Towards Standards For Integrated Gaming And Simulation For Incident Management

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Abstract

Simulation and gaming can support decision making through all phases of incident management including prevention, preparedness, response, recovery and mitigation. A number of gaming and simulation tools have been developed for the purpose but they generally utilize proprietary or unique data interfaces and their own view of partitioning the application and solution space. This creates a large obstacle for wide use, and in particular, prevents the use of these tools in an integrated manner to address the application space. This paper explores the groundwork needed to build standards for integrated gaming and simulation tools for incident management.

An architecture has been proposed to identify the required groups of simulation and gaming modules for incident management and define their scope in the solution space. A conceptual model is proposed for the data required for such simulations. Available data exchange standards are mapped to the conceptual data model. A concept prototype has been developed based on the architecture to demonstrate the value of integrated modeling and simulation and the architecture itself. A number of simulation and gaming modules have been utilized to model the major aspects of a hypothetical scenario. The exercise is used to identify the issues due to lack of data exchange standards.

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. Effective emergency response presents a number of challenges to the responsible agencies. One major challenge is the lack of opportunities to train the emergency responders and the decision makers in dealing with the emergencies. An on the job training approach is not appropriate given the thankfully infrequent occurrences of such events. The responsible agencies have tried to meet the need through organization of live exercises, but such events are hard to organize and expensive.

Simulation refers to the use of discrete event or continuous models to represent the real world actions in a computer. Gaming is the use of computer-based simulations to engage in interactions that use highly realistic scenes and allow the player to earn rewards through winning under defined rules. Game technology has primarily been used for entertainment rather than educational purposes in the past. Changes to game technology will be required to support incident management training needs.

Simulation modeling has been identified as one of the leading techniques for helping improve the incident management capabilities [1]. A recent survey [2] indicates that a number of modeling and simulation applications for analyzing aspects of 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 a radioactive plume released by terrorists will disperse, we also need to plan what traffic routes people will 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 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 need for such integration in the incident management context has been recognized as evident by the urban security project at Los Alamos National Labs that integrated plume simulation and traffic simulation to compute exposures to the cars traveling through a toxic plume [3]. The Simulation Object Framework for Infrastructure Analysis (SOFIA) project at Los Alamos National Laboratory developed a software framework for the modeling, simulation, and analysis of interdependent infrastructures [4]. Both of these efforts used ad hoc interfaces and scope of the simulation modules. It would be a fair guess to anticipate a large amount of effort for using the simulations in these projects to model another location or more importantly to integrate them with a simulation representing another aspect, such as, the emergency operations center.

There is a need for data exchange standards to facilitate the process of development of integrated gaming and simulation tools for incident management. Data exchange standards can enable the integration of independently developed modules to rapidly model a specific scenario.

The development of such standards is a challenging task and needs to address several fronts. A framework has been proposed to partition the incident management application space [5]. Section 2 presents an architecture defining the required simulation and gaming modules and thus identifying their scope at a high level. Section 3 introduces a conceptual data model for incident management gaming and simulation. Available data exchange standards are mapped against the conceptual data model in section 4 to identify their relevance. An integrated simulation and gaming concept prototype utilizing a few of the modules is described in section 5. The data exchange issues identified while building the prototype are discussed in section 6. The final section concludes the paper.

2. ARCHITECTURE FOR INCIDENT MANAGEMENT GAMING & SIMULATION

Simulation and gaming-based technologies can together be useful for incident management applications if integrated correctly using an appropriate architecture. Simulation involves defining the rules of operation and the probabilities of paths of action and time durations and letting the events unfold. Gaming relies on a trainee's actions to determine the course of events under defined rules and probabilities. In the context of incident management, simulation can be used for applications across the incident management lifecycle. It is particularly suitable for training emergency managers and decision makers of involved agencies. Gaming is suitable for training both first responders and emergency management personnel.

2.1. Requirements for the Architecture

The architecture for simulation and gaming for incident management should provide the following major capabilities:

- Creation of a federation of simulation and gaming modules appropriate to represent the selected incident management scenario.
- Integration among heterogeneous simulation federates modeling interrelated aspects of the emergency event.
- Integration among heterogeneous gaming modules with trainees role-playing within the same locale in the emergency event simulation.
- Synchronization between the macro and micro-level simulation models and micro-level gaming modules.
- Control over execution of both simulation and gaming modules through a world control console.
- Execution in Massively Multi-player Online Games (MMOG) mode to support a large multi-agency incident management exercise.
- Access to heterogeneous data servers for supporting simulation and gaming modules.
- Management of MMOG execution.
- Management of simulation federation execution.
- Reusability of simulation and gaming components.

2.2. Concept

An architecture to meet the above requirements is conceptually presented in Figure 1. The architecture will have two major subsystems – one for simulation and the other for gaming. Each sub-system partitions the associated solution space. The simulation modules will each represent

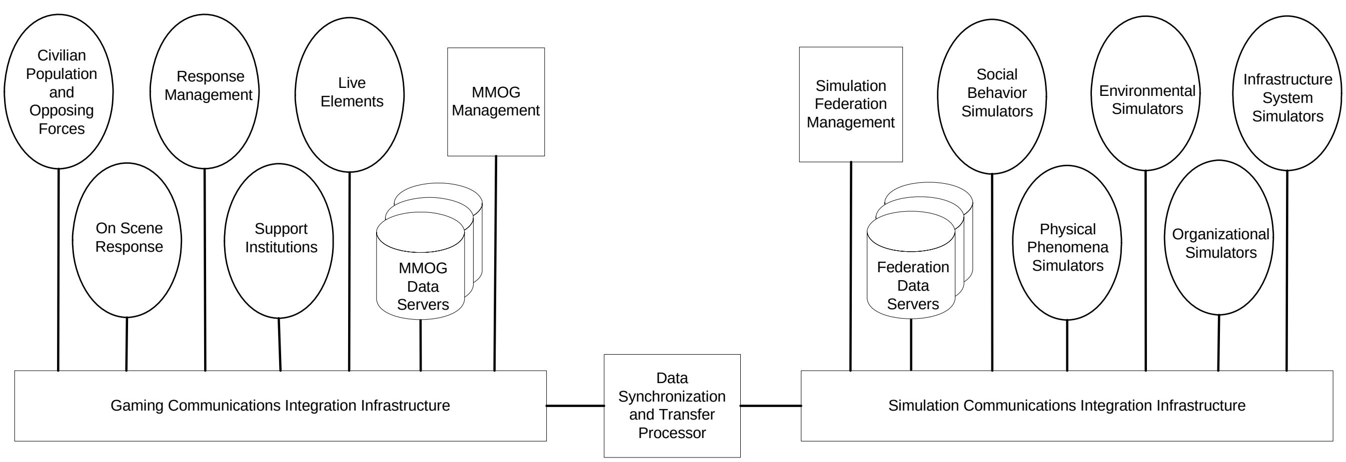

Figure 1. Architecture Concept for Simulation and Gaming Emergency Response Training System

one of the major aspects of the emergency event or its response. The simulations will be based on defined behaviors of involved entities including the incident management organizations. The gaming modules will provide for role-playing by emergency responders in roles represented in the figure. Simulation and gaming subsystems will have their individual communication integration infrastructure. The two infrastructures will be linked through a data synchronization and transfer processor as shown in the figure.

The simulation and gaming subsystem will each contain a number of modules within each of the groups [6]. For example, the social behavior simulators group will include crowd, traffic, epidemic, consumer and other simulators where the outcome is dependent on social interactions. Similarly, the civilian population and opposing forces group on the gaming side will include role playing clients for victims, general public, terrorists, media and others.

The proposed architecture will allow the virtual environment to be highly configurable. Simulation and gaming components can be selected and integrated based on a defined scenario. A scenario involving a terrorist attack using a dirty bomb can be modeled using components of the proposed system. The simulation modules employed for such a scenario may include crowd, traffic, explosion, plume, weather, fire, law enforcement, health care, transportation and communications. The gaming modules for the scenario may include victims, general public, terrorists, fire, police, emergency medical technicians (EMTs), hazardous material teams (HAZMAT), hospitals, shelters, and public transportation. A natural emergency event such as a hurricane would require a different set of modules. The available modules in the proposed architecture can thus be configured for different incident management applications across a range of scenarios.

The architecture concept will also allow flexibility in hardware systems for executing the virtual environment, in particular for training. The system modules can be distributed across a network of machines when training a large team. They may also be set up as multiple processes on a standalone machine using a multi-tasking operating system for individual training.

3. CONCEPTUAL DATA MODEL

This section presents a conceptual data model for incident management simulation and gaming from the user's perspective. The primary objective is to develop a structure for exchanging emergency related information among various emergency response simulations and gaming modules. The intent is to define data structures that can be used for both simulating the incident event and for managing actual response operations. The rationale is that if one data structure can serve both purposes, the need for data translation would be minimized.

The conceptual data model describing the top-level data requirements for incident management simulation and gaming is shown in Figure 2. It illustrates the major data elements and their relationships to each other. Thirteen major data elements are defined, namely, *Areas, Building-Structures, Chronology, Demographics, Environment, Hazard-Effects, Incident-Event, Infrastructure-Systems, Organizations, Policies-Procedures-and-Protocols, Response-Operations, Response-Resources,* and *Social-Behaviors.* The elements are briefly described below.

An incident refers to an event that requires an emergency response to protect life or property. There are two types of incidents: natural disaster and man-made attack. Natural disasters can, for example, include earthquakes, hurricanes, floods, wild-land and urban fires, mudslides, tsunamis, tornadoes, and tropical storms. Examples of man-made attack include hazardous materials spills, biological threats, chemical threats, nuclear threats, and other terrorist threats and attacks. Occasionally one event may trigger another event. The *Incident-Event* data element is needed to maintain information on the incident, such as event type, event time period, and event status including magnitude and casualty.

When an incident occurs, it helps the response providers to visualize the exact incident location on a map. The incident location might cover a small or big area. Depending on the size of the incident area maps at different scales may be needed, such as a street map, local map, regional map, or even national map. An incident site might be a residential house, office building, public facility, park, or metro station. The *Areas* and *Building-Structures* data elements contain map information and the site's characteristics including floor plans.

The *Organizations* data element is used to identify the organizations that provide emergency response support for the incident. These primarily include emergency response providers, for example, Federal Emergency Management Agency (FEMA), fire departments, police departments, hospitals, other federal, state, and local governments, and nongovernmental organizations. Nongovernmental organizations are private-sector owners and operators who represent critical elements of infrastructure or key resources whose disruption may have major impact during the incident. The *Organizations* data element contains the personnel contact information and emergency response capabilities including resources, services, etc.

An emergency organization normally sets its strategic plan for response operations and resource requirements, monitors the activities, and maintains the resources for the incident. The *Policies-Procedures-and-Protocols* data element identifies operational guidance for use by the emergency organizations and other personnel involved in conducting or supporting incident management operations. The operational guidance may be laws, regulations, policies, procedures, protocols, standards, and/or reports.

The response-operation activities carried out by the emergency response providers may include evacuation, search and rescue, food and water supply, recovery, and cleanup. The *Response-Operations* data element identifies

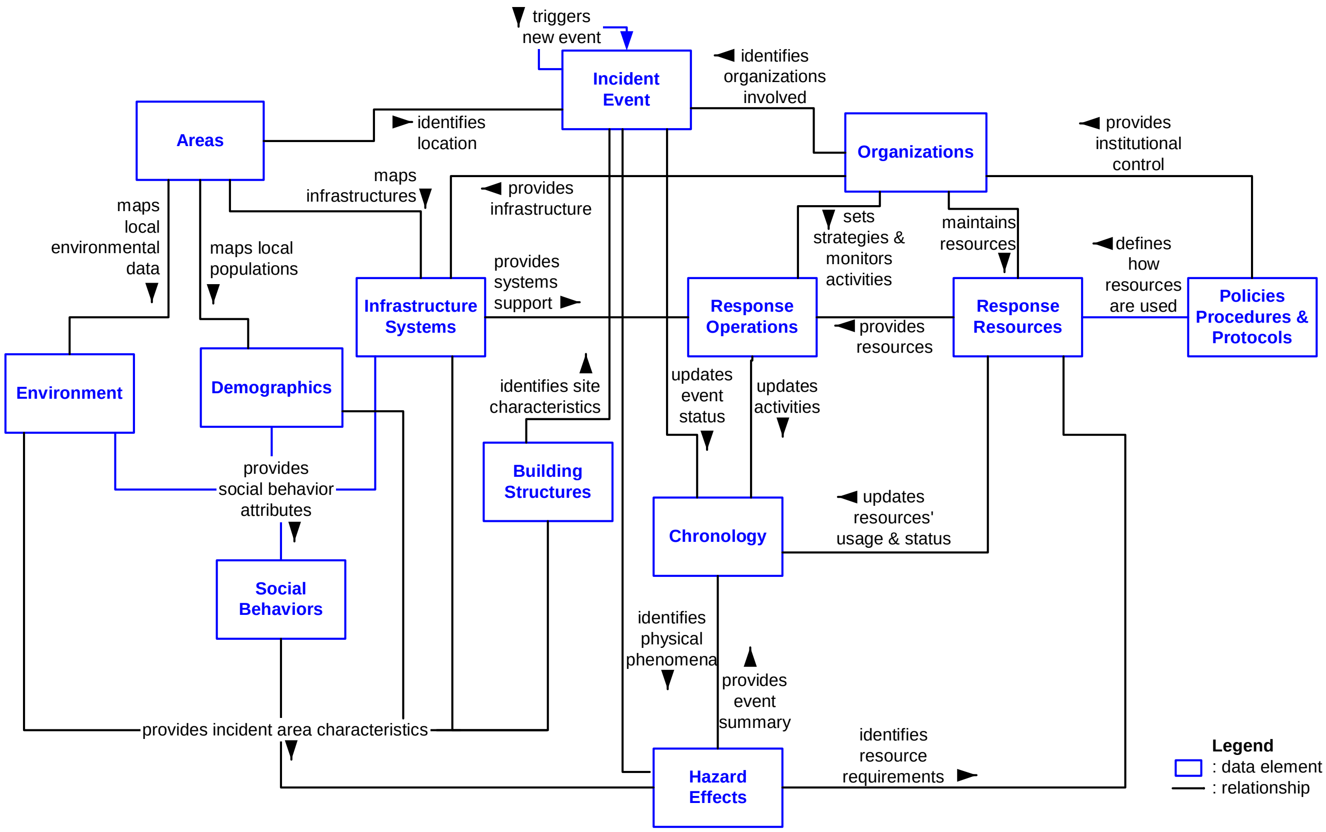

Figure 2. Conceptual Data Model for the Incident Management Simulation and Training

the response-operation activities, organizations involved, resources requirement, resources used, and their status.

Emergency-response resources are personnel, equipment, vehicles, supplies, and facilities available or potentially available for assignment to the incident response. Examples of emergency response resources are emergency medical technicians (EMT), personal protective equipment (PPE), communication gears, forensic equipment, fire trucks, and medical supplies. The *Response-Resources* data element defines type and quantity of emergency-response resources, and their availabilities and status.

The *Chronology* data element maintains the event summary information including incident status, response-operation activities, and resource usage and status. The *Hazard-Effects* data element identifies the hazard type, magnitude, and causality of the incident's status or prediction. The types of hazards may include fire, extreme weather, CBRNE (chemical, biological, radiological, or nuclear explosive), and disease.

When the incident area is identified on the map, some population and environmental data of the incident area can also be mapped by using the Census Bureau Maps, National Weather Service databases, and other public/private resources. The *Demographics* data element is used to represent age, sex, and culture of the population. There have been numerous incidents reported regarding overcrowding and crushing during emergency situations. The social-behavioral attributes may include population characteristics, environment complexity, time of day, location, familiarity, mobility, and alertness. The *Social-Behaviors* data element includes data for social-behavioral attributes. Environmental data may include weather, watershed, atmosphere, and indoor climate. Forecast is particularly important for every stage of the management of natural disasters including prevention, preparedness, response, and recovery. The *Environment* data element maintains different types of environmental data.

Infrastructure systems often play important roles during the incident. Examples of infrastructure systems include transportation, communication, gas, water, electricity, and sewage. Many critical elements of infrastructure systems may be provided by private sector. These organizations monitor and provide their services during the incident. The *Infrastructure-Systems* data element maintains the information of those critical infrastructure systems.

4. AVAILABLE STANDARDS

Table 1 lists the available standards relevant to incident management simulations. These standards are mapped onto the major data elements identified in the data model shown in figure 2. The standards listed in the table include those that have been approved by standard organizations, those that are undergoing the approval process, and de facto standards that have been adopted widely by users but have not been formally approved. From the table, please note that the standards do not evenly support the thirteen major data elements. It can be seen that only a few of the available standards support the *Chronology*, *Demographics*, and *Hazard-Effects* data elements. There isn't any standard available to describe human behavior and social interactions, and no standard to represent incident events. The research and user communities have to come together to identify priorities for standards and follow through with required development.

Table 1. Mapping of relevant available standards to major data elements in the data model

Major Data Element	**Relevant Available Standards**
Areas	• Content Standard for Digital Geospatial Metadata (CSDGM) [7] • Content Standard for Digital Geospatial Metadata (CSDGM) - Extensions [8] • Governmental Unit Boundary Exchange Standard [9] • Hierarchical Data Format-Earth Observing System (HDF-EOS) [10] • Shapefile for Geospatial Vector Data [11] • Earth-Referenced Spatial Data Transfer Standard (SDTS) [12] • Standard for a U.S. National Grid (USNG) [13] • GeoTIFF [14] • Keyhole Markup Language (KML) [15] • OpenGIS Specifications [16] • Vector Product Format (VPF) [17]
Building Structures	• CityGML - Exchange and Storage of Virtual 3D City Models [18] • National Building Information Model (NBIM) Standards [19] • The CIMSteel Integration Standards Release 2 (CIS/2) [20] • The Collaborative Design Activity (COLLADA)* [21] • The Industry Foundation Classes (IFC) [22]
Chronology	• NFPA Standard Classifications for Incident Reporting and Fire Protection Data [23]
Demographics	• Topologically Integrated Geographic Encoding and Referencing /Geography Markup Language (TIGER/GML) [24]
Environment	• Air Quality - Exchange of Data[25] • Binary Universal Form for Data Representation of Meteorological Data (BUFR) [26] • Digital Weather Markup Language (DWML) [27] • GRIdded Binary (GRIB) [28] • Extensible Markup Language (XML)* [29] • Really Simple Syndication (RSS)* [30] • Flexible Image Transport System (FITS) [31]
Hazard Effects	• Homeland Security Standards Database (HSSD)* [32]
Incident Event	• None located in the search
Infrastructure Systems	• Caltech-USGS Broadcast of Earthquakes (CUBE) Message Format [33] • Common Alerting Protocol (CAP) [34]
Organizations	• Emergency Data Exchange Language (EDXL) [35] • Digital Imaging and Communications in Medicine (DICOM) [36] • Health Level Seven (HL7) Standards [37] • IEEE 1512 Standards for Common Incident Management Message Sets for use by Emergency Management Centers [38] • The International Classification of Diseases [39] • National Response Plan (NRP)* [40]
Policies Procedures & Protocols	• Homeland Security Standards Database (HSSD)* [32] • National Response Plan (NRP)* [40]
Response Operations	• Homeland Security Standards Database (HSSD)* [32]
Response Resources	• Homeland Security Standards Database (HSSD)* [32]
Social Behaviors	• None located in the search
Others (for general purposes)	• The Collaborative Design Activity (COLLADA)* [21] • Comma Separated Value (CSV) [41] • Computer Graphics Metafile (CGM) [42] • Extensible Markup Language (XML)* [29] • Graphics Interchange Format (GIF) [43] • Hierarchical Data Format (HDF) [44] • Humanoid Animation Specification (H-Anim) [45] • Joint Photographic Experts Group (JPEG) [46] • Moving Picture Experts Group (MPEG) Standards [47] • Portable Network Graphics (PNG) [48] • Really Simple Syndication (RSS)* [30] • Tagged Image File Format (TIFF) [49] • Web Feature Service (WFS) [50] • Web Map Service (WMS) [51] • X3D [52]

* The standard is relevant to another major data element category and hence appears elsewhere.

5. CONCEPT PROTOTYPE

A concept prototype was developed to demonstrate the applicability of integrated gaming and simulation for incident management and the architecture for partitioning the solution space, and to understand the issues due to lack of data exchange standards. A hypothetical scenario was defined to serve as the basis for simulations. A number of simulation and gaming modules were developed to help understand the issues involved in modeling and integration as shown in figure 3. The hypothetical scenario and each of the implemented modules are discussed below with the full capability desired and the subset implemented for the demonstration.

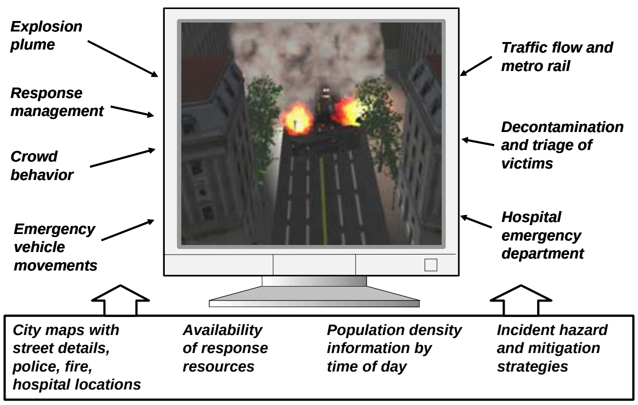

Figure 3. Concept Prototype for integrated simulation and gaming for incident management

5.1. Hypothetical Scenario

The scenario for the concept prototype is based on a dirty bomb attack in Washington DC on the evening of July 4. The fireworks on the National Mall on July 4 attract a large crowd. A large number of people utilize the metro rail system to get to the National Mall. The metro rail authorities actually close the Smithsonian metro station that is nearest to the National Mall to allow better management of the crowd flow on July 4. It does not take much imagination to identify streets nearby metro station entrances as potential targets for terrorists.

The scenario uses the area outside Federal Triangle metro station, that is the second closest station to the National Mall, as the target for detonation of a dirty bomb by terrorists. The scenario did not consider the feasibility or means of getting a dirty bomb to the identified location as the focus of the scenario was on the consequences if such an incident occurs.

The near term consequences of a dirty bomb explosion include the casualties and radiation exposure among the crowd in the immediate vicinity and in the area covered by the plume; and response by police, fire department and emergency medical technicians. The major consequences of the incident and the response need to be modeled for incident management purposes.

5.2. Simulation modules

The simulation modules included in this effort are briefly described below.

5.2.1. Plume Simulation

This module falls in the category of physical phenomena simulators shown in Figure 1. It was implemented using CT-Analyst software from Naval Research Labs [53]. This tool provides the desired capabilities for modeling plume dispersion as described above. It models the spread of the plume from the identified location taking into account the weather and the geometry of the buildings in the surrounding areas.

5.2.2. Crowd Simulation

The capability of modeling crowd behavior is a part of the social behavior simulators group in figure 1. It has been implemented by researchers from University of Arizona using AnyLogic software using the agent based simulation paradigm. Individuals and small groups are defined as agents with each of them having parameters such as age, mobility, and knowledge of the area, that determine their reaction to the incident and the behavior [54].

5.2.3. Traffic Simulation

Traffic simulation is another module in the group of social behavior simulators. This capability has been implemented using two modules that simulate traffic at different levels of detail. The Emergency Response Vehicle Simulator models the traffic at a macro level. It has been developed by researchers at the National Institute of Standards and Technology (NIST) using Java and GeoTools, an open source Geographic Information System (GIS) toolkit [55]. It mimics the movement of the response vehicles from their initial locations to the site of the incident. While individual response vehicles are modeled, the effect of the rest of the traffic is modeled using congestion factors for each road segment that they go through. The travel route is determined using Dijkstra's algorithm [56].

The micro level traffic simulation capability has been implemented using the Traffic Software Integrated System (TSIS) developed at the University of Florida and available through the Center for Microcomputers in Transportation (Mc*Trans*). The model simulates movement of individual vehicles in the immediate area around the National Mall before and after the incident. Following the incident, a number of vehicles come out of parking garages in the area and attempt to leave resulting in traffic jams. The software allows capturing the congestion factors for each road segment defined. The congestion factors determined through micro-level simulation of one area can be used to estimate congestion factors for the wider area modeled in the macro-level traffic simulation.

5.2.4. Health Care Simulation

The health care simulation module is part of the organizational simulator group in Figure 1. The concept demonstration includes a model for only one part of the health care system, namely, the emergency department. The operation of a hypothetical emergency department for handling the casualties from the incident is simulated. It was developed by NIST researchers using ProModel/ MedModel. Casualties arriving at the emergency department include serious cases of trauma and cardiac cases brought in by ambulances and walk-ins with minor injuries and the worried well. The model indicates the build up of queues for the walk ins. The ambulances carrying serious cases are occasionally diverted to other hospitals based on the status at the hospital modeled.

5.2.5. Transportation Simulation

Transportation simulation is a part of the infrastructure systems simulators group in Figure 1. A metro rail simulation model was developed for the purpose of demonstrating the concept of transportation simulation. The model was developed using AutoMod by NIST researchers working with Brooks Software personnel. It models the evacuation of people from the incident area using the metro rail system. The metro system lines passing through the incident area are modeled. The model helps determine the rate at which the crowd can disperse using the metro system.

5.3. Gaming Modules

The gaming modules would be especially useful for incident management training applications. Two of the modules were implemented, one at the responder level and the other at the management level.

5.3.1. Triage Application

Triage is part of the On-Scene Response group of gaming applications in Figure 1. This application allows trainees to play the role of emergency medical technicians conducting triage following a dirty bomb explosion. This module has been developed using collaboration between researchers from NIST and the Institute of Security Technology Studies (ISTS) at Dartmouth College. The ISTS researchers had previously developed the triage application for an airplane crash scenario [57]. The NIST researchers created the 3-D geometry of the incident location and worked with ISTS researchers to set up the application.

The gaming application allows a user to move around in the 3-D space representing the incident site. The user can see the fire caused by the explosion, the casualties lying on the ground, the fire trucks, other responders, objects and structures on the street and the surrounding buildings. They can go to each victim and perform triage by looking for the vital signs and asking specific questions if possible. The victims requiring immediate attention can be carried away on stretchers through a gross decontamination station created using hoses from two fire trucks. The application includes audio effects to make the experience closer to reality. A user has to contend with sounds of sirens, victims, and limited lighting conditions in performing his/her responsibilities for conducting triage.

5.3.2. Incident Management Strategy Gaming

The strategy gaming application falls under the Response Management category of gaming applications shown in Figure 1 and is targeted at the management level personnel for the responding agencies. This may be used by personnel at the Emergency Operations Center (EOC) to plan out the response resource deployments. The module has been developed by NIST researchers using C#.

The module shows a map of the incident site together with the locations of response resource providers including police stations, fire stations, and hospitals. The interface provides the capability to place icons representing response resources on the map thus making and visualizing the deployments. The map can be updated based on reports from the incident site. All the icons used are based on standards defined by the Homeland Security Working Group [58].

All the modules above were built to represent different aspects of the hypothetical scenario and the ensuing response. Two of the simulation modules, the emergency department simulation and the emergency response vehicle simulation, were integrated together in a distributed set up [59]. Data interfaces were studied for all the modules.

6. DATA EXCHANGE ISSUES IDENTIFIED

The development of the concept demonstration prototype helped identify the data exchange issues involved in building a system with integrated simulation and gaming modules. The issues are summarized below:

- The data inputs for the simulators were generally in proprietary formats. Some of the data had to be entered using input screens of the simulators. The tools developed internally at NIST allowed XML inputs.
- The GIS data inputs could be in a number of several GIS “standard formats.” There are multiple file formats defined with different versions, multiple earth models and multiple projections. There is no best combination of these factors and translation errors between the formats are common.
- The imported graphics required varied formats also. For an earlier version of the strategy board, the map had to be downloaded as a bitmap and then converted into Targa (.tga) format. Another tool required the bitmap to be converted to Jpeg (.jpg) format. Yet another required conversion to AutoCAD format.
- Communication with some of the proprietary tools was hard to implement as they were not designed to interact with external programs.

There were some instances of default standards that helped the process. For example, inputs of 3D models for the two different gaming software used was possible using 3D Studio Max format.

The experience underlined the need for data exchange standards for the simulation and gaming modules. Standards are also needed to enable plug and play interfacing of the modules.

7. CONCLUSION

A concerted effort is required to enable use of integrated simulation and gaming for incident management applications and thus contribute to improvement of such capabilities. The effort needs to address several fronts including a common understanding of the application and solution spaces and data exchange standards based on common terminology. An architecture was presented to partition the solution space and thus define the scope of the simulation and gaming modules required for incident management applications. A conceptual model was presented to organize the data required for such simulations. Available standards have been mapped to the conceptual data model to establish a baseline. A prototype for integrated gaming and simulation for incident management was built to explain the concept of integrated gaming and simulation and to gain first hand knowledge of the data exchange issues.

Future work is intended to further define and build the infrastructure required for enabling integrated gaming and simulation using independently developed modules. Such infrastructure will include defined standard architecture, interfaces and data formats that allow bringing together desired modules for incident management for different scenarios.

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DISCLAIMER

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

REFERENCES

†- All on-line sources were last accessed on Feb. 20, 2007.

[1] National Research Council, 2002. Making the Nation Safer: The Role of Science and Technology in Countering Terrorism. National Academies Press, Washington DC, USA.

[2] Jain, S. and C.R. McLean. 2003. Modeling and Simulation of Emergency Response: Workshop Report, Relevant Standards and Tools. National Institute of Standards and Technology Internal Report, NISTIR-7071. Available online via†: http://www.nist.gov/msidlibrary/doc/nistir7071.pdf

[3] LANL, 2001, “Urban Security Project,” Available on-line via†: <http://www.lanl.gov/orgs/d/d4/aquality/urban.html>

[4] LANL, 2000, “Interdependent Infrastructure Modeling, Simulation, and Analysis Project (SOFIA),” Available on-line via†: <http://www.lanl.gov/orgs/d/d4/infra/sofia.html>.

[5] Jain, S. and C.R. McLean. 2006. An Integrating Framework for Modeling and Simulation for Incident Management. Journal of Homeland Security and Emergency Management: Vol.3 No. 1, Article 9.

[6] Jain, S. and C.R. McLean. 2005. Integrated Gaming and Simulation Architecture for Incident Management Training. In Proceedings of the 2005 Winter Simulation Conference. eds. M. E. Kuhl, N. M. Steiger, F. B. Armstrong, and J. A. Joines, 904-913. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers.

[7] FGDC, 1998. FGDC-STD-001-1998. Content standard for digital geospatial metadata (revised June 1998). Federal Geographic Data Committee (FGDC). Washington, D.C. Available on-line via†: <http://www.fgdc.gov/metadata/csdgm/>.

[8] FGDC, 2002. FGDC-STD-012-2002. Content standard for digital geospatial metadata: Extensions for Remote Sensing Metadata. Federal Geographic Data Committee. Washington, D.C. Available on-line via†: <http://www.fgdc.gov/standards/projects/FGDC-standards-projects/csdgm_rs_ex/remote-sensing-metadata>.

[9] FGDC, 2003. Governmental Unit Boundary Exchange Standard. Federal Geographic Data Committee. Washington, D.C. Available on-line via†: <http://www.census.gov/geo/www/bas/standard/gubs_0103.doc>

[10] NASA, 2004. Hierarchical Data Format-Earth Observing System (HDF-EOS). National Aeronautics and Space Administration (NASA). Available on-line via†: <http://hdfeos.gsfc.nasa.gov/>.

[11] ESRI, 1998. ESRI Shapefile Technical Description. Environmental Systems Research Institute. Available on-line via†: <http://www.esri.com/library/whitepapers/pdfs/shapefile.pdf>

[12] Spatial Data Transfer Standard (SDTS): Available on-line via†: <http://mcmcweb.er.usgs.gov/sdts/standard.html>

[13] Standard for a U.S. National Grid (USNG): Available on-line via†: <http://www.fgdc.gov/standards/projects/FGDC-standards-projects/usng>

[14] GeoTIFF: Available on-line via†: <http://www.remotesensing.org/geotiff/spec/geotiffhome.html>

[15] Keyhole Markup Language (KML): Available on-line via†: <http://earth.google.com/kml/>

[16] OpenGIS Specifications: Available on-line via†: <http://www.opengeospatial.org/ogc>

[17] Vector Product Format (VPF): Available on-line via†: <http://www.tec.army.mil/fact_sheet/vpf.pdf>

[18] OGC, 2007. CityGML. Open Geospatial Consortium Inc. Available on line via†: <http://www.ogcnetwork.net/gml-citygml >

[19] NIBS, 2007. National Building Information Model (NBIM) Standards project. National Institute for Building Sciences (NIBS) Facility Information Council (FIC). Available on-line via†: <http://www.facilityinformationcouncil.org/bim/index.php>

[20] The CIMSteel Integration Standards Release 2 (CIS/2): Available on-line via†: <http://www.cis2.org/documents/summary.htm>

[21] The Collaborative Design Activity (COLLADA): Available on-line via†: <https://collada.org/public_forum/welcome.php>

[22] The Industry Foundation Classes (IFC): Available on-line via†: <http://www.iaiinternational.org/Model/documentation/IFC_2x_Technical_Guide.pdf>

[23] NFPA, 2006. NFPA-901: Standard Classifications for Incident Reporting and Fire Protection Data. National Fire Protection Association (NFPA). Available on-line via†: <http://webstore.ansi.org/ansidocstore/product.asp?sku=90106PDF>

[24] Topologically Integrated Geographic Encoding and Referencing /Geography Markup Language (TIGER/GML): Available on-line via†: <http://www.opengeospatial.org/pressroom/pressreleases/369>

[25] ANSI, 1999. Air Quality - Exchange of Data. American National Standards Institute (ANSI) Available on-line via†: <http://webstore.ansi.org/ansidocstore/product.asp?sku=ISO+7168-2%3A1999>

[26] WMO, 1991. Binary Universal Form for Data Representation of Meteorological Data (BUFR). World Meteorological Organization (WMO). Available on-line via†: <http://www.wmo.ch/web/www/WDM/Guides/Guide-binary-1A.html>

[27] NWS, 2007. Digital Weather Markup Language (DWML). National Weather Service (NWS). Available on-line via†: <http://www.weather.gov/xml/>.

[28] WMO, 1994. GRIdded Binary (GRIB). World Meteorological Organization (WMO). Available on-line via†:<http://www.wmo.ch/web/www/WDM/Guides/Guide-binary-2.html>

[29] Extensible Markup Language (XML): Available on-line via†: <http://www.w3.org/XML/>

[30] Really Simple Syndication (RSS): Available on-line via†: <http://www.xml.com/pub/a/2002/12/18/dive-into-xml.html>

[31] Flexible Image Transport System (FITS): Available on-line via†: http://fits.gsfc.nasa.gov/fits_home.html

[32] Homeland Security Standards Database (HSSD), Available on-line via†: <http://www.hssd.us/about.aspx>

[33] Bryant, S., K.M. Luethke, P. Jacobsen, L. Boden and E. Bader, 1996. Monitoring Earthquakes with ArcView and Seisport. ESRI User Conference. Available on-line via†: <http://gis.esri.com/library/userconf/proc96/TO400/PAP375/P375.HTM>

[34] OASIS, 2005. Common Alerting Protocol (CAP): Version 1.1. OASIS (Organization for the Advancement of Structured Information Standards) Committee Specification. 11-August-2005. Eds: E. Jones and A. Botterell. Available on-line via†: <http://xml.coverpages.org/CAPv11-CS-14204.pdf>.

[35] OASIS, 2005. EDXL-DE-V1.0 Emergency Data Exchange Language (EDXL) Distribution Element, v. 1.0. Eds: M. Raymond and S. Webb. OASIS Committee Draft. August 19, 2005. Available on-line via†: <http://docs.oasis-open.org/emergency/edxl-de/v1.0/EDXL-DE_Spec_v1.0.doc>

[36] RSNA, 2007. Digital Imaging and Communications in Medicine (DICOM): Version 3.0. Radiological Society of North America(RSNA). Available on-line via†: <http://www.rsna.org/Technology/DICOM/>.

[37] HL7, 2003. Health Level Seven (HL7) Standards. Available on-line via†: <http://www.hl7.org/>.

[38] IEEE, 2006. IEEE Std 1512-2006, IEEE Standard for Common Incident Management Message Sets for Use by Emergency Management Centers. Institute of Electrical and Electronics Engineers (IEEE). Available on-line via†: <http://grouper.ieee.org/groups/scc32/imwg/index.html>

[39] The International Classification of Diseases: Available on-line via†: <http://www.cdc.gov/nchs/about/otheract/icd9/abticd9.htm>

[40] US Department of Homeland Security, 2006. National Response Plan. Available on line via†: <http://www.dhs.gov/nrp>.

[41] Comma Separated Value (CSV): Available on-line via†: <http://www.creativyst.com/Doc/Articles/CSV/CSV01.htm#Overview>

[42] Computer Graphics Metafile (CGM): Available on-line via†: <http://www.itl.nist.gov/div897/ctg/graphics/cgm_std.htm>

[43] Graphics Interchange Format (GIF): Available on-line via†: <http://www.w3.org/Graphics/GIF/spec-gif87.txt>

[44] NCSA, 2005. Hierarchical Data Format (HDF5). National Center for Supercomputing Applications (NCSA). Available on-line via†: <http://hdf.ncsa.uiuc.edu/HDF5/doc/>

[45] Humanoid Animation Specification (H-Anim): Available on-line via†: <http://www.h-anim.org/Specifications/H-Anim200x/ISO_IEC_FCD_19774/>

[46] Joint Photographic Experts Group (JPEG): Available on-line via†: <http://www.w3.org/Graphics/JPEG/; http://www.jpeg.org/>

[47] Moving Picture Experts Group (MPEG) Standards: Available on-line via†: <http://www.chiariglione.org/mpeg/>

[48] Portable Network Graphics (PNG): Available on-line via†: <http://www.w3.org/Graphics/PNG/>

[49] Tagged Image File Format (TIFF): Available on-line via†: <http://home.earthlink.net/~ritter/tiff/>

[50] Web Feature Service (WFS): Available on-line via†: <http://www.opengeospatial.org/standards/wfs>

[51] Web Map Service (WMS): Available on-line via†: <http://www.opengeospatial.org/standards/wms>

[52] X3D: Available on-line via†: <http://www.web3d.org/about/overview/>

[53] Boris, J.P., K. Obenschain, G. Patnaik, and T.R. Young, Jr., 2002. CT-Analyst: Portable Tool for Dispersion Prediction with Zero Delay and High Fidelity. In *Proceedings of Fourth George Mason University Transport and Dispersion Modeling Workshop*, George Mason University, Fairfax VA. July 11-12.

[54] Shendarkar, A., K. Vasudevan, S. Lee, and Y.J. Son, 2006. Crowd Simulation for Emergency Response Using BDI Agent based on Virtual Reality. In *Proceedings of the 2006 Winter Simulation Conference*. eds. L. F. Perrone, F. P. Wieland, J. Liu, B. G. Lawson, D. M. Nicol, and R. M. Fujimoto. 545-553. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers.

[55] Geotools, 2006. Geotools – The Open Source Java GIS Toolkit. Available online via†: <http://geotools.codehaus.org/>.

[56] Dijkstra, E. W., 1959. A note on two problems in connexion with graphs. Numerische Mathematik, Vol. 1, No. 1, 269-271.

[57] ISTS 2006. Synthetic Environments for Emergency Response Simulation - Unreal Triage. Available online via†: <http://www.ists.dartmouth.edu/projects/seers/utriage.php>.

[58] HSWG 2006. Homeland Security Working Group Symbology Reference. Available online via†: <http://www.fgdc.gov/HSWG/index.html>.

[59] Jain, S. and C.R. McLean. 2006. A Concept Prototype for Integrated Gaming and Simulation for Incident Management. In *Proceedings of the 2006 Winter Simulation Conference*. eds. L. F. Perrone, F. P. Wieland, J. Liu, B. G. Lawson, D. M. Nicol, and R. M. Fujimoto. 493-500. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers.

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