An Integrating Framework for Modeling and Simulation for Emergency Response

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ABSTRACT

A number of modeling and simulation tools have been developed and more are being developed for emergency response applications. Each of these tools has focused on a specific aspect of the selected problem, for example, the modeling of spread of an agent using plume simulation. The tools do not attempt to address the overall emergency incident response. A set of tools that can help develop and evaluate coordination among plans for multiple aspects of the response can significantly improve the response capabilities. These tools need to be integrated together to reduce the time and effort for their use. A framework is proposed to ensure that modeling and simulation tools can be systematically integrated together to address the overall response. The framework addresses emergency response on three axes – disaster event, entities of interest and applications. It can help identify the gaps in availability of modeling and simulation tools and help define the integration needs.

It is designed to allow use of modeling and simulation across applications in the areas of planning, training, identification and detection, vulnerability analysis and real time response support. The framework can be rapidly implemented with the development of interoperability standards for modeling and simulation tools for emergency response. Together, the framework and interoperability standards can significantly enlarge the use of modeling and simulation for emergency response. In turn, it will substantially improve the nation's emergency response capabilities.

1. INTRODUCTION

There is a growing need for preparedness for emergency response both for man-made and natural disaster events. The man-made disaster risk has increased due to a rise in possibility of terrorist attacks against the United States. The natural disaster risk has increased due to progressively changing weather patterns caused by phenomenon such as El Nino (NOAA TAO project 2003). Recent incidents have highlighted the limitations of current response systems including the lack of interoperability (Bahora et al 2003). Effective emergency response presents a number of challenges to the responsible agencies.

Modeling, simulation[1] and visualization techniques can help address many of the challenges brought forth by the need for emergency response preparedness. Indeed, the role of modeling and simulation for emergency response has been recognized for decades (see for example, Sullivan 1985). The use of model based decision support systems for emergency response has been recommended (Moore and Abraham 1994). In a recent report, the Committee on Science and Technology for Countering Terrorism of the National Research Council identified “systems analysis, modeling and simulation” as the first of the seven crosscutting challenges to be addressed to counter the terrorism threat (National Research Council 2002). The report states: *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.*

A number of modeling and simulation applications for analyzing various disaster events exist. These need to be brought together for studying the impact of disaster events as a whole. Not only do we need to understand how will the radioactive plume disperse, we also need to plan what traffic routes will people use to evacuate the affected areas, what demands will be placed on the hospital resources in the area, etc. The individual simulation models such as those for studying the radiological release need to be

[1] Modeling and simulation in this paper refer to use of computer-based models and simulations. It is recognized that physical simulation such as mock exercises play an important role in emergency preparedness, but such activities are not within the scope of the discussion in this paper.

integrated with those analyzing the traffic movement through the highways and arteries of the affected area, and with those analyzing the resource constraints of hospital systems among others.

The Department of Defense has been using modeling and simulation effectively for war-gaming for years. They have led the development of the High Level Architecture (HLA) for integration of distributed simulation models, each modeling a part of the war-gaming scenario (Kuhl et al 1999). Similarly distributed simulation has been used to model supply chains, with each model representing the operation of one link in the supply chain. The knowledge and intellectual capital developed through such efforts needs to be brought together for development of integrated distributed simulation models for emergency response. The integrated effort will allow study of the whole picture rather than being limited to studying one aspect at a time.

The integration of simulation models developed independently presents a daunting challenge in itself. Interoperability standards need to be defined that will allow the conforming models and data sources to be integrated. Standards are required for data, architecture and interactions between the models. The interoperability of individual efforts will allow a tremendous synergistic increase in the effectiveness of the emergency response modeling and simulation capability.

This paper proposes the use of integrated distributed simulation models for all aspects of emergency response, including, planning, training, real-time response, vulnerability analysis, identification and detection. The current state of the art in modeling and simulation for emergency response is captured. A framework for integration of modeling and simulation tools for emergency response is envisioned. Requirements for interoperability standards for data and interactions are specified. The paper concludes with discussion of further research for achieving the vision of the integrated emergency response framework.

2. CURRENT STATUS

The focus has been on emergency response since the destruction of the twin World Trade Center towers and the damage at the Pentagon. A number of initiatives have been started since the incident with the aim of improving the security and the capability for response. This section provides a classification for modeling and simulation tools using some of the efforts as examples.

2.1. Disaster Impact Modeling Tools

Several efforts focus on studying and projecting the impact of a disaster event. The projections can then be used for planning the response to the disaster event. These tools do not provide any facilities to model potential response actions. Some of the tools in this category can be used in a mitigation role by iterating through modifications of configuration of systems under study and evaluations of the impact of the disaster event.

Such tools typically use geographic information systems to combine the relevant data and overlay the impact of the disaster to identify population, infrastructure and resources affected immediately and those to be affected subsequently by the event. Examples of such tools include: National Atmospheric Release Advisory Center (NARAC) facility at Lawrence Livermore National Laboratory for modeling hazardous atmospheric release (NARAC 2003), Radiological Assessment System for Consequence Analysis, Version 2.2 (RASCAL 2.2) developed at Oak Ridge National Labs for studying the atmospheric radiological material release (ORNL 2003), and building fire simulation tools developed at National Institute of Standards and Technology (BFRL 2003). Mazzola et al. (1995) provide a survey of 94 tools for modeling of atmospheric dispersion.

2.2. Emergency Response Planning Tools

Tools in this category allow evaluation of alternative strategies to respond to a disaster event. They may allow input of impact of disaster event estimated by experts or determined by using tools in the previous category, or they may themselves include the capability for disaster impact modeling. These tools may be used on the occurrence of an actual disaster event, or in preparedness role, that is, for planning the response for future potential disaster events. An example of tools in this category is the map analysis software provided by Innovative GIS/ Berry & Associates /Spatial Information Systems (BASIS) that can be used for planning responses to such events as a forest fire (Innovative GIS 2003).

2.3. Simulation Tools For Emergency Response Training

Tools in this category use simulation to mimic and present situations created by occurrence of a disaster event to human training subjects with the intent to improve their capabilities for emergency response. These tools extend from those targeted at decision makers to those targeted at first responders. The simulation tools for training decision makers present the overall scenario and evaluate decisions makers approach for making high level decisions such as units of first responders to be deployed in different areas impacted by the disaster. The tools at this level typically use one or more computer monitors to graphically display the simulated unfolding of disaster event and the response actions. An example of such tools is the Weapons of Mass Destruction Decision Analysis Center developed by Sandia National Lab as a way to simulate a war-room environment in the event of a terrorist attack (San Francisco Chronicle, 2002). Another example is the Emergency Preparedness Incident Command Simulation (EPiCS), a computer-based, scenario-driven, high-resolution simulation tool (ASTI 2003).

Some of the simulation tools for training first responders use immersive virtual reality (VR) that allows a first responder to enter the disaster zone and react to the simulated unfolding events at the detailed level. The tools may utilize accessories that provide physical feedback to the trainee or communicate with them using visual cues on the display. An example of tools in this category is BioSimMER, a VR application that immerses first responders in a computer-simulated setting (a small airport in which a biological warfare agent has been dispersed following a terrorist bombing) (German 1999).

2.4. Tools For Identification And Detection

Simulations of disaster events can be used for detailed analysis and developing techniques for identification and detection of the occurrence prior to the event. The identification of factors that provide an early warning of impending disaster events can provide a valuable means to mitigate or even prevent the occurrence. An example of such a tool is Warning Decision Support System (WDSS). It has been developed by National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) and the National Severe Storms Laboratory (NSSL) to better detect the low-top, high-shear thunderstorms that are responsible for many of the short-lived events classified as weak tornadoes (NSSL 2003).

2.5. Integration Efforts

The modeling and simulation tools discussed so far typically address one kind of disaster event or one of its major aspects. A number of simulation tools have to be integrated to address multiple aspects of a single disaster event as described in section 1. This integration is different than integrating a simulation tool to data management and communication modules discussed in Zografos et al (1998). The need for such integration is beginning to be recognized as evident by efforts described below.

The urban security project at Los Alamos National Labs integrates plume simulation and traffic simulation to compute exposures to the cars traveling through the plume (2003a). The Simulation Object Framework for Infrastructure Analysis (SOFIA) project at Los Alamos National Laboratory is developing a high-quality, flexible, and extensible actor-based software framework for the modeling, simulation, and analysis of interdependent infrastructures (LANL 2003b).

This section described a number of categories of modeling and simulation tools with examples. A more detailed survey of such tools is provided in Jain and McLean (2003a). The full potential of modeling and simulation tools can be exploited when the tools can be brought together rapidly to study and analyze all major aspects of a disaster event. Jain and McLean (2003b) describe an emergency response scenario with and without the use of integrated modeling and simulation tools to highlight their value.

3. CHALLENGES

A number of challenges need to be addressed to reach the stage of rapid integration and use of simulation models for emergency response. These challenges are parallel to those faced in the field of manufacturing simulation as described by McLean and Leong (2001). Among the challenges, the “interoperability challenge” is particularly significant. Interoperability includes a number of system integration, data translation, and model development issues. What is the nature of this problem?

1. Interoperability between emergency response modeling and simulation applications is currently extremely limited. The simulation software used to model emergency response situations have typically been developed for specific situations. Being recent and independent developments they do not use any common formats for the data. Neutral interface specifications that would permit quick and easy integration of emergency response modeling and simulation tools do not exist. The only qualification that needs to be added is that many emergency response simulation systems do have a capability for importing some form of geographical data (following any one of the multiple GIS standards). Considerable manual intervention is often required to make effective use of the geographical data within the simulation.

2. The cost of transferring data between emergency response simulation software applications is expected to be very high. Users must either re-enter data when they use different simulation software applications or incur high costs of experts for custom solutions. In some cases, it may not be possible to integrate “closed” simulation applications. "Closed" simulation applications refer to those with undocumented, proprietary data file formats.

3. The simulation model development process is labor-intensive. Users have recognized that the development and maintenance of models of their systems and resources for emergency response is very demanding in terms of expertise and time. For example, the development of a detailed simulation model of a building fire may take a group of scientists 4 to 6 weeks. Models must now be custom developed for each specific situation. Each user must build his or her models of systems, processes, and resources affected by the specific disaster event. If the user has several different simulation tools for the same event, plume simulation for example, unique models must typically be reconstructed for each tool. The models developed for one simulation tool are of little or no use to another. The simulation development process is very much an ad hoc process. Texts provide high level guidelines, but model development is perhaps more of an art than a science.

In addition to the "interoperability" issue, several other factors are worth noting:

- Building simulation models from "scratch" has a high expertise requirement and is a time-consuming process. Typical emergency response organizations usually do not have the technical expertise or the time for building simulation models.
- When a simulation involves a new system, process, or technology, good reference models or historical data may not be available to support the development effort (Law & Kelton 2000).
- Simulation model developers typically require considerable training and a diverse set of skills to be effective in their job (Rohrer and Banks 1998).
- Simulation models must be verified and validated. Does the model accurately represent the system or the process being modeled (Knepell & Arangno 1993, Balci 1998)?
- Interpretation of the simulation output data might not be a simple, straightforward process. Even after considerable resources are invested in the development of simulation models, it may not be clear what action should be taken based upon the results.

The challenge is to create modeling and simulation tools that have the capability to rapidly and automatically create a model configured to a specific disaster event occurring at a specific locale. The tools should be validated and proven using a wide range of scenarios prior to being made available for use. The simulation tools need to be completely data driven and the data needs to be available in standard formats. The tools needs be interoperable to allow bringing them together for an integrated distributed simulation of the whole scenario. For example, in one case the users may need to integrate a plume simulation, a traffic simulation, and a gas distribution network simulation, while in another case, one may need to integrate a building and fire simulation, a traffic simulation and a hospital simulation. The goal is to provide a number of interoperable modeling and simulation tools, an ability to select and integrate the appropriate tools based on the emergency situation at hand, and to create a simulated representation of the situation using data available in standard formats and structures. A framework is needed to direct the development and organization of modeling and simulation tools for emergency response.

4. PROPOSED INTEGRATED EMERGENCY RESPONSE FRAMEWORK

An integrated Emergency Response Framework is defined in this section to enable an organized approach to use of modeling and simulation for emergency response.

4.1. Integrated Emergency Response Framework (iERF) Concept

The emergency response domain can be classified using various criteria, but the three major dimensions are described below.

4.1.1. Disaster Event

The emergency response agencies have to respond to a number of man-made and natural disaster events. The disaster event will have large influence on the kind of modeling and simulation capabilities that need to be brought together. For example, a building explosion and fire event requires capabilities for modeling the impact of explosion and fire on the building structure and its occupants, while a hazardous release in the atmosphere requires capabilities to model the dispersion of the release in the atmosphere. Admittedly there are some capabilities that are required for a number of scenarios. These include capabilities such as traffic simulation and information flow simulation. Also, a few of the man-made and natural disasters may have similar impact. For example, forest fires can be initiated by intentional or unintentional actions of people or by natural causes.

4.1.2. Entities of Interest

The interest of all the agencies is to minimize the impact of disaster events on entities of interest. These include first and foremost, the human population. The impact of the disaster also needs to be understood and contained on the resources, in particular, on the infrastructure resources.

The response agents are the second major class of entities of interest. The actions of response agents need to be modeled to understand how they can contain and mitigate the impact of the disaster event. It is quite possible that the response agents will become the affected entities of interest themselves, for example, fire personnel suffer injuries while fire fighting. The models should allow understanding of the risk exposure for the response agents. The planners can test out different strategies that minimize the risk exposure for the response agents while allowing them to contain and mitigate the impact of the event.

4.1.3. Applications

The capability of the needed modeling and simulation tools will differ based on the application they are designed for. An application for understanding the impact of the disaster event will have capabilities somewhat different from one for training emergency response personnel. The training applications will have more interactive features and the ability to unfold alternate simulated event sequences based on the response of the trainees. Similarly, applications for identification and detection of threat will have capabilities for pattern matching against a number of historical scenarios to determine the likelihood of threat development. Various applications for the emergency response domain are briefly described below.

4.1.3.1. Planning

The planning application will include tools for determination of impact of a disaster event and the tools for aiding development of the response action plans and strategies. The planning applications can range from those for long term issues such as location of emergency response facilities and manpower or for focused issues such as aiding development of specific response procedures. Examples of planning applications include:

- Location of police and fire stations and hospitals

- Development of evacuation procedures
- Setting up a communication infrastructure

4.1.3.2. Vulnerability Analysis

The vulnerability analysis application is focused on evaluation and assessment of emergency response preparedness plans and strategies. Modeling and simulation tools can be used to create a number of disaster event scenarios and evaluate the performance of action plans and strategies. Examples of vulnerability analysis applications include:

- Evaluation of security plans and procedures at a nuclear plant
- Evaluation of city emergency response plans

4.1.3.3. Identification & Detection

The identification and detection application will include use of tools that study given scenarios and determine the possibility of the occurrence of a disaster event. It is anticipated that such tools will use pattern matching logic and past history databases to identify and detect potential threats. Examples of identification and detection applications include:

- Selecting security sweep targets in areas with majority of inhabitants from a target background
- Identifying the potential of tornado occurrence given the weather conditions

4.1.3.4. Training

The training application will include tools that allow training response agent personnel for handling emergency events. These may include interactive simulations where the tools create an imaginary scenario and the trainees input their response actions. The tools will help evaluate the response actions and thus help the trainee learn what works best under a given situation. These tools may range from interactive simulations using a monitor to totally immersive environments. Examples of training applications include:

- Antidote deployment sequence
- Evacuation management

4.1.3.5. Systems Testing

The systems testing application will include tools that allow testing of systems and equipment used for emergency response. These may include applications that allow hardware emulation and software simulation to create a scenario where part is simulated in software while remaining is simulated in real live exercise. It will allow testing of systems such as those for tracking emergency response vehicles and those that provide information to emergency operations centers. It will also allow testing of hardware such as communication devices in emergency response situation with severe overloading of bandwidth. Examples of systems testing applications include:

- Testing of emergency operations command and control systems
- Testing of remotely operated search and rescue devices

4.1.3.6. Real-time Response Support

The response application will include tools that evaluate the impact of a disaster through real-time updates on the situation, and use the available information to project current and future impact of the disaster. It also includes tools for evaluating alternative response actions and strategies based on the current and projected impact. The evaluations are then used to direct the response actions on the ground. Examples of response applications include:

- Response to a large explosion at an office building
- Response to a chemical agent release in the atmosphere

Figure 1 shows the concept of integrated Emergency Response Framework (iERF). The three major dimensions described above form the three axes of the cube that is used to represent the emergency response domain. Each cell in the top half of the cube along the entities of interest dimension will capture the impact of a particular disaster event on a particular entity of interest. While cells along the lower half of the cube along the same dimension capture the response by a particular response agent for the specific disaster event. The location of the cell along the application dimension classifies the capability of the tool for modeling and simulation of the impact of the specific disaster event on specific entities of interest.

4.1.4. Framework component attributes

Each of the components along the major dimensions will have some standard attributes. These attributes may be defined in various different ways by independently developed tools. Standardization of the attributes will allow integration and communication between tools. Sample attributes by components are listed below.

Attributes of “disaster event” should include:

- *Status* – defines the current status of the event, such as, event ended, event developing (for example, for atmospheric release), event anticipated (for example, for expected natural disasters such as hurricanes).

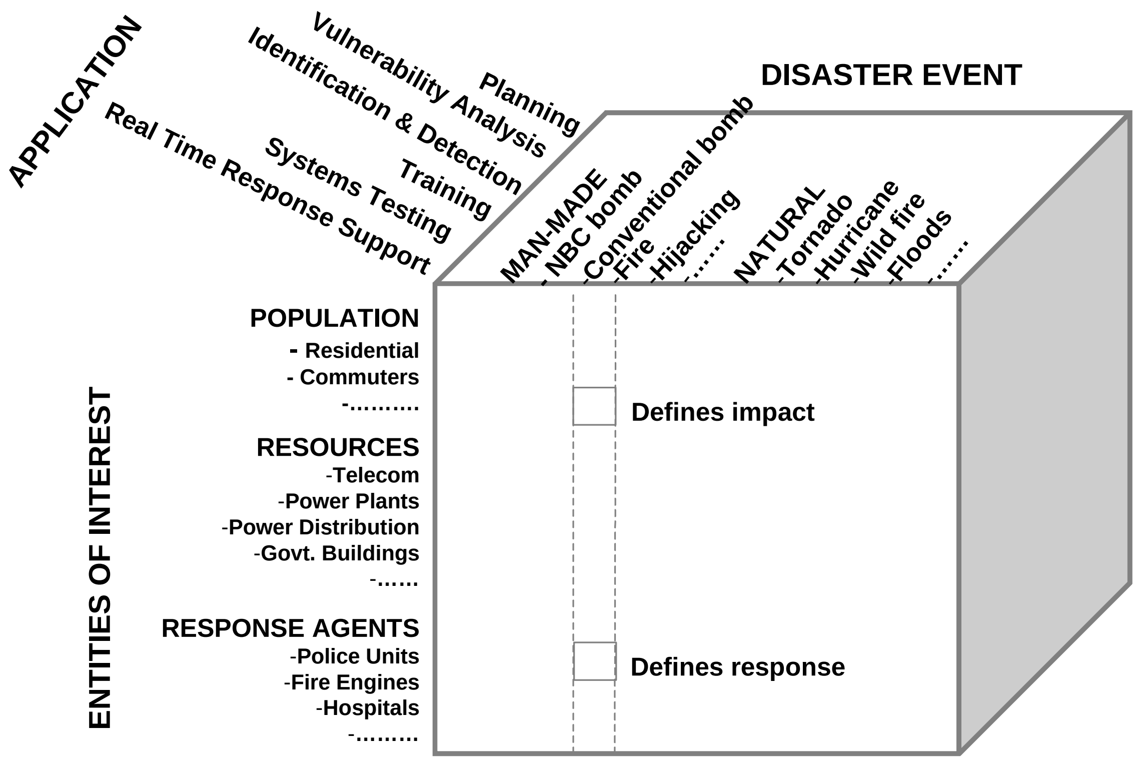

Figure 1. Integrated Emergency Response Framework (iERF)

- *Mobility* – defines the mobility of the impact of disaster event if applicable, such as, travel rate and direction for a hurricane or an atmospheric release.
- *Potential impact zone* – defines the geographical area that could potentially be affected by the disaster event.
- *Impacted entities* – identifies the entities that could be affected by the event, such as, population, emergency response agents, infrastructure elements, etc.

- *Effect on entities* – defines the impact on entities, such as, current and expected casualties, current and potential damage to infrastructure, etc.
- *Duration* – defines the elapsed time since occurrence and expected time until the event is completed, if applicable.
- *Lifecycle pattern* – defines the projected lifecycle of the disaster event, such as, how long such an event will last. This may be more applicable to natural disasters and man-made disasters involving atmospheric release.
- *Growth pattern* - defines the projected growth of the disaster event, such as, how is the impact of the event estimated to grow. This may be more applicable to natural disasters and man-made disasters involving atmospheric release.

Attributes of "resources" should include:

- *Status* – defines the current status of resources, such as, normal, damage percentage, completely failed/destroyed.
- *Mobility* – defines the mobility for movable resources, such as, mobile communication vehicles, food and medical supplies aid shipments.
- *Target index* – defines the potential for being targeted by terrorists and other unlawful elements. Resources such as nuclear power plants may have a higher target index than a government office building.
- *Linked entities* – defines the related entities to the resource. This may define the area that may be affected due to damage to a power plant, surrounding buildings and services that may be affected due to attack at a government facility, etc.
- *Parent organization* – identifies the parent organization responsible for the resource to help in coordination of emergency response.
- *Role* – defines the role of the resource to help in determining the affected capabilities based on the status of the resource.
- *Live/ Equipment* – defines if the resource is composed of live humans such as expert professionals, government and non-governmental personnel responsible for critical functions..

Attributes of "response agents" should include:

- *Status* – defines the status of response agents, such as, operational, injured, lost.
- *Mobility* – defines the mobility of response agents primarily based on their own status and that of their vehicles.
- *Target index* - defines the potential for being targeted by terrorists and other unlawful elements. Armed response agents such as police may have a higher target index than ambulances.
- *Quantity* – defines the number of personnel or units available
- *Information latency* – defines the speed at which the information can be communicated to the response agent.
- *Role* – defines the role of the unit specific to the disaster event, such as, guarding the perimeter, rescue and recovery, etc.
- *Live/ Equipment* – identifies if the response agent is a live human unit or a piece of equipment such as robotic search and rescue device.

Attributes of "population" should include:

- *Status/Number* – defines the status and the number of the affected populace, such as, number of injured, number of dead, number in potential danger, etc.
- *Mobility* – defines the mobility of the population primarily based on the status.

The "application" attributes may include:

- *Level of detail* – defines the level of detail needed for the application. Real time response support application will need more detailed data than planning application.
- *Input and outputs* – defines the input data and output data that tools for that application should use and provide.

Existing tools can be matched to application area, disaster event and entities of interest using the attributes such as those defined above. New tools can be designed to model the impact of one or more selected disaster events on one or more entities of interest for one or more applications.

4.1.5. Example Scenarios in iERF

The following example scenario in iERF demonstrates its use for organizing emergency response events. The real-time response support application for a conventional bomb explosion at a public place will be represented in the iERF as shown in figure 2. The figure shows the impact of the man-made disaster event on the entities of interest including the population, resources and response agents. For a response application, the real time information will feed the modeling and simulation tools. The tools will be used to test out the implementation of the pre-planned response procedures and to modify the plans as events occur that are not provided for in the procedure. The tools can predict the impact of the events as they occur and evaluate response alternatives for feeding back to the response teams on the ground. In the figure, the impact on population can be based on early estimates provided by the fire crews already on the scene, the impact on water lines and buildings could be based on the models using estimates of the strength of the explosion. The models can be used to map out the resulting traffic jams and the most suitable hospitals for receiving the injured based on the damage to the infrastructure and the traffic situation. For example, the nearest facility might be affected by damage to water and power lines and the next nearest hospital may be the most suitable facility to take the injured.

The example shown is for the real-time response support application. For a planning application, modeling and simulation tools will be used for creating a scenario of conventional bomb explosion and the output of impact from these models will feed the other models that trigger the response.

4.2. iERF Data Sources

The integrated Emergency Response Framework (iERF) by definition integrates a wide variety of diverse emergency response tools. A number of data sources, knowledge bases and tools can be organized using the iERF. Table 1 lists some of the types of data and the sources for the data that will be used by modeling and simulation tools in the iERF.

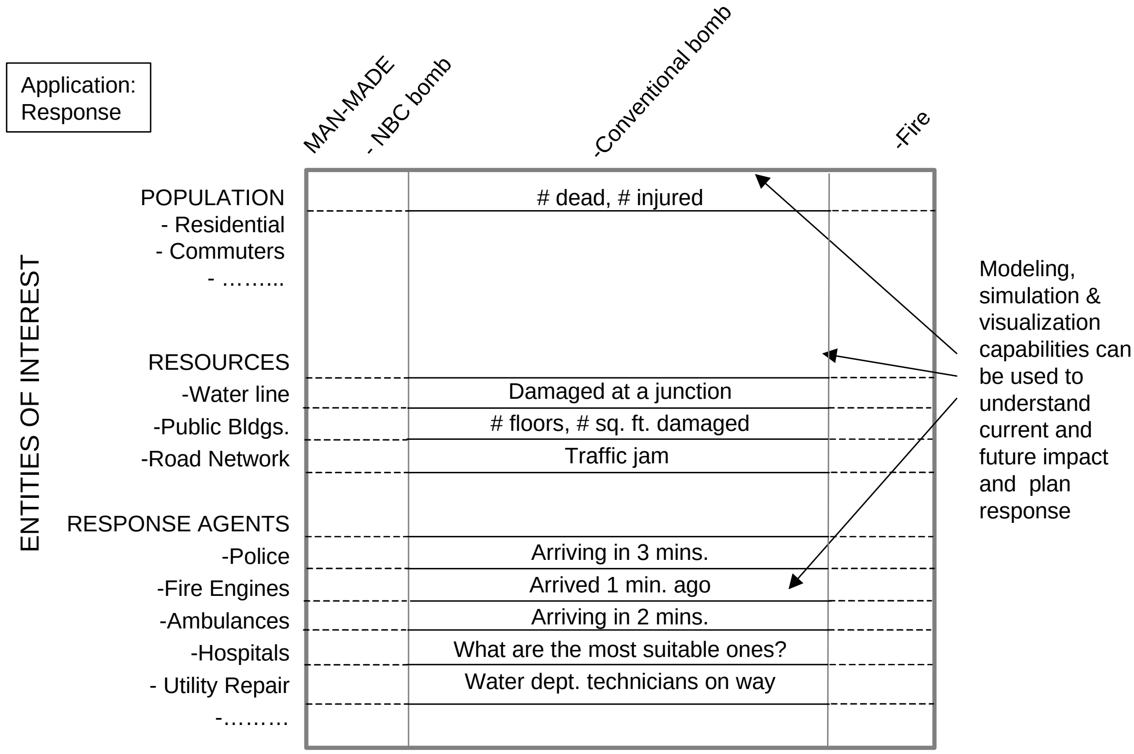

Figure 2. iERF Representation of a Real-time Response Support Application for a Conventional Bomb Explosion at a Public Place

Table 1. Sample data and sources for M&S tools in the iERF

TYPE OF DATA	POTENTIAL DATA SOURCES
Terrain maps	US Geological Survey
Street maps	Map software companies, Atlas publishers, Federal Emergency Management Agency
Response agency locations	City office
Response plans	City office , police, fire and health departments
Utility and infrastructure locations	Utility companies, telecom companies
Weather	National Oceanic and Atmospheric Admin.
Population density	US Census Bureau
Business area population density, Transportation patterns	Local transportation departments
City evacuation plans	City office
Building design records	City office, building management
Building evacuation plans	Building security

4.3. iERF Modeling, Simulation and Visualization Tools

The iERF can accommodate a wide range of modeling and simulation tools. The tools will vary based on their application, disaster event and their consideration of entities of interest as discussed in the previous section. In addition they will vary based on the scope and abstraction level (or the level of detail) and the modeling technique used.

The scope of the tools can vary from national level modeling for large disaster events such as volcanic explosions to those modeling a city block for a scenario like a building explosion and fire. A tool may have the capability to model at more than one abstraction level.

The modeling techniques may include:

- State graphs
- Spreadsheets
- Agents and objects
- Petri Nets
- Systems dynamics simulation
- Discrete event simulation
- Physical process simulation employing models that capture the physical phenomenon
- Emulation or live exercise supported by simulation models

Visualization plays an important part in communicating the results of modeling and simulation to the users. It allows rapid understanding of the results of modeling and simulation. It is particularly essential for training applications. The visualization tools for emergency response may include:

- Graphs
- Flow Diagrams
- 2D displays
- 3D displays
- Immersive Virtual Reality

4.4. iERF Applications Security

The nature of the application highlights the need for secure communications and models in the iERF. The framework is essentially a distributed simulation framework. It is intended that it will use the DoD-developed High Level Architecture (HLA) for integrating the distributed simulation models together. The HLA has been accepted as an IEEE standard for the purpose. The HLA specification does not address security, but some research efforts are in progress for the purpose (Andrew et al 2002). Until HLA is enhanced to address security issues, one of the following options may be used for iERF security:

- Physical security for the hardware access and use of private networks for communication among distributed simulations
- Encryption of communications between the distributed simulators

The advantage of the encryption option is that it allows inclusion of legacy applications into the iERF without limiting the framework for use over private networks. Other options such as applications developed using new HLA Run Time Infrastructure that addresses security can not be deployed to legacy applications.

5. INTEROPERABILITY REQUIREMENTS

The integration of modeling and simulation tools that use widely different techniques and have been developed independently in various environments presents a daunting challenge. Interoperability standards are required to enable the integration of the simulation tools and exploit the synergy for a step improvement in emergency preparedness capabilities. The interoperability standards need to address data as well as architecture guidelines. The requirements for data standards are discussed below while architecture requirements will be addressed in future.

5.1. Data standards requirements

Data standards requirements for emergency response can be developed and specified using Unified Modeling Language (UML). UML provides a standard approach for structured and object-oriented modeling (OMG 2003). It is a visual language and includes diagrams such as: use cases, static data structures, sequence diagrams, and state/activity diagrams.

Generic use cases can be created that define the actors and their roles in an emergency response scenario. Successive levels of detail can be added, proceeding from a high-level emergency response scenario use case. These use cases can include:

- Man-made disaster event occurrence
- Natural disaster occurrence
- Manage site security
- Manage fire response
- Manage emergency medical response
- Manage investigative agency response
- Manage traffic
- Communicate with response agents
- Communicate with general public
- Define simulation study parameters.

The "manage site security" use case may include the following actors: police chief, police teams, terrorists, general public, and injured people at the disaster scene. Lower level use cases may include:

- Analyze disaster event
- Plan response to disaster event
- Dispatch police teams
- Plan escape route
- Attempt capture of terrorists
- Direct public movement at disaster site
- Isolate injured at disaster site
- Determine performance metrics.

Use cases for response to various disaster events can be created and successively decomposed to lower levels to detail the scenarios. UML static diagrams can be used to create a high level conceptual definition for the data types needed to support the "emergency response" use case. The static structure diagrams can identify the major data types, their attributes, enumeration of value constraints for data attributes, and the relationships between major types. Diagrams can be created for all entities of interest including the population, the resources and the response agents, for all man-made and natural disaster events, and for all applications ranging from planning to real-time response support. Once the UML use cases and static structure diagrams are completed, the data interfaces can be specified using XML.

5.2. Available data standards

The need for integration of modeling and simulation tools for emergency response has been only recently recognized, and hence few generic standards exist for data for the specific purpose. Some domain-specific standards for data and metadata listed below have become recently available or are under development.

- Intelligence Community Markup Language (ICML) (IC MWG 2002).
- Data standards for efficient sharing of environmental information among EPA, states, tribes and other information partners (EPA 2003) including: Biological Taxonomy, Chemical Identification, and Facility Identification, Federal Facility Identification and Reporting Water Quality Results for Chemical and Microbiological Analytes.
- Data registry to assist in cataloging and harmonizing data elements across organization and to utilize selected Health Insurance Portability and Accountability Act (HIPAA) data elements (USHIK 2003).
- The IEEE Intelligent Transportation Systems Data Registry (ITS-DR), a centralized data dictionary including data items for Intelligent Transportation Systems, including Traffic Management, Incident Management and Emergency Management (IEEE 2003).
- Data registry for standardizing the aviation terms (FAA 2003).
- Metadata Registry Implementation Coalition, a forum for information exchange on the implementation of metadata registries based on the ISO/IEC-11179 Specification and Standardization of Data Element standard.
- DoD Defense Modeling and Simulation Office (DMSO) data standards to support common representations of data across models, simulations, and warfighter command, control, communications, computers and intelligence (C4I) systems (DMSO 2003a). Some of the data fields may be relevant to civilian emergency response.

Currently, the domain-specific efforts mentioned above are among those that are attempting to define standards for some of the data relevant to modeling and simulation of emergency response. The existing examples of integrated simulations presented in section 2.5 are based on unique interfaces developed between the tools involved. Establishing the standards specific to emergency response applications is the first step towards the realization of the integrated Emergency Response Framework (iERF).

Standards for defining the data interfaces for modeling and simulation for a broad application area are hard to find in general. NIST researchers are working towards a standard interface for machine shop data that can be used to rapidly develop simulation models (Mclean et al 2002). The experience from the machine shop data will help in development of standards for the emergency response area.

6. CONCLUSIONS

The need for improved emergency response can be met by extensive use of modeling and simulation tools. A number of individual M&S efforts for emergency response are already in progress, however, each individually can address only a small part of the problem. Effective emergency response requires a coordinated response by all responsible agencies. Effective use of modeling and simulation requires study and analysis of all aspects of a disaster event occurrence and its follow through. Modeling and simulation of all aspects can be achieved by integrating the individual tools that model complementary aspects of the disaster event. This paper proposed an integrated emergency response framework for modeling and simulation of emergency response. The need for interoperability of modeling and simulation tools was highlighted. Requirements for data and architecture standards need to be established as a first step towards development of such standards.

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