and performance of various systems, equipment, and tools that are used in incident management, emergency response, and other homeland security related operations, or are affected by incidents and operations. The most significant application for this type of simulation is systems engineering. Examples of systems, equipment, and tools that may be modeled include: aircraft, ships and other watercraft, and vehicles; security scanners, sensors, and related systems; bomb disposal equipment; construction and fire fighting equipment; hazardous material decontamination and disposal systems; material handling systems; medical systems; personal protective equipment; search and rescue equipment; and various test equipment. Models may be used to support the development and enhancement of those systems, evaluate the effectiveness of those systems for specified purposes, and/or to provide detailed functional models for use in other simulations.

Functions:

- *Create the model* – Provide development capabilities for representing the structure and/or geometry of the system, equipment, or tool; define its component modules, and the functioning of those modules. Provide mechanisms for establishing its operational environment; functional characteristics; and the ways its functionality may be degraded or otherwise affected by an incident or the environment.
- *Set initial conditions* – Define the environmental, hazard and associated conditions with respect to the incident for which the system is to be used.
- *Execute the model* – Update the response of the system or its effects on the incident or hazards resulting from the incident.
- *Interact with other simulations* – Obtain environmental and physical phenomena hazard data from associated simulations; provide the state of other systems, equipment, and tools for organization simulators.
- *Analyze the results* – Determine the effectiveness of systems, equipment, and tools in incident response operations.

Data Requirements:

- *Incidents* data sets determine the need for systems, equipment, and tools in response operations.
- *Environment* data sets define the conditions under which systems, equipment, and tools are used.
- *Controlling Documents* define how systems, equipment, and tools may be used in response to an incident.
- *Spatial* data sets provide information on the region or the structures in which the system, equipment, or tool is to be used.
- *Demographic and Behavioral* data sets provide information on the characteristics of the population where the system, equipment, or tool is to be used.
- *Investigative Intelligence* data sets provide forensics data for analysis by systems, equipment, or tools, or as outputs from those systems.

Examples – Some recent implementations of detailed equipment behaviors include: a virtual reality system to train medical first responders [32] and a full driving simulator for urban traffic [33].

9. Conclusions and Next Steps

This paper has identified major classes of simulators that may be developed to support planning, decision support, training, risk analysis, and system engineering objectives for homeland security mission areas. For each class of simulation, its purpose, types of implementations, and potential uses have been identified. A brief summary of functional and data needs was also provided for each class of simulation. Finally, references to examples of past implementations of each type of simulation are also provided. A more comprehensive technical report is under development that specifies functional requirements for each type of simulation in greater detail. These needs will help determine interoperability and interface requirements for homeland security modeling and simulation applications. External review workshops are planned in 2008 to obtain expert feedback from the homeland security community on the needs analysis and requirements specifications. Future work will focus on identifying and establishing a database of existing MSA applications, identifying best practices found in existing applications, identifying existing standards and gaps that need to be filled to support MSA applications.

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