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An Integrated Gaming and Simulation Architecture for Incident Management Training

Sanjay Jain
Charles R. McLean

National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

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Sanjay Jain
Department of Decision Sciences
School of Business
George Washington University
Washington, DC 20052
jain@gwu.edu

Charles R. McLean
Manufacturing Systems Integration Division
Manufacturing Engineering Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899-8260
mclean@cme.nist.gov

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Abstract

The nation's emergency responders need to work in a coordinated, well-planned manner to best mitigate the impact of an emergency incident. They need to be trained and be ready to act in view of the increased security threat. The training has been traditionally provided using live exercises at a great expense. Simulation and gaming systems could provide a wider range of training at a much lower expense. The incident management simulation-based training systems that are available or under development today are typically focused on a macro level sequence of events. A few systems targeted at individual responders are under development using gaming environments. Separate uses of such systems provide disparate experiences to decision makers and individual responders. There is a need to provide a common training experience to these groups for better effectiveness. This paper presents a novel approach integrating gaming and simulation systems for training of decision makers and responders on the same scenarios preparing them to work together as a team. An integrated systems architecture is proposed for this purpose. Major modules in gaming and simulation subsystems are defined and interaction mechanisms established. Advanced visualization, human interaction, data access and management capabilities needed for meeting the training objectives are described. Research and standards issues for implementation of the proposed architecture are discussed.

Keywords: modeling, simulation, gaming, training, architecture, incident management, emergency response, integration.

1. Motivation

There is a growing need for improved management of both man-made and natural incidents. The man-made disaster risk has increased due to a rise in possibility of terrorist attacks against the United States. Effective incident management through all its phases, that is, prevention, preparedness, response, recovery and mitigation, 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 useful 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.

Modeling, simulation,[1] and gaming techniques can help address many of the challenges brought forth by the need for improved incident management. What is simulation? In the "Handbook of Simulation", Jerry Banks [1] defines simulation as:

> *"…. the imitation of the operation of a real-world process or system over time. Simulation involves the generation of an artificial history to draw inferences concerning the operational characteristics of the real-system that is represented. Simulation is an indispensable problem-solving methodology for the solution of many real-world problems. Simulation is used to describe and analyze the behavior of a system, ask what-if questions about the real system, and aid in the design of the real system. Both existing and conceptual systems can be modeled with simulation."*

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. A number of changes will be required to support incident management training needs. New functionality will need to be incorporated into game software to make it suitable for training applications. A common development strategy, a standard architecture, and neutral data interfaces will also be required to ensure that the game components are highly reusable.

Video game technology could be used to create virtual environments for the incident management trainee. These environments would contain realistic three-dimensional graphics and sound that could significantly enhance the learning experience (for examples, see [2]). Learning applications might address theory and operation of incident management actions and equipment. They also might include various operational scenarios where strategies and tactics are covered. Training could be developed for all facets of the incident management including

[1] Modeling and simulation in this paper refer to use of computer-based models and simulations. Live exercises are identified separately when their use is referred to.

law enforcement, health care, fire department, and urban search and rescue. Decision makers and first responders alike could make effective use of these training capabilities.

Simulation involves defining the rules of operation and the probabilities of paths of action and time duration and letting the events unfold. Gaming uses trainee's actions in determining the course of events under defined rules and probabilities. In the context of incident management, the two can be used together such that simulations maintain the technical correctness of the scenario while gaming clients allow the interaction with the trainees.

A recent survey [3] indicates that a number of modeling and simulation (M&S) 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 a radioactive plume released by terrorists 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 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 integrated set of simulation tools should be used for training the emergency responders at all levels. It is important that the first responders and emergency managers go through training experiences on the same scenarios to effectively work as a team. Human beings can make good decisions under a stressful situation if they can recognize the pattern as similar to something they have experienced in the past per a study by Klein [4]. If they have not experienced a similar situation in the past, their capability to make the right decisions is impaired as there isn't enough time to evaluate all the possible options and select the right ones. The understanding of human decision making from the Klein study suggests two important directions for emergency response training. First, simulation should be used to expose the emergency responders to a range of situations based on the potential scenarios that may occur in their jurisdiction. This will prepare them to select the right responses when faced with an emergency. Second, the responder teams across all levels should go through similar scenarios to develop similar mental concepts. This will allow emergency managers to develop similar approaches and the emergency responders to fully support them having experienced the success of the approaches in past simulations.

To provide the experience of the same scenarios across all levels of an emergency response team requires execution of large-scale live exercises such as those conducted under TOPOFF (Top Officials) series. These large-scale exercises are hard to organize since they require coordination across a large number of agencies across multiple levels of hierarchy. With the large number of resources devoted to such exercises, each exercise cycle costs tens of millions of dollars. TOPOFF 3 conducted in April 2005 had a budget of $16 million [5]. And, even with all the effort and expenses they are able to expose the responders, emergency managers and government officials to a limited set of scenarios. The creations of emergency events are limited in realism to avoid risk.

The limitations of live exercises can be overcome to a large extent through use of integrated gaming and simulation models that allow emergency response personnel across multiple levels in multiple agencies to get exposed to the same set of scenarios. The Department of Defense has found that use of simulations instead of live exercises for training can reduce the training costs by up to 90% [6]. Use of integrated gaming and simulation over a distributed network can allow people to participate from different locations and thus provide some flexibility in scheduling the resources. Most importantly, use of simulation will allow providing the responders with experience of a wide range of response scenarios and thus significantly improve the emergency preparedness.

The development of integrated gaming and simulation for emergency response training is a challenging task that requires addressing technical, business, and social issues. This paper focuses on the technical aspect of developing an architecture for the integration. The integration of simulation models developed independently itself requires action on multiple aspects. Interoperability standards need to be defined that will allow the conforming models and data sources to be integrated. A framework and an architecture for integration needs to be agreed upon by the M&S community involved in developing applications in the area of emergency response. Infrastructure for development and deployment of the integrated solutions needs to be established.

This paper proposes an architecture for integrated gaming and simulation for incident management training. Relevant reported frameworks and architectures for modeling and simulation are reviewed. The proposed overall approach for integrated gaming and simulation tools for incident management training is described. The proposed architecture itself is presented and its major components discussed. The paper concludes with discussion of further research for achieving the vision of the integrated gaming and simulation for incident management training.

2. Background

The applicability of modeling and simulation to different phases of incident management has been recognized for decades (see for example [7]). However, the idea of integrating the M&S tools for a more comprehensive modeling of the scenario is more recent. In this section, a few of the M&S tools for incident management are discussed followed by efforts for integration of such tools. A framework for M&S for incident management is presented to define the scope of their application and identify the training application as part of a continuum of applications through the incident management life cycle.

2.1 Modeling & Simulation tools for Incident management

This sub-section provides a classification for M&S tools for incident management using some of the efforts as examples.

2.1.1 Incident Impact Modeling Tools

Several efforts focus on studying and projecting the impact of an incident. The projections would help determine if the incident is an emergency event or a major disaster and can be used for planning the response to the incident. 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: Contaminant Transport (CT) Analyst for modeling plume dispersion developed at Naval Research Labs [8], National Atmospheric Release Advisory Center (NARAC) facility at Lawrence Livermore National Laboratory for modeling hazardous atmospheric release [9], and building fire simulation tools developed at National Institute of Standards and Technology [10]. A survey of 94 modeling tools for atmospheric dispersion is available in [11].

2.1.2 Emergency Response Planning Tools

Tools in this category allow evaluation of alternative strategies to respond to an incident. They may allow input of impact of the incident estimated by experts or determined by using tools in the previous category, or they may themselves include the capability for incident impact modeling. These tools may be used following the occurrence of an incident, or in preparedness role, that is, for planning the response for future potential incidents. Examples of tools in this category include the Threat Response Management System that utilizes an agent simulator to evaluate the planned response under various scenarios [12], and 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 [13]. Another example at a more detailed level is the Assisted Evacuation Simulation System by Takenaka Corporation of Japan that is designed to simulate evacuation of patients who need assistance to move [14].

2.1.3 Tools for Incident Management Training

The simulation tools in this category mimic and present situations created by occurrence of an incident to human training subjects with the intent to improve their capabilities for incident management. 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 decision-maker’s approach for making high level decisions such as units of first responders to be deployed in different areas impacted by the incident. These tools abstract and execute the model at a macro-level. The tools at the macro level typically use one or more computer monitors to graphically display the simulated unfolding of a 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 [15]. Another example is the Emergency Preparedness Incident Command Simulation (EPiCS), a computer-based, scenario-driven, high-resolution simulation tool [16].

Simulation tools for training first responders may abstract and execute the model at micro-level detail. These tools may use agent-based techniques to simulate the detailed actions of first responders and/or terrorists. In such use they are parallel to the use of troop level detailed simulation by the US Army to analyze the impact of tactical approaches for different scenarios. The micro level simulations require specification of behaviors of involved characters and detailed procedures. While they are more useful for planning purposes such as evaluating evacuation plans for a facility, they can be used for training through their use to iteratively evaluate suggested response approaches by incident management trainees.

Detailed simulations are also used for supporting live exercises. For example, simulation has been used to model the spread of a chemical agent in a live exercise [17]. This allows the live exercise to be conducted without exposing the first responders to danger. While the use of simulation at a micro level of detail is useful for training first responders on successful approaches, they allow limited interaction. The first responders gain more when they are able to experience the emergency and respond to it. Gaming tools described next provide such capabilities.

The computer based tools most suitable for first responder level training are the gaming tools. These may be immersive using advanced hardware configurations or based on the use of personal computers. The immersive tools use 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 of a small airport in which a biological warfare agent has been dispersed following a terrorist bombing [18].

The architecture presented in this paper has been designed to integrate both simulation and gaming tools for incident management training.

2.1.4 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) that 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 [19].

This sub-section described a number of categories of M&S tools with examples. A more detailed survey of such tools is provided in [3]. The full potential of M&S tools can be exploited when the tools can be brought together rapidly to study and analyze all major aspects of a disaster event. An emergency response scenario with and without the use of integrated M&S tools to highlight their value is described in [20].

2.2 Integration Efforts and Architectures

A number of simulation tools have to be integrated to address multiple aspects of a single disaster event as described in section 1. 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 integrates plume simulation and traffic simulation to compute exposures to the cars traveling through the plume [21]. 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 [22].

A number of research efforts have been targeted at integration of simulation models outside the context of incident management. In particular, Department of Defense has spent a large effort in developing war gaming capabilities that integrate a number of simulation models and humans-in-the-loop. The United States (U.S.) Department of Defense (DoD) sponsored research in this area started in the late 1980's with Simulation Networking (SIMNET) project for real-time battlefield simulations of tanks in a virtual training environment. Most recently one thread of the work is evolving into the Standard Simulation Architecture, designed as a combination of the High Level Architecture (HLA) and the Synchronous Parallel Environment for Emulation and Discrete-Event Simulation (SPEEDES) developed in the mid to late 1990's [23]. Another group of researchers is proposing bringing HLA together with the Model Driven Architecture (MDA), a concept developed by the Object Management Group (OMG). The model driven architecture uses a language, vendor and platform independent meta-model as the core representation, with facilities defined to translate the representation for implementation. The combination of HLA and MDA offers benefits to both the developments and is recommended by Tolk [24]. Any proposed architecture based on HLA should weigh the alternate approaches and their support in the industry and accordingly plan the implementation. Overall, the focus of the DoD developments has been on war gaming involving a number of human decision-makers and actors. The associated research should prove to be very useful for integrated simulations for incident management, particularly for training applications.

Simulation applications for homeland security can get a jump start through adaptation of DoD integrated simulations, in particular, for larger jurisdictions with sufficient funding availability. United States Joint Forces Command is carrying out a leading effort in this direction. The Joint Theatre Level Simulation (JTLS) and Joint Conflict and Tactical Simulation (JCATS) have been integrated for multi-resolution modeling for training of emergency management staff [25]. The integrated system was used successfully for the Determined Promise 2004 homeland security exercise involving a large number of emergency response personnel across multiple locations.

The integration of simulation models requires that the data is translated from one model to another model in the right context. Typically, human analysts have to spend some time ensuring that the translation of data is consistent based on the semantic understanding. Translation using syntactic grammar can be more efficient but not always possible. An agent-based architecture has been developed that uses object-oriented modeling techniques to encapsulate and organize the syntactic information while the semantic information of the objects is examined for data integration purposes [26]. The proposed architecture can provide value for interoperability of incident management simulations.

The Dynamic Information Architecture System (DIAS) has been developed at Argonne National Laboratory as an object-oriented simulation system that provides an integrating framework for new and legacy applications and can adapt to different contexts [27]. The system has been used both for U.S. Department of Defense applications and civilian applications. It is frame-based and uses the concept of entity objects as analogs to the real world entities being studied. It uses an extensive library of entity objects that can be used in modeling environmental, transportation, and command and control applications. The requirements for building the library of objects may require a large effort for implementation of the system in an incident management context.

HLA has been used for integrating distributed simulation models in the manufacturing domain. A neutral reference architecture was developed for integrating distributed manufacturing simulation systems with each other, with other manufacturing software applications, and with manufacturing data repositories [28]. The need for standardization of interfaces was highlighted. Experience from this past research may be useful in the development proposed here.

This brief review of related research indicates the feasibility of developing an architecture for M&S of incident management and at the same time indicates a need for standardization of interfaces and semantic and syntactic representations.

3. Framework for Incident management

An integrated framework for incident management is defined in this section to enable an organized approach to the use of M&S in this area. The proposed framework is based on an earlier work [20], but it goes beyond through use of terminology and concepts used in the National Response Plan (NRP) developed by the United States Department of Homeland Security [29]. The primary users of such a framework would be developers of M&S tools as they would gain from an organized approach to the incident management area. The framework identifies the scope of the incident management area, provides a scheme to map the current tools and determine the gaps, and helps identify the interfaces that the tools may have to other tools. It will thus help capture the interoperability requirements for the M&S tools. Although the framework has been designed to help guide the M&S efforts, it may be seen that it provides a general scheme for organizing the incident management area.

The incident management area can be classified using various criteria and various viewpoints. A high level framework is proposed to help organize the area. The framework is designed to be three dimensional for ease of understanding. Additional dimensions should be accommodated at more detailed levels of the framework. The three major dimensions are described below.

3.1 Incident

An incident is defined as “an occurrence or event, natural or human-caused, that requires an emergency response to protect life or property” [29]. The kind of incident will have a large influence on the kind of M&S capabilities that need to be brought together for response and its management. 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, man-made and natural incidents may have similar impact. For example, forest fires can be initiated by intentional or unintentional actions of people or by natural causes.

3.2 Domain

A domain is defined as a group of entities that have similar characteristics with respect to incident management considerations. The incident may have an impact across different domains including civilian population, critical infrastructure, and environment. The response to and management of the incident may involve multiple domains including government agencies and private sector. Entities within domains may both suffer the impact of incidents and may be involved in response. The domains may be modeled at a level of detail appropriate to the objective of the study. Each of the domains represents multiple entities as discussed below.

- The civilian population domain includes affected residential and commuter civilians in the incident area and identifies the capability to model individual and unorganized groups of human beings. Various aspects of civilian population may be of interest including casualties, social and psychological effects of the incident, behavior of groups before, during and after the incident. The civilian population behaviors would influence the extent of an incident such as spread of epidemics, exposure to and transmission of released biological or chemical agents, crowd movement, rioting, and evacuation patterns. The assets owned and operated by the civilian population, e.g., vehicles are also considered part of this domain. The civilian population domain would include the "unaffiliated volunteers" identified in the NRP.
- Critical infrastructure domain includes transportation networks, electric power generation and distribution facilities, water filtration and distribution structure, and communication networks. and identifies the capability to model the behavior of such systems and associated organizations under peak, normal and damaged use. Both public and private elements of infrastructure are included. While there have been several different lists of critical infrastructures, this category is intended to include the most comprehensive list of twenty infrastructures defined in a report to U.S. Congress [30]. The organizations responsible for the operation and management of critical infrastructures are also included in this domain. The domain also includes the assets of such organizations.
- The environment domain includes both the natural and built up components. The natural environment includes terrain, ocean, weather, and hydrology, together with the capability to model them in three dimensions and their respective behaviors. The built up environment includes buildings, structures, cultural and historical resources that are not part of critical infrastructures discussed above. It includes the capability to model building and structures in three dimensions with their features and the impact of disaster events on them. The environment may be modeled at anywhere from regional, state, county, city or block level as appropriate to the incident being studied. An incident in a national park may involved modeling of the natural environment at block level without including the built up environment. The reverse may be true for an incident in the downtown area of a city.
- The government agencies domain includes all the government organizations that either play a role in incident management or are affected by the incident. This includes fire, police, and city management, and identifies the capability to model the organization and its people with their command and control structure and information flows. It also includes multi-agency organizations such as Emergency Operations Centers (EOCs) that may be temporarily formed for incident management. It also includes the assets that are owned and operated by the government agencies including fire trucks, personal protective equipment, and computer and communication equipment in the EOC.
- The private sector domain includes all the private organizations, commercial and non-profit, that may be affected by and/or involved in the incident management activities. The entities in this domain may be modeled as a group, such as, the airline industry or as individual organizations, such as the individual airlines playing a role in evacuation efforts. In addition to understanding the impact of their roles in response, modeling this domain would also be needed if the objective is to study the financial and economic impact of large scale incidents.
- The final category of "other" is defined to include entities that don't clearly fit into one of the previous categories but may need to be modeled for specific cases. For example, it may be important to model farm animals for an attack on the food supply.

3.3 Life cycle phase

Incident management includes prevention, preparedness, response, recovery, and mitigation for emergency and disaster incidents [29]. The capabilities of the needed M&S tools may differ based on the incident management lifecycle phase they are designed for. Applications for the lifecycle phases in the incident management area are briefly described below.

3.3.1 Prevention

In the prevention phase, simulation-based applications can be used for vulnerability analysis and surveillance and detection. The vulnerability analysis applications would be focused on evaluation and assessment of physical security features and strategies, policies and procedures. M&S tools can be used to create a number of incident scenarios and evaluate the performance of physical security and strategies. The identified shortcomings can be reduced or eliminated. Examples of vulnerability analysis applications include evaluation of physical security and procedures at a nuclear plant and evaluation of cyber security for a government agency.

The surveillance and detection applications will include use of tools that study given scenarios and determine the possibility of the occurrence of an incident. Actions can then be taken to prevent or mitigate the occurrence. It is anticipated that such tools will use pattern matching on past history databases to identify and detect potential threats. Examples of such applications include selection of security sweep targets in areas with majority of inhabitants from a target background and identification of the potential for tornado occurrence given the weather conditions.

3.3.2 Preparedness

In the preparedness phase, simulation-based applications can be used for planning, training and systems testing. The planning applications will include tools for determination of impact of an incident 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 to focused issues such as aiding development of specific response procedures.

The training applications will include tools that allow training response 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 for a given situation. These tools may range from interactive simulations using a monitor to totally immersive gaming environments including data gloves, helmets and force feedback devices. Examples of training applications include first responder resource deployment decisions following an incident, and fire fighting.

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 a part is simulated in software while the 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.

3.3.3 Response

The response applications will include tools that evaluate the impact of an incident 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, and response to a chemical agent release in the atmosphere.

3.3.4 Recovery

The recovery phase will require tools that evaluate the long-term impact of an incident and recovery actions. During this phase M&S tools can be used for evaluating alternative restoration actions and strategies based on the current and projected impact. Results of simulation will allow determining the best course for recovery. Examples of recovery applications include decontamination of the area affected by a chemical agent release in the atmosphere, and restoration of the damaged infrastructure following an earthquake.

3.3.5 Mitigation

Applications for mitigation may overlap in function and scope with other lifecycle phases since mitigation measures may be implemented prior to, during, or after an incident [29]. For the purpose of the proposed framework, the mitigation lifecycle phase is defined to focus on post-incident activities. M&S application in this phase can be used to evaluate alternative loss reduction measures using the data for past incidents. They can also be used to estimate the losses avoided due to the presence of previous mitigation measures. Examples of mitigation applications include selection of measures for reducing losses due to terrorist attack at a chemical plant, and, estimation of losses following a flood in the absence of a dam built around the city center.

Figure 1 shows the concept of Framework for Incident Management (FIM). The three major dimensions described above form the three axes of the cube that is used to represent the incident management area. Each cell in the cube defines the management and/or impact of an incident type or a specific incident on a particular domain and the associated applications required in the phase defined along the lifecycle dimension. The cells will also include the modeling of results of actions by the entities within the domains. The location of the cell along the lifecycle phase dimension classifies the need for the affected domains.

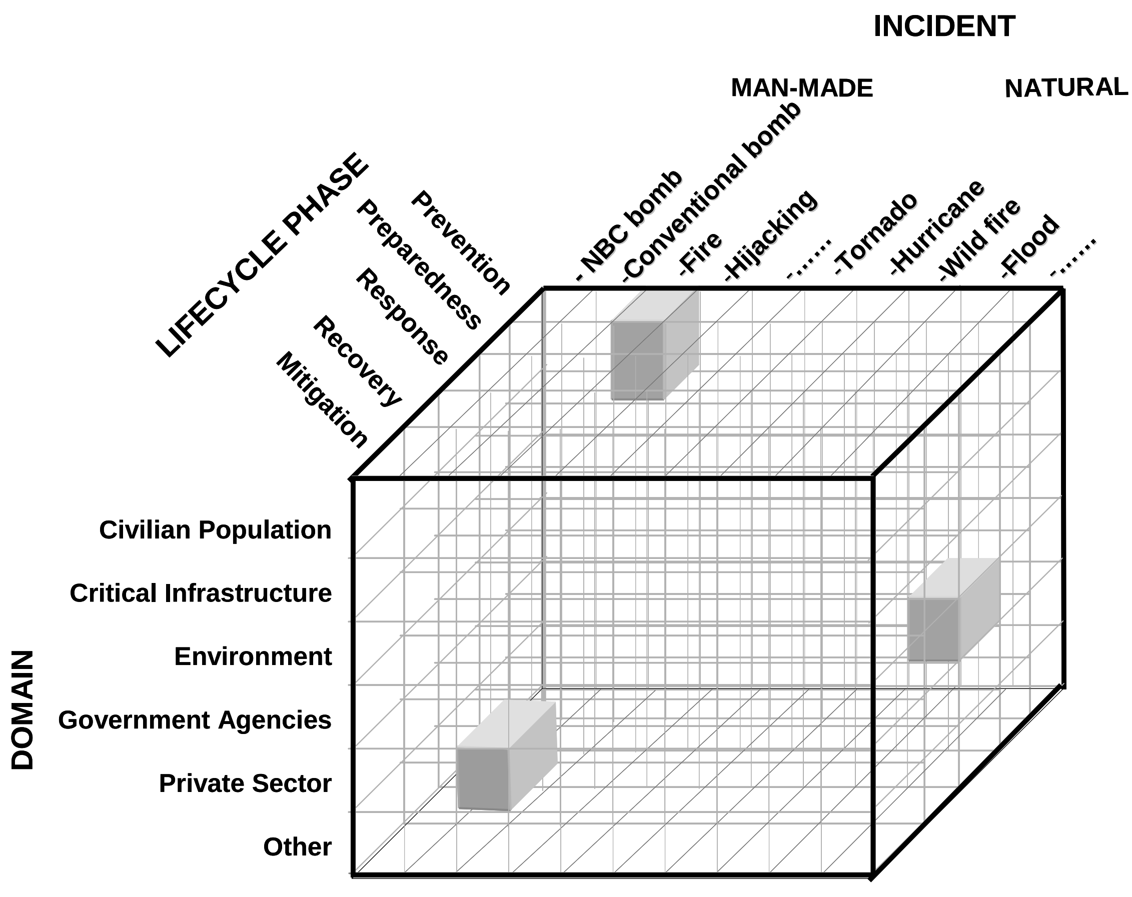

Figure 1. Framework for Incident Management (FIM)

The Framework for Incident Management also defines the framework for M&S as it defines the needs that M&S applications should satisfy. Each cell of the FIM defines needs that M&S tools can fill or support. For example, incident management may need to address the training requirements for government agencies for a fire disaster event in preparedness lifecycle phase. M&S applications can provide models that train people for various aspects of dealing with a fire emergency, such as determining the escape route, determining the means to put out the fire at individual firefighter level and at the fire company level. The framework thus captures the needs for M&S applications for incident management.

The framework also identifies the need for M&S applications for supporting an event at each phase in its totality. In the above example, M&S capabilities addressing each of the affected and involved domains can jointly provide the ability to analyze and support an event from a holistic viewpoint. The M&S capabilities for such a holistic approach may be provided in a monolithic application or more likely through a number of applications, each covering one or more of the entities within identified domains, integrated using a distributed simulation architecture such as the one proposed below.

4. Architecture

Simulation and gaming-based technologies can together provide a highly effective means for incident management training if integrated correctly using an appropriate architecture.

4.1 Requirements

The architecture for simulation and gaming for incident management training 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-level modeling of simulation and micro-level modeling of gaming modules.
- Control over execution of both simulation and gaming modules through a training manager 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 module components.

4.2 Concept

An architecture to meet the above requirements is conceptually presented in Figure 2. The architecture will have two major subsystems – one for simulation and the other for gaming. The simulation modules will each represent 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 communications infrastructure may be based on HLA. HLA is a standard, originally initiated by the DoD, for implementing distributed simulation [31]. In HLA terms, the individual simulations are called federates and the distributed simulation is referred to as a federation. The HLA defines a framework by which individually executing federates can be combined into a distributed simulation federation.

The HLA framework has three major parts. The first part is a set of rules that federates and federations must adhere to ensure that a federation operates properly. The second part is a software system called the Run Time Infrastructure (RTI). The RTI defines an interface that provides a number of services that federates can use to communicate (i.e., exchange simulation data), and coordinate their execution (i.e., synchronize simulation clocks) with other federates in a federation. The third part of the HLA is called the Object Model Template (OMT). The OMT provides a means for describing the format of the data that will be exchanged between federates. For more information on distributed simulation using HLA, see [33].

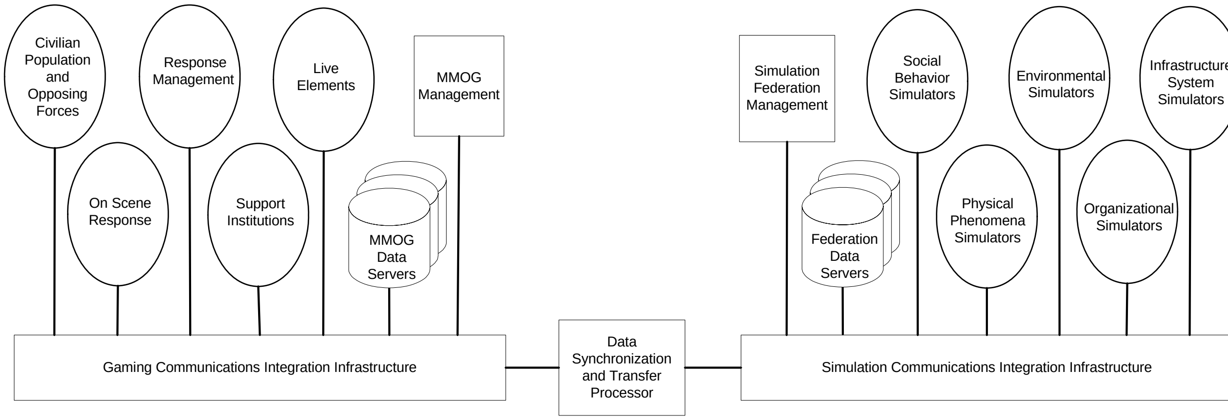

Figure 2. Architecture concept for Simulation and Gaming Incident management Training System

HLA may need to be enhanced to meet the requirements for the incident management training environment including the need to synchronize with the gaming subsystem. For example, a pre-definition of the Federation Object Model (FOM) representing all the objects used by federates is required by HLA. This requires a large set up time for creation of the federation. A distributed scheme similar to that used in [32] may be useful to reduce the set up time and thus enable plug compatibility.

The simulation subsystem will contain a number of modules within each of the groups shown in figure 2. The individual modules will model an aspect of the incident or response and will interact with other modules based on the scenario. The modules will also interact with the data servers and will be controlled by the simulation federation management. The data servers will include one for Geographical Information Systems (GIS) data. Such data will be used as input to simulation modules and for visualization of simulation outputs. All the interactions will go through the simulation communications integration infrastructure.

The gaming communications integration infrastructure may be based on the Massively Multi-player Online Gaming (MMOG) architecture. Traditionally, MMOGs have used a client server architecture. The massive scale of these games has led to distributing the server load on a set of machines arranged in a grid or a cluster. Similar to the HLA discussion above, the MMOG architecture will need to be enhanced to meet the requirements of incident management training and the need to synchronize with the simulation subsystem modules.

The gaming subsystem will also contain a number of modules within each of the groups shown in figure 2. Trainees will immerse themselves into the scenario using the modules as game clients. They may interact with other trainees on other game clients and with entities that are controlled by simulation modules. The gaming modules will also interact with the data servers for the required data to execute the games. The information would include the detailed 3-D descriptions of the locales at and around the location of emergency incident. The locale 3-D geometry data will be accessed as warranted by the simulated movement of the trainees around the simulated area. The interactions will occur logically in the game environment and physically over the gaming communications integration infrastructure.

The proposed architecture will allow the training 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 during Independence Day fireworks on the National Mall in Washington DC 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 (EMT), hazardous material (HAZMAT) professionals, hospitals, shelters and public transportation. A natural emergency event such as hurricane would require a different set of modules. The available modules in the proposed architecture can thus be configured to train incident management personnel across a range of scenarios.

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

4.3 Issues

Realization of the proposed architecture presents some challenges. The primary challenge is the development of mechanisms for communications and time synchronization between and among simulation modules and game modules. Major issues associated with distributed multi-player games are how and when players receive information on fellow players' actions. Time lags may occur between when a player initiates an action and when other players see the action. This latency causes problems in the execution of distributed games. The HLA RTI technology does not require the use of servers for centralized management of game data but uses time synchronization mechanisms that may be unacceptable in a game environment. In the HLA RTI world, simulators publish and subscribe to data objects to communicate. Simulations may be time-regulating or time-constrained.

An associated challenge is the management of the training of people from different levels of incident management hierarchy. The best mode for training the first responders using a game client is to execute in real-time (i.e., time progress in game environment same as wall clock time). The best mode for training the incident managers and other personnel operating in Emergency Operation Centers (EOCs) may be segments of real-time execution interspersed with accelerated time (i.e., time progress in simulation environment faster than wall clock time) and fast forwards (i.e., simulated time jumping to a few hours or a day later). This mode will allow the EOC team to train in decision making over few simulated days of an unfolding emergency event while spending only a day in wall clock time. Combined training of first responders and EOC teams would require careful orchestration of time segments and fast forwards.

Distributed simulation architectures have come a long way. HLA is the current standard architecture for the purpose. However, HLA has grown from the background of war games executed in real-time. While HLA has been used for accelerated time execution to some extent, it may be a challenge to achieve speedups of 10 times and above with the large number of modules envisaged for a full scenario training.

MMOG architecture is still evolving. There is no standardization in this field as each game provider is using its own proprietary architecture. An open MMOG architecture will need to be developed that would allow plug compatibility of different gaming modules. The architecture should also allow plug compatibility of components of the core game engine also.

Massively Multi-Player (MMP) functionality involves the use of servers and is widely used in the gaming world. Due to its success as a commercial mechanism for distributed simulation and gaming, it should receive serious consideration for incident management applications. There have been security vulnerabilities associated with MMP games that have allowed players to cheat therefore appropriate safeguard must enacted. For more information on MMP technology, see [34].

Software licenses for game development systems and game distribution are often quite expensive. Pervasive use of this technology will require that many contractors of the United States Department of Homeland Security will need access to licenses to develop training applications. Perhaps hundreds of thousands of game-based training applications will ultimately be distributed. Game engine developers often collect royalties on each game sold. If commercial game engine software is used, the traditional business models of these software vendors may need to change.

5. Subsystems

The architecture description in the previous section showed two major subsystems - simulation and gaming, each with a number of major groupings. This section provides descriptions of the two major subsystems and their major groups.

5.1 Simulation subsystem

The simulation subsystem includes simulators that model the major capabilities and phenomena involved in incident management as shown in Figure 3. Together these simulators will create the incident with all its major aspects and the responses by all the major agencies involved. The modeling of all the major aspects will capture the interactions, planned and random, that will create unanticipated situations that occur in the real world during an emergency incident. Thus the simulation subsystem will create the emergency incidents in the virtual world. The ability to represent the incident in the virtual world together with the associated major aspects and the creation of unanticipated interactions will provide a valuable training environment.

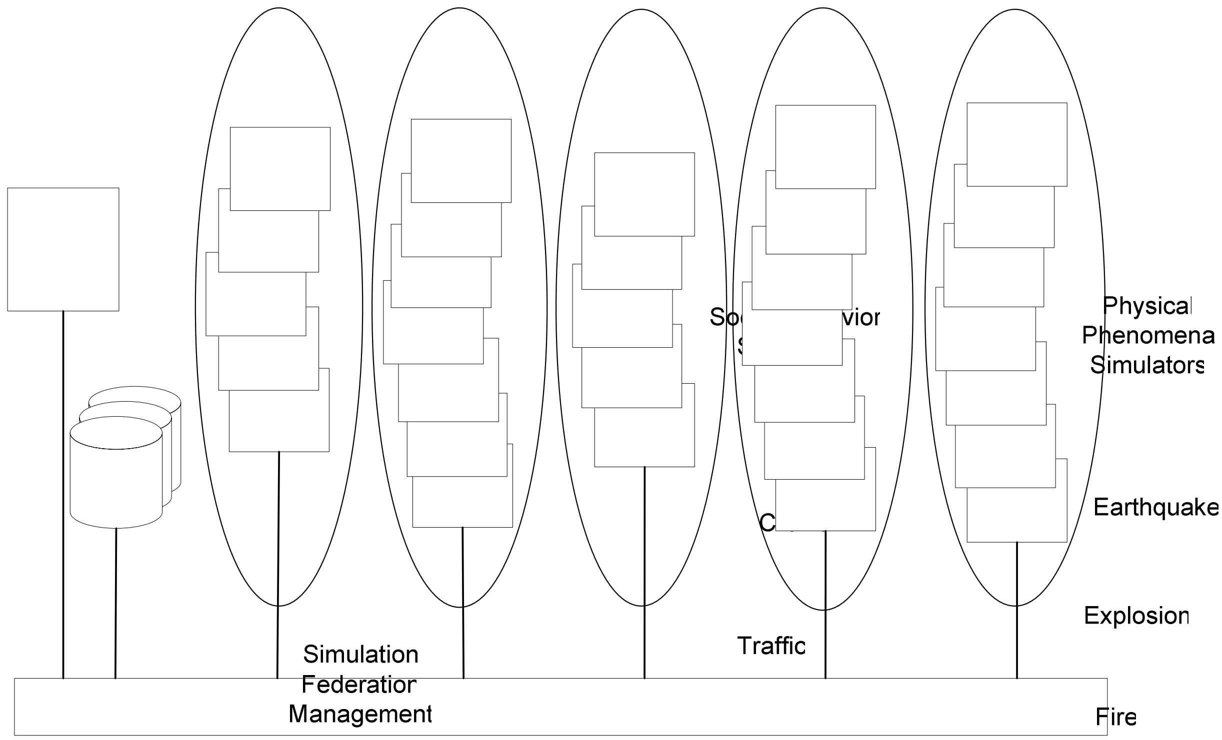

Figure 3. Simulation subsystem and its modules.

The simulators in the simulation subsystem will need to operate at a level appropriate to the training audience. It will be appropriate to simulate the incident and the response at a macro level for training of emergency managers if they are being trained alone. If only the emergency responders are being trained, the incident needs to be simulated at a micro level. To have both the emergency manager and responders experience the same incident a combination of simulations at macro and micro levels will be needed. For example, emergency managers would need to know the time it takes for response vehicles to get to an incident site. However they may not need to get into the detail of the traffic congestion they had to go through along the route to get there. The vehicle travel times can be determined through a macro level simulation that may require determining the route from dispatch point to incident site and determine the travel time based on the distance and congestion factors based on the time of the day. On the other hand, for training a responder in the same scenario, the actual drive may need to be modeled. The responding unit needs to experience going through the traffic and facing the movement of individual cars. A micro level simulation will be needed in this case.

The description of the simulators below provides a brief description of their capabilities. For brevity, the functionality at macro and micro levels is not discussed. An increase in level of detail from macro to micro simulation similar to the traffic simulation example above can be envisaged. Each of the modules should include capability for empirical and detailed simulation.

5.1.1 Social Behavior Simulators

The social behavior simulators will simulate phenomenon based on actions of multiple individuals. These include modeling of crowd, traffic, epidemic and consumer behavior. Other additional modules may be defined for social behaviors that are needed for specific situations. Each of the defined modules involves interaction of individuals leading to a collective behavior or phenomena. These models are individually described below.

1. *Crowd Simulation* should model crowd status and movement at locations of interest under different event scenarios, crowd behavior and crowd management strategies. The locations of interest may include areas around actual and potential emergency incident sites, major business, commercial and residential areas that may be affected by evacuation directives, and major public transportation points such as bus and train stations, local rail transport stations, and airports. Different event scenarios may include normal, rush hour,

terrorist attack, accidental fire, natural disaster, etc. The models may predict crowd movement and crowd density variations along movement directions, predict occurrence of stampede and casualties, perform route planning through the crowd for selected individuals (such as first responders), determine location of individuals as a function of time, predict individual movement times between selected points. Inputs may include street layouts including pedestrian areas, layouts within public buildings such as train stations and public parks, crowd volumes and density data, probabilities for stampede and casualties, weather conditions, location of emergency incidents, behavioral models of individuals, sensor data, and communications. Outputs may include location and status of specific individuals in the crowd, crowd volumes and density by city block and passages within public buildings and parks, crowd movement times between selected points, and crowd management systems data.

2. *Traffic Simulation* should provide models of general traffic flow and specific vehicle movements for a given region under different event scenarios (normal, rush hours, off-peak hours, terrorist attack, natural disaster, evacuation, etc.), driver behavioral models, and traffic management strategies. The model may perform automatic route planning for selected vehicles, generate random events that disrupt traffic flow (vehicle breakdowns, accidents, traffic management system failures), determine vehicle locations as a function of time, predict travel times between locations, etc. Inputs may include road network layout and characteristics, traffic management system description and status, individual vehicle locations and status, driver moods, historical traffic volume and vehicle density data, pedestrian data, probabilities for accidents, incidents, weather conditions, location of emergency incidents, behavioral models of vehicle operators, sensor data, and communications. Outputs may include locations and status of specific vehicles, traffic volume and densities by area or road segment, travel times between selected locations, accident data, and traffic management system data.

3. *Epidemic Simulation* is included within social behavior simulation as the spread of epidemic is highly dependent on social interactions. This component should provide models on the spread of epidemics in a given region for different types of diseases under various initial conditions (exposure at public place such as shopping mall, at an event with a large gathering such as football games, at public schools etc) and under different public awareness scenarios (normal, heightened following the news of epidemic, very high following the imposition of movement restrictions by authorities). Inputs may include the demographic distribution in the region of interest, population interaction parameters, likelihood of epidemic spread under different conditions, strategies by health agencies for vaccination and containment, strategies by government agencies for public information and containment, and weather conditions. Outputs may include a time profile of the spread of an epidemic and resulting need for health care, law enforcement and other services.

4. *Consumer Simulation* should model consumer behavior following the occurrence of an emergency event. It will model such phenomenon as stocking of food, fuel and other essential supplies and resulting shortages. The shortages can in turn lead to rioting situation unless checked. Inputs may include perceived and actual impact on essential supplies following an emergency event, consumer behavior patterns, demographic information together with purchasing power profiles, number, location, operating hours and inventory status for outlets of essential supplies. Outputs may include time profile of availability of essential supplies, consumer sentiment and behavior.

5.1.2 Physical Phenomena Simulators

These simulators will model the physical phenomena involved in the creation and growth of the emergency incident. These may include such physical phenomena as earthquake, explosions, fire, chemical, biological or radiological plume, etc. These simulators will provide the extent of the damage while other simulators may model the impact of the damage on the associated systems. For example, the earthquake simulators will predict the extent of damage to the road network; the transportation system simulator will model the impact on transportation at a high level while the traffic simulator will simulate the impact on traffic resulting from the damaged road network at a detailed level. The simulators described below include the major physical phenomenon relevant to incident management. Other modules may be defined as needed.

1. *Earthquake Simulation* should provide modeling of an occurrence of an earthquake, the resulting damage to physical structures and associated casualties. Inputs may include description of critical infrastructure elements in the region of interest, their vulnerability to earthquakes, the description of major buildings and facilities and their human occupancy profile for different times of the day, the probability of occurrence of earthquakes of different magnitudes, the location of other assets of interest (vehicles, etc.) inside and around the structures. Outputs may include the identification of region affected by earthquake, the damage to different elements of infrastructure (road network, power distribution, communications, etc.), the damage to buildings and facilities, the number and kind of human casualties in the affected region, identification of damaged assets and the extent of damage.

2. *Explosion Simulation* component should model the damage to structures and casualties resulting from explosions of different magnitudes. The structures may include critical infrastructure elements such as bridges, dams, power stations and communication towers, public facilities such as train stations, malls, and office buildings and structures of national significance such as monuments. Inputs may include description of physical structures, their vulnerability to explosions of different magnitudes, human occupancy profiles for different times of the day, the location of other assets of interest inside and around the structures. Outputs may include the identification of structures affected by the explosion(s), the damage to different elements of infrastructure (road network, power distribution, communications, etc.), the damage to buildings and facilities, resulting fires in the structures considered, resulting plumes from the explosion, the number and kind of human casualties within and around the affected structure, identification of damaged assets and the extent of damage.

3. *Fire Simulation* should simulate the damage to structures and casualties resulting from fire. The structures may include critical infrastructure elements and public facilities as listed above. Inputs may include description of physical structures including characteristics relevant to spread of fire (contents and inflammability), initiation and location of fire (accidental, intentional with fire accelerants, fire bombs, explosions, etc), human occupancy profiles for different times of the day, location of other assets of interest inside and around the structures, and weather conditions. Outputs may be similar to the two modules in this group discussed above.

4. *Plume Simulation* should model the dispersion of plumes of various kinds including chemical, biological and radiological agents. Inputs may include the characteristics of the agent released, release mechanism used, the location of release point, terrain and structures around the release point, and weather conditions. Inputs may alternately be based on the sensor readings over time in the area of interest indicating the presence of an agent and the direction(s) of the spreading plume. Outputs may include time profile of the plume, and exposure profile for the population in the region affected by the plume over time.

5. *Disease and Bio-agents Simulation* should simulate spread of diseases and bio-agents based on physical phenomenon, such as release of a bio-agent using a crop duster plane over a populated area. For some diseases, this component may model the initial spread of the disease based on physical phenomenon followed by the use of epidemic simulation component to model further spread of the disease based on social behavior. Inputs may include the characteristics of the disease virus, bacteria or bio agent, method of release or introduction of the agent into the environment, location of release point, demographics of the region of interest including the vulnerability to the particular agent, and weather conditions. Outputs may include the spread of the agent and exposure profile for the population over time.

6. *Biotic Invasion Simulation* should model the spread of biotic invasions such as malicious introduction of predatory species into the local environment with significant economic impact. Inputs may include the characteristics of the species, the description of land or water mass where the species was introduced, the land and water system interconnections, the population of local species that may be affected by the predatory species, and characteristics of efforts to stop the spread of the predatory species. Outputs may include the spread or decline of the biotic invasion over time.

5.1.3 Environmental Simulators

These simulators will model the environmental phenomena that may affect the growth or containment of the emergency incident, its impact on the population or the efforts by responding agencies. Such environmental phenomena include weather, watershed, indoor climate, and ecology. These simulators will model these phenomena and provide the outputs to other simulators for modeling the impact. For example, the weather simulator will model the weather pattern over the duration of simulation; the fire simulator will model the growth or reduction in the fire due to weather conditions, while the fire department simulator will model the impact on fire fighting efforts due to weather conditions. These simulators are described below.

1. *Weather Simulation* should model the weather conditions during the simulation horizon. Inputs may include the initial conditions and the probability of incoming weather systems of different types (clouds, storms, winds, etc.). Outputs may include the change in weather conditions over the simulated horizon including wind speeds and directions, temperature, pressure changes, and precipitation.

2. *Watershed Simulation* should simulate the watershed systems of the region of interest and its impact on the growth or containment of the emergency incident. This component will be needed for incidents such as release of toxic agents in water systems by terrorists, or release of predatory foreign species. The inputs may include the description of watershed systems in the region of interest, the links and flows between different parts of the watershed system, and the weather conditions. The outputs may include the spread of the introduced agents or species through the watershed system.

3. *Indoor Climate Simulation* should model the climate systems within buildings and other structures occupied by people. This component should simulate the spread of air-borne agents introduced through indoor climate systems. Inputs may include the description of the duct systems including the intakes and vents, the capacity of the system, the location and sizes of door, windows and other openings, the method of introduction of air-borne agents (through air intake, through windows, doors), the characteristics of the air-borne agent and the occupancy profile of areas of the building/structure. Outputs may include the spread of the agent through the building/ structure over time and the extent and number of people exposed in different areas.

4. *Ecology Simulation* should simulate the ecological system in the region affected by an emergency incident. For example, this component should model the effect of a toxic plume on the ecology of the area exposed. Inputs may include the characteristics of the toxic released in the region of interest, the composition of the ecology of the area including the landscape, watershed, plant and animal species in the area, and the weather patterns. Outputs may include the time profile of impact on the ecology due to the release of the toxic.

5.1.4 Organizational Simulators

These simulators will model the actions of the organizations involved in any aspect associated with the incident. The organizations modeled may include the fire, law enforcement, health care, other government agencies and the terrorist organization. The simulator will model the flow of information within the organization, flow of authority and decisions and the resulting actions. It will utilize the relevant policies and procedures to model the behavior of the organization and its members. These simulators are described below.

1. *Fire Department Simulation* should simulate the actions of the fire department in response to an emergency incident including the assignment of resources for response, the actions of the fire crew at the incident site, handling of any casualties among fire crew and any subsequent requests for additional resources. The model will determine the resources assigned based on the incident, and predict the time required to accomplish the rescue and/or subdue the fire. Inputs may include the description of the emergency incident (location, magnitude, etc.), the time profile of the incident (determined by other simulators such as the growth of a fire by the fire simulator), the number of people trapped inside the affected structure, the number and profile of assets of interest within and around the affected structures, the information available from the associated 911 call, availability of fire department resources at responding locations, probability of fire crew casualty associated with incident magnitude and the affected structures, and directives from

law enforcements (such as presence of terrorists at the site preventing the fire crew from entering the incident zone). Outputs may include the number of people rescued from affected structure, the response time by the fire department, actions taken and the injuries suffered by the fire crew. Other simulators such as the fire simulator may model the impact of actions of the fire crew. For example, the fire department simulator will model the number of water hoses pointed at the fire, while the fire simulator will model the reduction in the spread of fire based on the water delivery rate and the magnitude of the fire. The two simulators will thus interact closely to model the unfolding events until the fire is put out completely.

2. *Law Enforcement Simulation* should model the actions of law enforcement agencies in response to an emergency incident including the assignment of resources for response and investigation, the actions of personnel at the incident site including engaging in any shootouts and high-speed chases against terrorists, and request for additional resources based on the unfolding events. This component will thus model the action of multiple agencies involved in law enforcement including police department and the Federal Bureau of Investigation (FBI). The model logic will include the relevant policies and procedures to determine the roles and responsibility of the involved agencies. Inputs may include the description of the emergency incident (location, magnitude, etc.), the time profile of the incident (determined by other simulators such as the terrorist actions by the terrorist organization simulator), the number and location of civilians involved (such as hostages held by terrorists, the number and profile of other assets of interest within and around the affected structures, the information available from the associated 911 call, availability of law enforcement resources at responding locations (personnel at different skill levels such as sharp shooters, vehicles, weapons, etc.), probability of law enforcement personnel casualty associated with incident nature (shootouts, use of explosive, falling structures due to earthquake aftershocks), and information from other response organizations (such as magnitude of fire preventing law enforcement officials from entering a burning structure). Outputs may include the actions by the law enforcement agents over time including response times of different agencies. The impact of the actions may be determined through interactions between the law enforcement simulators and other associated simulators such as terrorist organization simulator, traffic simulator and crowd simulator.

3. *Health Care Simulation* should model the actions of the health care organizations (including emergency medical technicians, hospitals) in response to an emergency incident including the deployment of resources and actions for triage and treatment of injured at the incident site, movement of casualties to hospitals, and treatment at the hospitals. The model logic will include relevant policies and procedures for emergency situations including calling in medical staff, using temporary accommodations for the injured, acquiring needed supplies and equipment. Inputs may include the number, location and type of casualties from an emergency incident, the availability of staff at work and off (on-call), the availability of resources (own and those that can be acquired quickly from surrounding jurisdictions), the time and resources required for attending to each casualty type, and the probabilities of death from different casualty types over time. Outputs may include the operation of the health care system over time including the number of people treated and released, admitted, dead, waiting for treatment, and the state of the staff and facilities (to determine their capability to deal with another incident).

4. *Government Agencies Simulation* should model the operations of local, state and federal government agencies that are involved in incident management including state emergency management agency, Federal Emergency Management Agency (FEMA), Department of Health and Human Services (HHS), Center for Disease Control and Prevention (CDC). This component should simulate the actions of the government agencies. For example, it should model the processes and procedures followed by a state emergency management agency for organizing resources for various emergency support functions. The execution of the emergency support functions including communication, warnings, emergency public information, evacuation and mass care should be modeled. Inputs may include the role, processes and procedure followed by the agency and the number, characteristics and location of resources under its purview. Outputs may include the results of actions of the agencies modeled including the availability of emergency services to affected population over time.

5. *Military Simulation* may be used for modeling military operations when the magnitude and nature of the incident requires military deployment. In particular, military resources may be requested in response to a Weapons of Mass Destruction (WMD) incident. This component should model the actions of the military

to support the response effort. It should model the military support in arenas such as decontamination, medical support, rapid mobilization and mass logistics. Inputs may include the role, processes and procedure followed by the military and the number, characteristics and location of its resources. Outputs may include the results of actions of the military over time including such metrics as number of people decontaminated, number of casualties processed by the medical support team and people evacuated.

6. *Terrorists Simulation* should model the actions of terrorist organizations for setting up and carrying out primary and secondary attacks. It should have the ability to model a range of attack scenarios including suicide bombing, use of WMD devices, conventional explosives, release of biological and chemical agents, and armed attacks. Inputs may include the primary and alternate action plans, the number and roles of terrorist resources, the number, type and location of resources available to the terrorist organization, and the level and percentage of sympathizers to the terrorist cause around the area of planned attack. Outputs may include the results of the terrorist actions defined by damage to critical infrastructure, damage to structures of significance, civilian and military casualties, terrorist casualties, and terrorist arrests.

5.1.5 Infrastructure System Simulators

These simulators will model the behavior of the infrastructure systems following the occurrence of an emergency incident. They will model the propagation of the impact of damage through out the infrastructure system based on the damage to one part due to the emergency incident. For example, the earthquake simulator may predict the destruction of food warehouses in the affected region. The food supply simulator will model the diversion of food shipments from other regions to the affected region. These simulators are described below.

1. *Food Supply Simulation* should model the behavior of the food supply infrastructure including the movement, storage and distribution of food supply to affected population. The model will be used to predict the time for supply of food shipments to affected areas, the deterioration of food supplies in storage, and the shortages. Inputs may include the damage to the food supply infrastructure, the availability of food supplies in the surrounding regions, probabilities of disruptions in food supply, probabilities of deterioration in food supplies, and the resources available for food supply distribution. Outputs may include the profile of food supply over time to the affected region. A crowd simulator, for example, may use the outputs from this simulator to model rioting situations caused by food shortages.

2. *Power Distribution Simulation* should simulate the behavior of the power distribution infrastructure including the interruption and restoration of power supply to regions affected by an emergency incident. The model will be used to predict the behavior of the power grid following damage to one part, to determine the application of resources for restoration and to determine the time for power restoration. Inputs may include the description of power grid with its characteristics, the vulnerabilities in the power grid, and the resources available in immediate and surrounding regions. Outputs may include the profile of power supply and outages in the affected region over time.

3. *Water Supply Simulation* should represent the behavior of the water supply infrastructure including the interruption, restricted operation and restoration of water supply to regions affected by an emergency event. It should also model the impact of a terrorist attack on the water supply system such as contamination of water supply. Inputs may include the description of the water supply system including the water sources, the collection, filtration and distribution system, the operation and maintenance resources available, the links to other critical infrastructure systems including power distribution, road and rail networks. Outputs may include the volume and quality profile of the water supply in the affected region over time.

4. *Transportation Simulation* should mimic the transportation system infrastructure including highways and road network, rail network, waterways, marine and air transport. It should model the impact of man-made or natural disasters on the transportation infrastructure components. Inputs may include the description of the transportation system infrastructure together with its network, characteristics of node points, traffic volumes across arcs and through the nodes, traffic control mechanisms, failure characteristics of major control mechanism and equipment, operation and maintenance resources, multi-modal links and links to

other critical infrastructure. Outputs may include the impact of modeled emergency events on the operation of the transportation infrastructure over time.

5. *Communications Simulation* should reproduce the impact of emergency events on simulated communications infrastructure including wired and wireless telephone links, microwave and satellite based communications, and radio and television broadcasts. Inputs may include the description of the communications infrastructure together with the locations and types of assets such as phone lines, communication towers, radio and televisions stations, links to other critical infrastructure, failure characteristics, and operation and maintenance resources. Outputs may include the impact of modeled disaster events on the operation of the communication infrastructure over time defining interruptions, limited operation and restoration to full operation capabilities.

6. *Computer & Networks Simulation* should model the computer and network operations under the impact of the modeled emergency events including any cyber-attacks. Inputs may include the description of the computing and network infrastructure together with the security mechanisms used, reliability information, links to physical components and critical locations, procedures for creating and using back-up systems, and operation and maintenance resources. Outputs may include the impact of the modeled event or cyber-attack on the operation of the computing and networking infrastructure over time describing the interrupted capabilities and operations, limited operations, loss of data, restoration of data, and restoration of the systems to full operation capabilities.

5.2 Gaming Subsystem

The purpose of the gaming subsystem is to provide an immersive incident management environment in which users, i.e., players can interact with each other, and with simulated systems and organizations described in the previous section. The video game development community has become a leading innovator in the use of graphics, audio, and force feedback to create virtual worlds. Multiplayer game technology allows many players to interact in the same virtual world across the Internet. As such, it is only natural to look to the technology leaders for solutions to creating the front-end interface to a virtual incident management environment.

Elements of the video game-based training systems would include, where appropriate, real-time computer generated graphics and audio. Objects represented would include the environment, the incident scene, various emergency response vehicles, affected population, equipment, emergency responders, etc. Emergency responders would include various characters that represent the fire department, urban search and rescue, health care, law enforcement and terrorists. Physics models and artificial intelligence would be used to give objects physically correct behaviors and movements, or enable them to act autonomously without human intervention.

The game engine, associated simulation modules, and reusable learning objects would be tested for security and certified by appropriate testing facilities (please see [35] for definition of reusable learning objects). The software would be secure and prevent the introduction of any security holes, viruses, worms, etc. onto the trainee's computer. The software also would not allow the student to achieve any unauthorized access to the host computer system areas or other networked systems as a result of the installation of the simulation-based training application.

Simulation-based learning applications could be developed for use in stand-alone mode or distributed multi-player mode to enable team training. Multi-student training applications would need distributed simulation capabilities to synchronize the software running on different platforms. Servers would be needed to store and distribute data to support these training exercises.

What functions does the gaming subsystem need to provide? Some of the key functions that need to be supported:

- Allow the creation of different game genres such as strategy, role-playing, and puzzle solving based on individual training needs
- Provide user interfaces that allow a variety of user input devices
- Animate characters and other objects
- Render graphics scenes, generate audio, and provide force feedback
- Sequence all processes in a timely fashion
- Implement intelligent behaviors for both player and non-player characters
- Coordinate multi-player game play across the Internet

- Enable user modifications, commonly referred to as “modding” in the computer gaming community, of the game environment through high level scripts
- Compile high level scripts into more efficient low level code
- Manage user sessions and security
- Provide a central repository for game assets or resources

Figure 4 shows the major elements of the manufacturing gaming subsystem, i.e., clusters of game applications, game management, data servers, and communications infrastructure. The next sections discuss these elements in more detail.

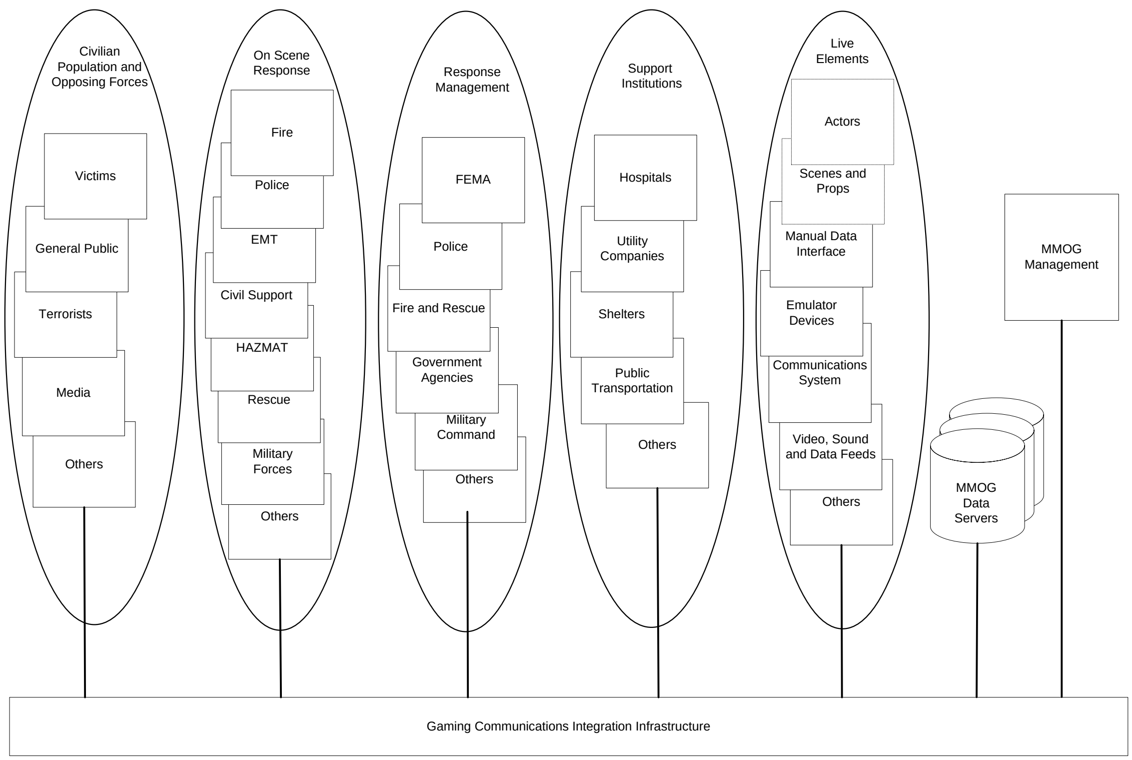

Figure 4. Gaming subsystem and its modules.

5.2.1 Game Applications

Incident management gaming applications should be created to support the roles that users may need to play during an incident for training purposes. Five groups of roles and game interfaces have been initially identified as shown in figure 4. Other roles and interfaces might also be defined in the future. Each group is briefly described below:

- *Civilian Population and Opposing Forces* – Allows players to assume various roles of the civilian population affected by an incident and the opposing forces that may be involved in the case of a man-made incident. The opposing forces, that is, the terrorists, would normally mingle within the civilian population and may require several features that are common with other entities in this group. Some of the possible roles in this group include victims, general public, terrorists, and media personnel.

- *On Scene Response* – Players take on the roles of responders on an incident scene. They should be able to execute response tasks such as securing the perimeter of the affected area, crowd control, attending to victims, identify continued threats, and containing spread of fire. Some possible roles include fire, police, EMT, civil support, HAZMAT, rescue, and military personnel.

- *Response Management* – Players assume the roles of management personnel of the responding agencies. They should be able to participate in a simulated Emergency Operations Center setting, have access to information and displays similar to a real life EOC at the appropriate level (local, state, federal), and make and communicate decisions. The decisions may be communicated to simulations executing the responses or to other players playing the role of first responders at the scene of the incident. Some possible roles include Federal Emergency Management Agency (FEMA), police, fire and rescue, other government agencies and military command.

- *Support Institutions* – These roles and interfaces allow the players to execute tasks carried out by personnel of institutions that play a supporting role in incident management. Players may treat victims at the emergency department, perform repairs on utility services affected by an incident, set up a shelter for people affected by an incident, set up and run transportation services for evacuation, etc. The possible roles include hospital, utility services, shelter, and public transportation.

- *Live elements* – The roles and interfaces enable the incorporation of live game play (outside of the virtual world), video feed, external communications channels, etc.

The above list of player roles and interfaces is only intended to be a sampling of what is possible. A game-style interface could be devised for almost any role within an incident management setting. Incident management resources include many case study scenarios that could form the basis for engaging game interactions in each of these areas.

5.2.2 Core Game Engine

The Core Game Engine (CGE) provides the basic functionality required to play video games in stand-alone mode and in distributed mode using remote servers, and networks. The CGE executes the game content, outputs graphics to display devices, sound to speakers, and receives user input from different types of peripherals. The architecture of the CGE defines its major modules and the relationships of those modules to each other.

Figure 5 illustrates the major modules of the CGE and their general relationships to each other (Client Interface Module is not shown). The component modules of the CGE are briefly described below:

- Game Content Module (GCM) - consists of the scripts and objects of a particular game-based training application that are created by the content developer.
- Supervisory Controller Module (SCM) - provides an operating system that sequences processes and executes game content scripts and other internal subsystem functions.
- Script Interpreter-Compiler Module (SICM) - translates game content scripts into an internal computer program that invokes internal system services and functions of other modules within the game engine
- User Input Module (UIM) - processes and redirects user inputs from various peripheral devices
- Data Management Module (DMM) - provides support functions for maintaining and accessing shared data
- Data Import/Export Module (DIEM) - moves and translates data between external files and internal data stores
- Artificial Intelligence Module (AIM) - performs various decision-making or problem-solving processes that are normally associated with human or animal intelligence
- Physics Module (PM) - models behaviors of objects associated with various physical phenomena, e.g., collisions, gravity, buoyancy, aerodynamics
- Animation Module (AM) - manipulates various characteristics of objects over time to effect graphic, audio, and force renditions
- Graphics (GM), Sound (SM), and Haptics Modules (HM) - output information to displays, speakers, and force feedback devices
- Client Interface Module (CIM) – provides mechanisms for synchronizing timing and data interactions with other players via communications networks and remote data servers.

The development of the game engine architecture was carried out in collaboration with the U.S. Naval Education and Training Command to support the Navy’s future simulation-based training needs. For a more detailed discussion of the game architecture, see [36].

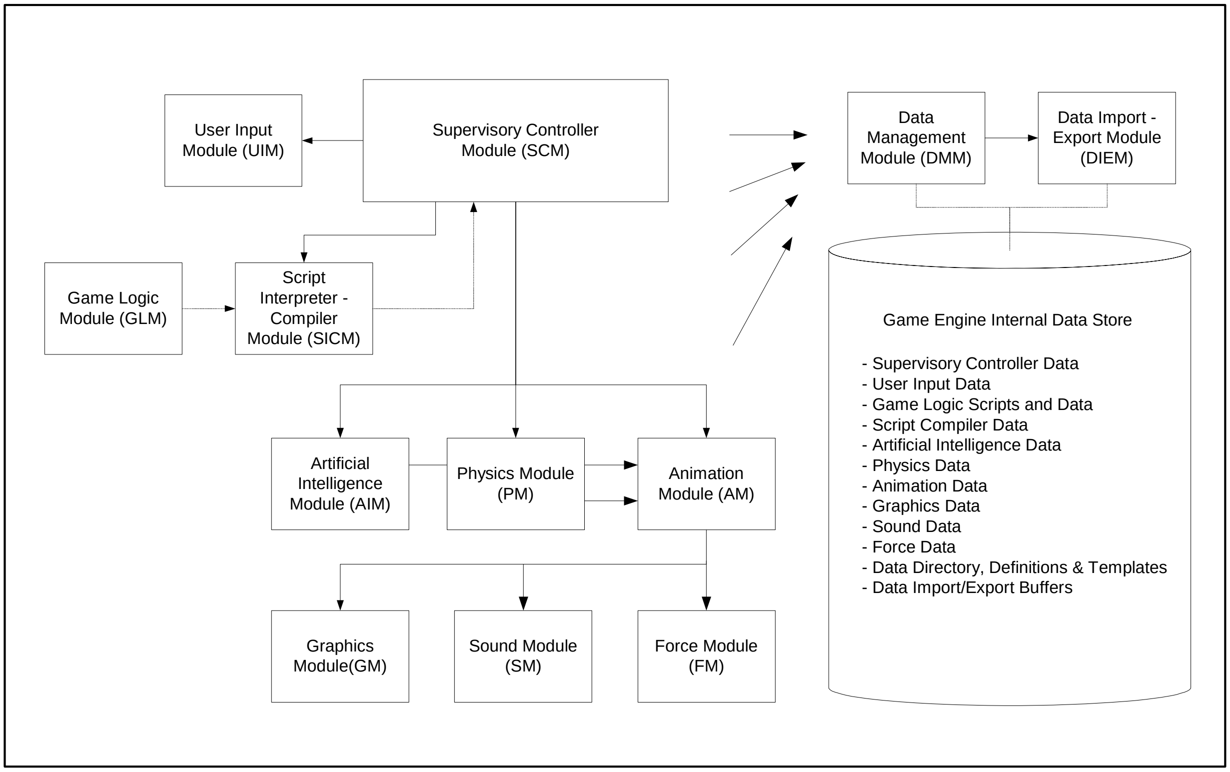

Figure 5. Major modules of the core game engine and their general relationships to each other.

5.2.3 Game Integration Infrastructure

Unlike distributed simulation, there is no standard for integrating distributed multi-player games. In the simulation world, a number of implementations of the HLA Run-Time Infrastructure (RTI) have been developed. In order to integrate a set of distributed simulations, one vendor's RTI implementation must be selected and software must be adapted to work with that RTI.

In the game world, there is no standard approach corresponding to the HLA RTI that can be used to integrate multi-player games. For various reasons including cost, performance and complexity, the HLA RTIs have been considered unsuitable by game developers. Perhaps the primary reason that the game world has been less than enthusiastic about HLA is their need for real-time performance. HLA can help guarantee that simulations behave in a technically correct manner, e.g., messages arrive at recipient in proper order, but in doing so HLA implementations may sacrifice efficiency and performance to achieve technically correct behavior. Also in the HLA world, there is no requirement for centralized control or persistent data storage. Multi-player games typically need to centralize control and maintain game state data for long periods of time.

Although a common gaming integration infrastructure does not exist, there are some features that are typically used to integrate multi-player games. Features that will be briefly discussed include the client-server interaction model, proxies, arbitration, and socket-based communications.

- *Client-server interaction model* – The primary mechanism used for integrating multi-player games today is the client-server model. Peer-to-peer games have been implemented in the past, but it is unlikely that they will be used in the future. Players do not communicate with each other, but rather with the server. The client-server model is capable of supporting a large number of players, where the peer-to-peer model does not. In client-server game implementations, the server acts as a centralized control point for the game. Game action takes place on the server, but is reflected in the player's display on the local platform. The server is responsible for determining the advancement of time.

- *Proxies and arbitration* – The characters and action that the player views on the local platform is just a proxy for the real characters and actions that exist on the server. When the player moves a proxy character on the local platform, the server must verify that the move is acceptable. The server can later adjust the movement and location of the character, if it determines that the move is not right. An action taken by a player on the local platform must be confirmed by the action on the server. The server as an arbitrator of game interaction and is the ultimate authority on determining game state. For example, if two players are involved in a battle, the server ultimately determines who wins and who loses.

- *Socket-based communications* – The most common mechanism used for communications between clients and servers in multi-player games are sockets. A socket is an endpoint of a two-way communication link between two programs running on a communications network. A socket is bound to a particular port number on a networked computer. The client and server programs write message packets to the socket for delivery to each other. Sockets guarantee the delivery of game data packets across the Internet.

It appears unlikely that the integration infrastructure requirements of the gaming and simulation worlds will be reconciled any time soon. For the purpose of the proposed reference architecture, a separate local integration infrastructure has been identified for each world. A bridge has been defined to join the two worlds, i.e., simulation and gaming. The bridge does not guarantee that the two worlds can be successfully integrated in all circumstances. Time synchronization between the two worlds is perhaps the major problem. If the simulation world can keep up with real-time or generate and store data in advance of game play, integration may be achievable. If a game is turn-based, its performance requirements are not severe, or its execution can be slowed for synchronization purposes, integration may also be achievable. Otherwise, a mutually acceptable integration solution must be found between the two worlds.

5.2.4 Game Management and Data Servers

Because of the extensive use of the client-server-computing model in multi-player gaming, data servers perhaps play a more important role in gaming than they do in simulation. Servers are needed to establish connections for players joining a game session, manage and distribute content, and maintain game state and arbitrate interactions between game players.

These servers may be implemented using the relational, object-oriented, or web-based technologies. In addition to the purely game-based servers, two other types of servers may be used to support educational games: learning content management system (LCMS), and learning management systems (LMS) servers. Each of the four major types of gaming and educational servers is described below:

- *Game Connection Server* – Large multi-player games may require multiple game world servers to run concurrently in order to support the large number of players involved. Rather than connect directly to the game world, the player first contacts a connection server that acts as operator. The connection server validates the player's identity and routes the player to an appropriate game world server. As such, the connection server may perform load balancing to ensure an appropriate number of players are being supported by each game world server.

- *Game World Server* – The game world server is typically a powerful computer that hosts the game for many players. It is responsible for maintaining game state data for all players. It maintains persistent data between game play sessions. It arbitrates interactions between players. It provides security mechanisms to ensure that players cannot hack or unfairly manipulate game play. Game world servers may divide the regions of game play into cells. As players move around the world, they may move into different cells and be routed to new servers. As programmers update game worlds over time, the preferred approach is to patch the code on the servers rather than on client computers. This simplifies software updates since code does not need to be distributed to clients, rather only game world data is transferred.

- *Learning Content Management System Server* – The LCMS is a development environment where multiple learning content authors can create, store, reuse, manage, and deliver digital learning content. The LCMS provides a central repository for the storage and retrieval of learning content objects. The LCMS may include Learning Management System (LMS) and Course Authoring System (CAS) functions. The LCMS may also interact with external LMS and CAS systems developed by other software vendors.

- *Learning Management System Server* - The LMS server is a system for managing learners, keeping track of their progress and performance across all types of training activities. Other functions of the LMS may include publishing a catalog of course offerings, providing communications connectivity and interact with the LCMS to obtain course content, providing access control to courses including mechanisms for course enrollment and checking of prerequisites, managing personalize learning plans, launching and tracking progress on learning applications. It also provides instructor interfaces for grading, retaking courses, setting up courses, maintaining transcripts for the student population, taking required tests and assessments online, track student progress, scores, completion, etc. The LMS may also enable collaboration and communication between students and instructors, and enable virtual classrooms. It also may provide an Application Programmer's Interface to enable interactions between courseware and the LMS.

5.2.5 Game Information Model

A common information model will help facilitate integration of gaming systems with each other and with incident management simulators. Currently no such model exists. If a common model did exist, developers working on different aspects of a game development could reasonably expect to be able to share information with modules created by other developers. NIST staff has begun to identify the major kinds of data that would be required in a common incident management information model, as well as the data required to support game-based training in two other application areas, i.e., manufacturing and Navy training applications. At the highest level, the major types of data required for gaming within the core game engine and/or on the server include:

- *Supervisory controller data* – information about internal game processes and scripts, priority, and status.
- *User input data* – information about the configuration of user input devices (e.g., game controller, keyboard, mouse, camera), input data stream, and status.
- *Game scripts and data* – structures to store program and data information such as game levels, objects, game world and character state in languages used for game scripting, including Python, Lua, Ruby, Perl, and C++
- *Script compiler data* – data structures used in the translation of high level scripts into low level executable code
- *Artificial intelligence data* – data structures used to model intelligent behavior and decision making processes based on various techniques such as finite state machines, genetic algorithms, fuzzy logic, and general problem solvers
- *Physics data* – various physical parameters of game objects and the environment including geometry, mass, location, and velocity
- *Animation data* – animation plan, key frames definitions, interpolation parameters, motion and morphing algorithms and data
- *Graphics data* – scene structures, object geometry, textures, lighting, special effects such as smoke and fog
- *Sound data* – audio clips, playing parameters, audio source location, environmental parameters, special effects
- *Force data* – force feedback, vibration, etc.
- *Data import/export buffers* – directories and files, file types, translators, mapping of file data to internal data structures

The above list of data types is not exhaustive, but is indicative of the various types of data that must be incorporated into a common information model that supports gaming.

6. Modes of operation

The architecture described above can be used as the basis for development of a Simulation-based Incident Management Training system (SIMTrainer). Such a training system can provide for the needs across multiple domains in preparedness phase of incident management for both man-made and natural incidents. It can thus address a large part of the preparedness "slice" of the Framework for Incident Management presented in Figure 1. The SIMTrainer should support the following modes of operation:

- Individual trainees at responder or management level
- Training of teams from one agency involving only responders, only management level personnel, or responders and management level personnel together
- Training of large teams from multiple agencies involving only responders, only management level personnel, or responders and management level personnel together

The system should allow training of an individual or a team. The value of the system will be fully exploited for training teams involving both emergency management and responder level personnel representing multiple agencies. For individual training, the game environment should run on PC family computer systems including workstation, desktop, laptop, hand held, and PDA variety computers. The computers used to run the software could be available hardware in offices of emergency responders or the trainee's personal computer at home. The software could also be used for classroom and team training at centralized training facilities. The software engine, simulations, and other course content would all be delivered over the Internet via a Web browser interface. The software would install and run automatically without requiring special computer support expertise on the part of the student. Updates to software and course materials could be routinely disseminated over the Internet without resorting to the distribution of physical media, such as CD-ROMs.

The training administrators will configure SIMTrainer to present the training scenarios selected by the users. For example, the Washington DC police may request training to respond to potential attack scenarios at the national mall during July 4 fireworks event. SIMTrainer will be configured using data and graphics files describing the national mall area, and the response resources and organizations to be modeled. It will utilize the modules and subsystems corresponding to the mode of operation and the scenario. For an individual responder level training for a simultaneous attack scenario involving conventional explosives at multiple locations followed by sarin gas attacks at surrounding metro stations in Washington DC, the corresponding responder level game client module will be used while other elements in the scenario will be modeled using modules in the simulation sub-system. That is, for training a policeman the police game client in the gaming sub-system will be used. Corresponding simulation subsystem modules will generate the behavior of other entities in the scenario, such as victims, general public, and EMTs.

The SIMTrainer system will allow training the responders and emergency managers in a range of capabilities. For the example scenario, the police personnel at the responder level can be trained to deal with an unfolding emergency situation including:

- Quick decisions to select next action until specific commands are provided by the command center
- Direct crowd in the right direction and handling people in panic
- Keep an eye open for more attacks
- Decide on how to deal with suspects in the crowd
- Identify casualties and call in medical help
- Perform informal triage to identify those who should move to exit points by themselves and those who should stay until help arrives

Command level personnel can be trained in management and decision-making skills for issues such as:

- Deployment of responder level personnel and resources (e.g., number and locations of policemen on foot, on bicycles, and in police cruisers)
- Mutual aid requests to surrounding jurisdictions
- Decision on cordoning off the affected area to identify people who were exposed to radiations and bio-agents. Also, to identify potential suspects.
- Decisions on controlling mobility outside the immediate area, such as, shutting down the metro system to avoid exposed people from contaminating other people, or shutting down the bridges going out of the district.

The discussion below addresses the system modules that may be utilized to train the personnel in capabilities listed here.

6.1 Responder Level Training

The scenario will initially unfold based on a basic script and will take the path determined by trainee actions executed through the game client. The scenario will be set up using historical data on crowd densities at the selected time and with other parameters such as police presence and EMT stations as specified by the trainers. As the scenario begins, the corresponding simulation module will model the explosion and its impact on surrounding structures and the crowd. The behavior of the crowd following the explosion will be modeled using another simulation module. The simulation modules will be executed in real time and at micro level for the entities in the vicinity of the game clients in the scenario. The policeman may be placed in the scenario near one of the explosive blast locations and expected to react in assisting the victims while also being on guard for additional attacks by nearby terrorists. The visualization component of the game client will show him the scene of the blast with victims lying around and the crowd rushing in multiple directions in panic mode. He may have to decide between assisting the victims and chasing a suspect. The modules utilized in this scenario and modes of operation include:

- Gaming sub-system:
  - On scene response: police game client
- Simulation sub-system (real-time; micro level):
  - Social behavior simulators: Crowd
  - Physical phenomena simulators: Explosion
  - Environmental simulator: Weather
  - Organizational simulators: Law enforcement, health care, and fire. More may be included based on scenario definition and the duration of the training session.
  - Infrastructure system simulators: Communications

Multiple responder level trainees from the police department for the same scenario will utilize multiple police game clients and the simulation modules listed above. They will be able to work jointly within the scenario using their game clients. For more variability in scenario, the trainers may decide to include other players playing the role of victims, bystanders, media and terrorists using respective game client modules. A number of terrorist game clients may be included for "red teaming" training approach.

6.2 Management Level Training

If the individual trainee were to be a police department on-scene commander, or the department representative at the Emergency Operations Center, the game client will be at the response management level. The trainee will be presented with the on-scene command post or the EOC including available information screens and communications that describe the unfolding scenario. The simulation modules in this case can execute at macro level and can be run at varying execution speeds. Initially, the simulations will execute at a speed to provide a real-time information stream to the command post. Once the trainee has made his decisions regarding responder deployments, the executions can be speeded up to model the consequences of the decisions. The trainers will control the pace of execution appropriate for achieving the training objectives. The modules utilized for incident management level trainee for the above scenario are as below.

- Gaming sub-system:
  - Response management: police game client
- Simulation sub-system (real and/or accelerated time; macro level):
  - Social behavior simulators: Crowd
  - Physical phenomena simulators: Explosion
  - Environmental simulator: Weather
  - Organizational simulators: Law enforcement, health care, and fire. More may be included based on scenario definition and the duration of the training session.
  - Infrastructure system simulators: Communications, computers and, networks

6.3 Joint Management and Responder Level Training

As mentioned earlier, the maximum benefit of the proposed architecture will be derived by allowing responders, commanders and emergency management personnel to train on the same scenario to develop shared experiences and understanding. A training involving both responder and management level trainees will require multi-resolution modeling. The areas in the vicinity of the game clients will be modeled at a micro level while other areas in the scenario will be modeled at a macro level. The modules included in this case will be as below.

- Gaming sub-system:
  - On scene response: police game client
  - Response management: police game client
- Simulation sub-system (real and/or accelerated time; macro level):
  - Social behavior simulators: Crowd
  - Physical phenomena simulators: Explosion

- Environmental simulator: Weather
- Organizational simulators: Law enforcement, health care, and fire. More may be included based on scenario definition and the duration of the training session.
- Infrastructure system simulators: Communications, computers, and networks

Finally, when multiple agencies are involved in the training for such a scenario, corresponding game clients will be included. For example, if the agencies involved include fire, EMT and police trainees and management, the gaming sub-system will include game clients for the on-scene and response management game clients for these agencies.

The system will be thus highly configurable to the composition and needs of the individual and/or groups that are being trained. The proposed architecture will provide the configurability and plug compatibility needed to support the concept of operations described in this section.

7. Concept Demonstration Prototype

A concept demonstration prototype has been developed to explore the issues involved in implementing the architecture proposed above. The prototype is also intended to help communicate the concept to potential users of such a capability in the emergency response community. It has been developed around a hypothetical scenario of a radiological dispersion device (RDD, commonly known as dirty bomb) explosion by terrorists during the July 4 fireworks in Washington DC. A number of simulation and gaming modules have been developed to model the consequences and help address the training needs to prepare for such a scenario. With respect to the Framework for Incident Management presented in Figure 1, the implemented modules address the sections framed by preparedness phase, dirty bomb incident, and part of the following domains: civilian population, environment, government agencies and private sector. Specifically the following modules have been implemented:

7.1 Simulation Modules

- *Plume Simulation* is used to determine the path and growth over time of the area affected by the radiological plume generated by the dirty bomb. This will help determine the areas that need to be evacuated to prevent or minimize the exposure to the population present there. The simulation module has been implemented using the software, CT-Analyst, developed at the Naval Research Labs.
- *Crowd Simulation* is used to determine the directions and volumes of people movement to plan the containment and evacuation efforts. The module has been developed by the researchers at University of Arizona using an agent-based modeling approach implemented using the simulation software, AnyLogic.
- *Emergency Vehicles Response Simulation* is used to plan and evaluate response times by emergency vehicles (e.g. police, fire, ambulances, etc.) to get to the scene. For ambulances, the evaluation may include the times for multiple trips for ferrying victims to hospitals. The module has been developed by NIST researchers using Java and GeoTools, an open source GIS toolkit. The modeling approach is similar to that used by macro level traffic simulation tools.
- *Incident Area Traffic Simulation* is used to plan and evaluate traffic planning strategies for evacuation and emergency vehicle routing in the immediate area surrounding the incident scene. This module is also used to estimate the congestion factors that are used in the macro traffic simulation. The model was developed by George Washington University utilizing the Traffic Software Integrated System (TSIS). The approach used is micro-level traffic simulation.
- *Metro Simulation* is used to plan and evaluate metro rail system strategies for evacuation and for support actions such as taking trains to decontamination stations. The model has been developed using AutoMod simulation software by NIST researchers with assistance from Brooks Software, the software vendor.
- *Emergency Room Simulation* will be useful for planning and evaluating the deployment of emergency room resources. It will also help identify the situations that may lead to overloading of emergency rooms of hospitals near the incident site requiring the redirecting of incoming ambulances to hospitals further away. The model has been developed by NIST researchers using the discrete event simulation software, ProModel.

7.2 Gaming Modules

- *Strategy Gaming Client for Event Planning* helps develop the strategy for pre-deployments of emergency response assets. Management personnel of first responders can use the tool to interactively place the assets in a 3D display of an event site. The first version for this module was developed by NIST researchers using GLEST, an open source real-time strategy game engine written in C++. A second version is being designed for improved functionality.
- *Triage Gaming Client* is targeted for use at the first responder level, specifically, the emergency medical technicians (EMTs). It allows EMTs to walk through an incident site in virtual mode; locate, examine and interview victims, and based on their assessment attach the appropriate triage tag for further action. This application was built jointly by researchers from NIST and the Institute of Security and Technology Studies at the Dartmouth College. A 3D gaming approach is used with the game being built on the Unreal game engine.

The modules together allow study of multiple major aspects of the emergency incident and the response. The concept of the integrated simulation is depicted in Figure 6.

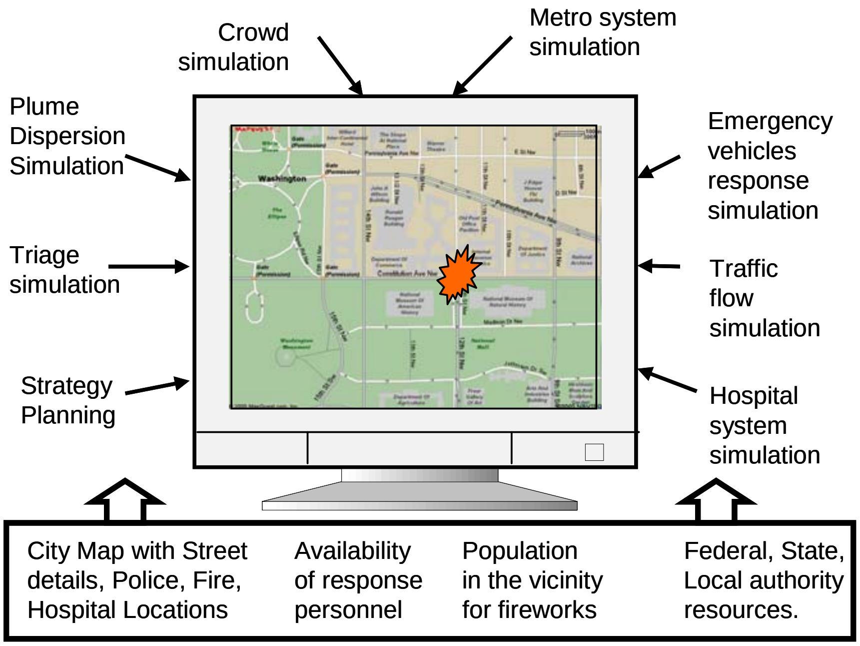

Figure 6. Modules of the concept demonstration prototype

8. Conclusions

This paper presented an architecture for integrating gaming and simulation for incident management training. This integration will bring together the interactive environment provided by gaming for taking actions and making decisions for a situation with the capability to use simulation to produce technically correct impact of the actions taken and decisions made. The integration allows the use of gaming for serious applications for the incident management community. Such serious gaming applications are expected to be quite effective for the coming generations of workforce that have grown up playing video games.

The integration of gaming and simulation will also allow training of personnel and testing of applications that simultaneously address different levels of incident management hierarchy. Such simultaneous involvement of hierarchically diverse personnel and applications will provide improved opportunities for team training. The capability to train responders and commanders together on a wide range of scenarios will enable development of effective incident management teams. These teams can build on their shared sets of experiences developed through incident management training using the integrated simulation and gaming modules. The shared experiences will develop understanding of capabilities and command decisions in the team resulting in increased cohesiveness and effectiveness.

It is proposed that the architecture be implemented as a common infrastructure that can be used to integrate independently-developed simulation and gaming modules. The availability of such an infrastructure will strongly encourage development of gaming and simulation modules covering the breadth and depth of the incident management applications. Incident management personnel can select the modules applicable to their environment to create a capability to serve their training needs.

An implementation of the architecture will provide a test bed for the Homeland and Industrial Control Security Program at NIST and other standards organizations. It can be used to test the interoperability of incident management simulation and gaming applications. It can also be used to test the interfaces for such applications. The proposed test bed will be highly effective if supported with repositories for templates and test case data. Academic and commercial researchers can use the templates and test case data to quickly test out new developments. The test case data can also serve as a benchmark for comparison of alternate approaches for similar applications and thus further spur development and help incident management personnel by providing a common scale to rank vendor offerings.

Implementation of the architecture as a common infrastructure will require development of standards at several fronts including the data models, interfaces, distribution and synchronization mechanisms and user interaction devices. Current work in progress on integration of gaming and simulation is expected to lead to more such activity in the future.

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10. Disclaimer

Software architecture, models, languages and software are identified in context in this paper. This does not imply a recommendation or endorsement of the associated commercial software products by the authors or NIST, nor does it imply that such software products are necessarily the best available for the purpose.

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