

Design of an Urban Chemical Disaster Simulation Federation for Preparedness and Response

James E. Coolahan, Ph.D.

Michael T. Kane

John F. Schloman

Johns Hopkins University Applied Physics Laboratory

11100 Johns Hopkins Road

Laurel, MD 20723-6099

240-228-5155, 240-228-8746, 240-228-0626

James.Coolahan@jhuapl.edu, Michael.Kane@jhuapl.edu, John.Schloman@jhuapl.edu

Roy P. Koomullil, Ph.D.

Alan M. Shih, Ph.D.

Yasushi Ito, Ph.D.

University of Alabama at Birmingham

1530 3rd Avenue South

Birmingham, AL 35294-4461

205-934-0832, 205-934-8461, 205-934-0707

rkoomul@uab.edu, ashih@uab.edu, yito@uab.edu

Evangelos I. Kaisar, Ph.D.

Florida Atlantic University

777 Glades Road

Boca Raton, FL 33431-0991

561-297-4084

ekaisar@fau.edu

Kenneth K. Walsh, Ph.D.

Makola M. Abdullah, Ph.D.

Florida A&M University

2525 Pottsdamer Street

Tallahassee, FL 32310-6046

850-410-6386, 850-412-5102

walsh@eng.fsu.edu, makola.abdullah@famou.edu

Keywords:

Homeland Security, Catastrophic Event Response, Chemical Transport, Traffic Flow, HLA

ABSTRACT: *In late 2005, the Department of Homeland Security (DHS) selected a multi-University consortium led by the Johns Hopkins University (JHU) to form a National Center for the Study of Preparedness and Catastrophic Event Response (PACER). One of the initial three-year cross-cutting projects being performed by the PACER center is the construction of an initial integrated M&S framework focused on preparing for the response to catastrophic events. This project, started in the fall of 2006, is led by the Applied Physics Laboratory of JHU (JHU/APL), and involves researchers from the University of Alabama at Birmingham (UAB), Florida Atlantic University (FAU), Florida A&M University (FAMU), and the Brookings Institution. The first prototype simulation federation is being developed using the High Level Architecture (HLA) standard – an Urban Chemical Disaster federation to be completed in the winter of 2007-08.*

Building upon a technical paper presented at the 2007 Spring Simulation Interoperability Workshop (paper 07S-SIW-077), this paper will present a detailed view of the design of the Urban Chemical Disaster federation, and the chlorine-containing railcar explosion/rupture scenario that is being used in its initial execution. The design presented will include descriptions of the simulation components that will be part of the real-time federation execution, as well as descriptions of simulations that will be executed prior to federation execution, in order to permit its execution in real time. The components include three airborne chemical transport simulations developed by UAB (for wind field generation in the scenario location in downtown Baltimore, chemical transport, and real-time insertion of chemical concentrations into the federation); a traffic flow simulation employed by FAU (populated with road network, traffic signal, and demographic information for the city center area of Baltimore); the dynamic mechanical simulation of the railcar explosion/rupture employed by FAMU, and the resulting chemical release rate simulation; and sensing and command/control simulations developed by JHU/APL.

This research was supported by the U.S. Department of Homeland Security (Grant Number N00014-D6-1-0991) through a grant awarded to the Center for Study of Preparedness and Catastrophic Event Response (PACER) at the Johns Hopkins University. Any opinions, findings, conclusions and recommendations expressed in this publication are those of the author and do not represent the policy or position of the Department of Homeland Security.

1. Background

1.1 DHS PACER UCE Background

In late 2005, the U.S. Department of Homeland Security (DHS) selected a multi-University consortium led by the Johns Hopkins University (JHU) to form a National Center for the Study of Preparedness and Catastrophic Event Response (PACER). As stated in the Broad Agency Announcement (BAA) for the solicitation under which the Center was established [1], the Center is performing research into preparation for high-consequence events, and its research is addressing the technical, systemic, behavioral, and organizational challenges such events pose. The Center is engaging in mission-oriented research to significantly enhance the capabilities of first responders and others.

1.2 Integrated M&S Framework Project Background

As part of its research program, the PACER Center has established several integrated cross-cutting projects. One of these is the construction of an initial integrated M&S framework focused on preparing for the response to catastrophic events. This three-year project, started in the fall of 2006, is led by the Applied Physics Laboratory of JHU (JHU/APL), and involves researchers from the University of Alabama at Birmingham (UAB), Florida Atlantic University (FAU), Florida A&M University (FAMU), and the Brookings Institution. Ultimately, the M&S framework is intended to provide a composable set of simulations that can be used as an aid to decision-makers in training/rehearsal for responses to catastrophic events.

1.3 Project Objective and Specific Aims

The overall objective of the project is to develop a unifying common simulation framework into which smaller, more focused, simulations developed within PACER and/or by other DHS entities can be integrated to address, in a synergistic fashion, various multi-disciplinary problems associated with catastrophic, high-consequence events. The specific aims of the project are to:

- Develop a unifying framework for integrating and applying the most promising modeling and simulation (M&S) tools available to address distribution and allocation of resources, to determine the effects and efficacy of interventions, and to evaluate long-term consequences of preparedness and response strategies.
- Integrate, into interoperable simulation federations, selected sets of simulations of diffusion and dispersion of chemical, biological, and radiological (CBR)

agents, transportation networks, emerging infectious diseases, and behavioral epidemiology.

- Make available such tools to policy-makers, public health professionals, and other end-users in order to aid decision-making, and identify specific training and educational needs.

2. The Urban Chemical Disaster Simulation – Objectives and Scenario

2.1 Objectives

As discussed in an earlier paper on the project presented at the 2007 Spring Simulation Interoperability Workshop [2], the six objectives of the Urban Chemical Disaster (UCD) simulation federation are as follows:

1. To demonstrate a prototype simulation capability that establishes an IOC for the PACER integrated M&S framework.
2. To simulate the release and airborne transport of a dangerous chemical agent in a representative urban environment under representative, varying environmental conditions.
3. To simulate realistic sensing mechanisms and command and control strategies to respond to the catastrophic event for several hours after the initial release.
4. To simulate a representative flow of traffic that could result on the urban road network, and realistic traffic routing and signal control strategies that could be employed.
5. To execute the simulation federation for a scenario, agreed to be realistic by local subject matter experts (SMEs), incorporating the elements in objectives 2 through 4 above, over a reasonably-sized urban area (e.g., 2 km by 2 km in size).
6. To ensure, by the judicious selection and modification of simulation components, that the simulation federation can execute in real time (or faster) on a small set of affordable desktop or laptop personal computers.

2.2 Scenario

At the UCD simulation federation kickoff meeting, held at the FAU Jupiter, FL, campus on February 8-9, 2007, a 2 km x 2 km area in downtown Baltimore was selected as the location for the scenario. Figure 2.1 is an overhead image of this area, from GoogleEarth. In the lower left of the area is a railroad track that proceeds west to east, south of the football stadium, and then turns to the north, entering a tunnel just southeast of the baseball stadium.

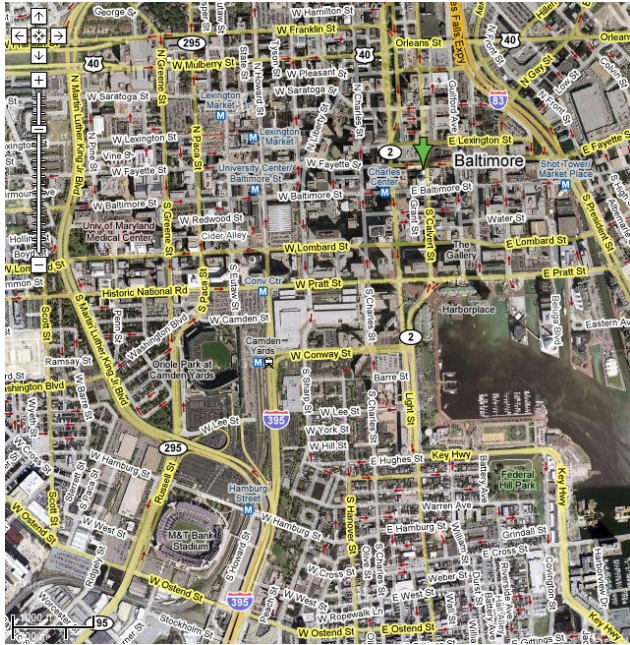


Figure 2.1 Scenario Location in Downtown Baltimore.

This tunnel was the site of a derailment and fire of a train carrying hazardous materials in the summer of 2001, so it was felt that the approach to the tunnel would be a realistic site for the scenario.

The scenario starts at 1:00 pm on a clear spring afternoon (April 15, 2008), with an ambient temperature of approximately 75 degrees Fahrenheit, and light (approximately 5-knot) winds from roughly a south-southwest direction. A train, which includes multiple railcars containing chlorine, is moving west to east and then turns to the north. A satchel-sized explosive, assumed to be previously placed surreptitiously by a terrorist on one of the railcars containing chlorine near the rear of the train (on the west-to-east segment), is detonated remotely, rupturing the railcar. The train is assumed to stop at this point, but several minutes later, a second explosive located on a chlorine-containing railcar near the front of the train (on the south-to-north segment) is detonated remotely, rupturing it as well.

The hole in each ruptured railcar is of such a size that the chlorine escapes slowly in gaseous form, forming a cloud that gradually moves, driven by the prevailing winds, toward the city center. Alerted by the explosion, local emergency response units follow standard procedures in responding to the event and in assessing the situation. News reports begin to emanate from local TV and radio stations. After assessing the situation, local commanders make decisions as to whether to direct that people in the downtown area shelter in place or evacuate. Police in protective gear are dispatched to intersections, and traffic

signals are also used to direct traffic away from the affected area. Chemical sensors are placed at selected locations to monitor the chlorine concentrations. The volume of traffic in the downtown area increases as more individuals react (either in accordance with orders to evacuate, or despite shelter-in-place directions) to leave the area in vehicles.

3. UCD Simulation Design and Components

3.1 Overview

From a functional perspective, in addition to simulation management, data logging and visualization, there are six separate functions that must be performed by the UCD simulation to achieve the objectives:

1. Rupture of the railcar(s) by explosive detonation;
2. Release of the chlorine pollutant from the railcar(s) as a function of time;
3. Airborne transport of the chlorine pollutant through the three-dimensional cityscape;
4. Sensing of chlorine concentrations at various locations;
5. Command and control exercise by local emergency response units;
6. Traffic flow of vehicles through the urban road network.

The rupture of the railcar is a virtually instantaneous event that serves only to trigger the release of the chlorine pollutant, which in turn provides the input for the airborne chemical transport simulation. However, there is no feedback interaction to this simulation component from any of the other simulation components. Therefore, the explosive detonation simulation component need not be part of the federation, and can be executed in advance.

The airborne transport of the chlorine pollutant through the three-dimensional cityscape is a very complicated process. It requires accurate data on the size of all buildings in order to calculate the wind field even in the absence of the pollutant. The transport of the pollutant after its release through the wind field is also a complex process. Execution of similar simulations on other cityscapes has shown that, with current computing capabilities, this function requires a multiprocessor configuration, and cannot be executed in real time. As a result, a design decision needed to be made to divide this function into three steps:

- Generation of the wind field (slower than real time);

- Insertion of the pollutant into the wind field and its transport as a function of time (slower than real time), forming a data file of chlorine concentrations;
- Extraction of chlorine concentrations in real time from the data file.

As a result, the first two steps need to be executed in advance of the real-time simulation federation. Because the second step depends on the release rate of chlorine from the ruptured railcar(s), the chlorine release simulation, although not computationally intensive, also needs to be executed in advance. The remaining three functions can be performed in real time as part of the federation.

Figure 3.1 shows the design concept for the UCD simulation, including both the non-real-time components to be executed prior to federation execution, and the real-time components used during federation execution, along with principal data flows.

3.2 Non-Real-Time Simulation Components

3.2.1 Explosive Detonation and Railcar Rupture

The simulation of the explosive detonation and resulting railcar rupture is being performed by researchers at FAMU using the LS-DYNA simulation. LS-DYNA is a general purpose transient dynamic finite element program that can be used to model a wide range of physical events.

It is used in the present work to simulate the effect of the explosive detonation on the railcar and to predict the resulting structural failure (rupture). The final output from the structural simulation is the hole size due to the rupture of the railcar material. The hole size is then used in the calculation of the chlorine pollutant release rate (see section 3.2.2) for the ensuing real-time simulation.

The railcar used in the structural simulation is a Department of Transportation (DOT) 105A500W with a gross rail load of 1,169.88 kN, which is the most common type of railcar used to transport chlorine in North America [3]. A schematic of the railcar is presented in Figure 3.2 for reference. The car is insulated and pressurized in order to provide safe and economic transport of the chlorine gas. As a result, the car is composed of a 0.1016 m thick layer of fiberglass insulation located between a steel inner shell and outer jacket. The inner shell and outer jacket are made of ASTM A516 grade 70 steel and have thicknesses of 0.0199 m and 0.0030 m, respectively. The car's inner shell has a diameter of 2.59 m with a length of 12.13 m, resulting in a total volume of 63.91 m³. Successful detonation of an explosive on a railcar, either while stationary or en route, requires a fast and effective means for explosive placement and detonation. The scenario presented herein is based on a single individual carrying 133.45 N (30 lb) of C4 plastic explosive. A C4 plastic explosive was selected for the detonation material because C4 is capable of providing a large explosive force for a relatively small amount of material (lightweight). This type of explosive is also easily placed due to its

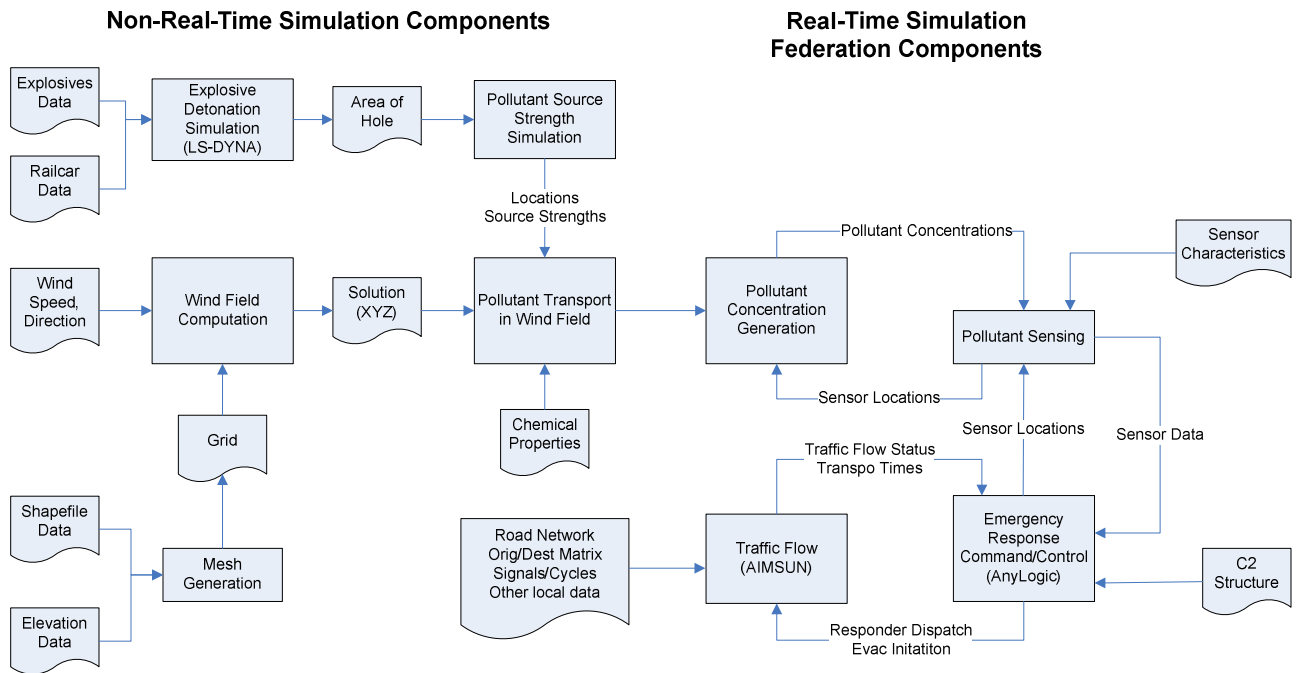


Figure 3.1 UCD Simulation Block Diagram.

adhesiveness and pliability, and represents one of the more stable types of explosives as it will not detonate unless simultaneously exposed to both heat and pressure. The C4 explosive is placed on the underbelly of the railcar, as this location would be easily accessible by an individual traveling on foot. The C4 plastic explosive used in the detonation model has a mass of 13.60 kg, mass density of 1,630.35 kg/m³, and a detonation velocity of 8,193.00 m/s. Simulations are currently being conducted to determine the degree of tank rupture due to the resulting explosive force. During the simulation, the railcar is fixed in place to isolate the effect of the explosion on the body of the car.

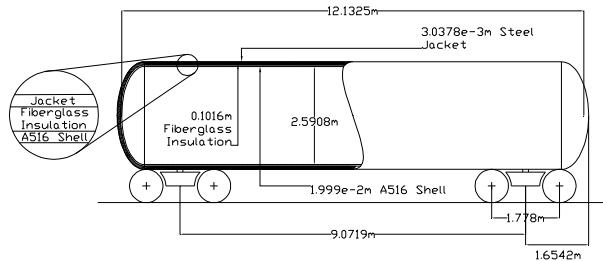


Figure 3.2 Railcar Schematic.

3.2.2 Pollutant Source Strength Computation

The computation of the source strength of chlorine as a function of time as a result of the railcar rupture is being performed by researchers at JHU/APL.

Source strength is computed using three fluid discharge sub-models derived from Ref. [4]: a model of liquid discharge through a tank rupture, a model of the release of compressed gas, and a model of vapor released through a rupture above a boiling liquid. Along with environmental data (atmospheric temperature, pressure and wind speed), and the state of the tank, its rupture and the critical properties of the chemical contained within are used as inputs at each time step to select the appropriate sub-model and to calculate the mass flow rate at that time. Mass balance models are then used to calculate the drop in pressure, the qualities of two-phase flow and the new evaporation rates to define the new state of the system for the next time step. The final outputs are the flow rates at every time, aggregated together (see Figure 3.3).

3.2.3 Wind Field Computation

The computation of the wind field in the urban area defined by the scenario is being performed by researchers at UAB. A Shapefile is used to define the cityscape providing the boundaries of buildings [5]. Shapefile data contain a set of 3D curves, each of which has an elevation

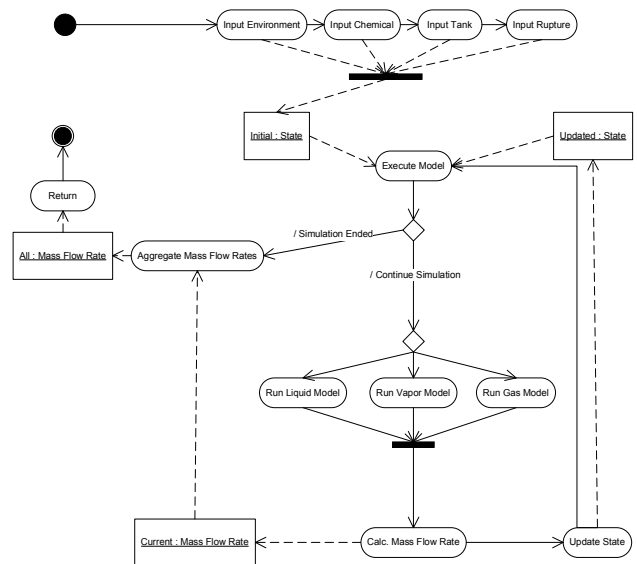


Figure 3.3 Activity Diagram of the Source Strength Model.

value associated with it. There are three steps to create a 3D surface model based on this data. First, those curves are triangulated using a Delaunay triangulation method to fill the footprint of the buildings with triangles (Figure 3.4a). Second, the footprint is copied to the height of the buildings (Figure 3.4b). Third, walls are filled with triangular strips (Figure 3.4c). The resulting buildings are represented as sets of triangulated simple solids. Since the Shapefile defines flat roofs, domes, slanted roofs, or more detailed roofs cannot be generated. In addition, there may be very small gaps or two solids may be in contact, while a typical mesh generator requires a two-manifold surface model as input [6]. It is not easy to fix all of these problems automatically.

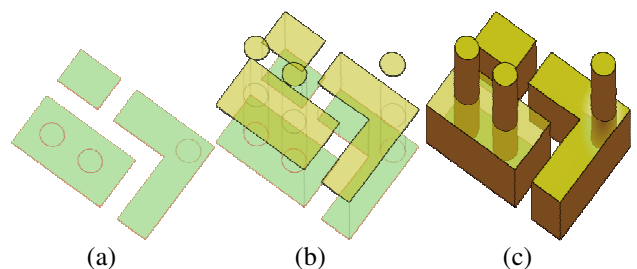


Figure 3.4 ShapeFile to 3D Buildings: (a) triangulated 3D curves; (b) roofing; (c) walling.

In this project, an octree-based mesh generation method has been developed because it accepts non-two-manifold surfaces to create volume meshes [7]. Four parameters are provided to control resulting meshes: (a) mesh type – all tetrahedral, hybrid (hexahedra, tetrahedra and pyramid) and generalized (arbitrary polyhedra); (b) the size and the center of an outer boundary; (c) resolution; and (d) transition speed of mesh density. In the case of

tetrahedral mesh generation, node smoothing and face swapping methods are applied to improve the mesh quality. Figure 3.5 shows a hybrid mesh with 8,918,046 nodes and 12,588,297 elements (6,904,218 hexahedra, 3,896,848 tetrahedra and 1,787,231 pyramids) for Baltimore buildings. A Shapefile for the Baltimore area was obtained from Sanborn. Octants intersecting or inside the buildings are removed during the mesh generation process. Currently, no projection or cut cell methods are applied to the surfaces. Although they become bumpy, and small features of the buildings are lost, a volume mesh can be created from non-two-manifold surface models easily and automatically. The number of elements of the mesh can be changed easily using the four parameters.

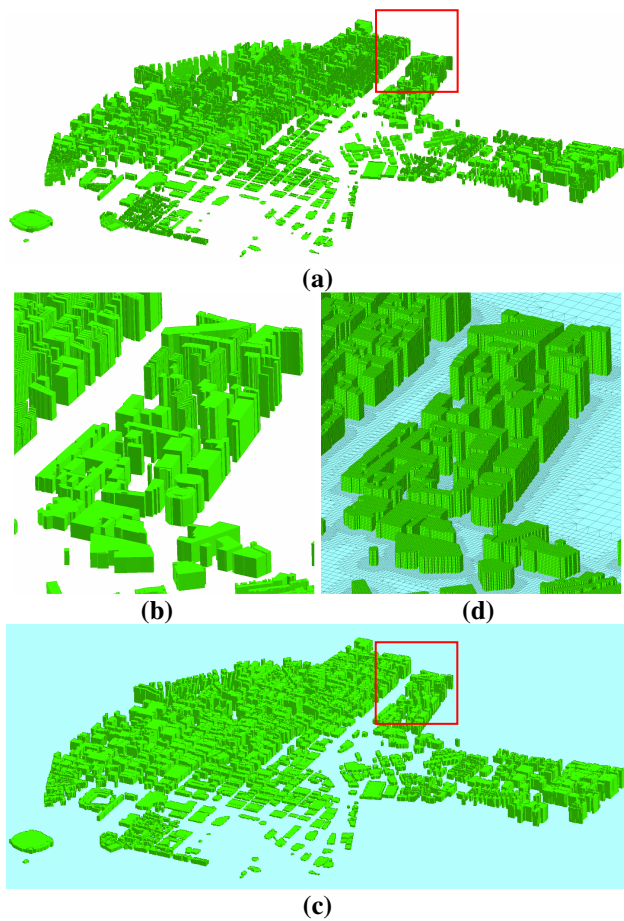


Figure 3.5 Octree-Based Hybrid Mesh for Baltimore:
(a) Buildings from a ShapeFile; (b) Enlarged view of a; (c) Surface mesh; (d) Enlarged view of c.

Typical wind speeds within a city fall in the low speed flow regime and can be considered incompressible. In this study, the artificial compressibility form of the Euler equations are taken as governing equations for the incompressible flow. The effect of viscosity is omitted in

the simulation of the wind field. It is well known that the viscous effect is important primarily in the boundary layer region. For the problem of simple geometries or a small domain, resolving this effect is relatively easy with current computer capability. However, it is extremely computationally intensive to resolve the boundary layer of flow around complex geometries and with disparate length scales; thus, this cannot be an efficient numerical approach for simulating the wind field around numerous buildings and terrains of a city. Even with the simplification of inviscid fluid flow, the number of cells required for the wind field simulation for an entire city can be of the order of tens of millions, which necessitates a parallel simulation environment. Keeping this in mind, a parallel finite-volume, cell-centered scheme is developed for incompressible flow simulation using generalized grids, in which the discretization of the physical domain can be of structured, unstructured or an agglomeration of cells with an arbitrary number of faces (polytopes) [8],[9].

The integral form of the Euler equations is taken as the governing equation for the fluid flow. The spatial discretization of the governing equations is based on a cell-centered, finite volume upwind scheme. The convective fluxes at the cell-faces are evaluated using Roe's approximate Riemann solver [10]. Higher-order accuracy in the spatial domain is achieved using a Taylor series expansion of flow variables. The gradients at the cell center for the Taylor series expansion is estimated using either the Gauss theorem together with a weighted averaging procedure or a least-square fit of the variables in the neighboring cells. The least-square system resulting from the latter approach is solved using the Gram-Schmidt method. A limiter function is added to the Taylor's series expansion to avoid the creation of local extrema during the reconstruction process. Limiters by Venkatakrishnan [11], and Barth and Jespersion [12] are implemented in the generalized grid framework.

The flux Jacobian for the implicit scheme is evaluated either analytically assuming the Roe averaged matrix to be constant or numerically. Newton iterations are used to improve the temporal accuracy for the case of time-accurate simulations using the implicit scheme [13]. The block sparse matrix system resulting from the linearization of the governing equations is solved using a symmetric Gauss-Seidel algorithm. The parallelization of the code is achieved by decomposing the physical domain into a set of smaller regions using METIS [14], which utilizes the graph of the grid to perform the decomposition. The Message Passing Interface (MPI) is used to pass the information across the block interfaces. Figure 3.6 shows a wind field for the area of downtown Baltimore used in the scenario, computed as described.

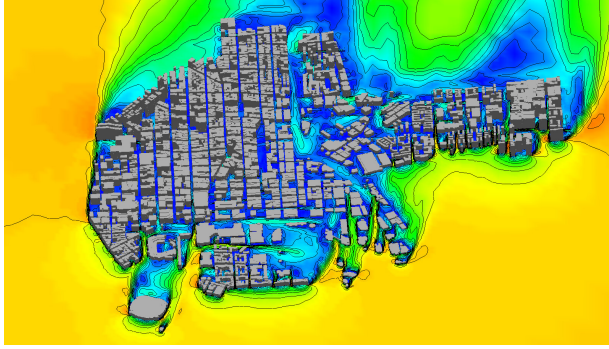


Figure 3.6 Computer simulated wind field in the city of Baltimore.

3.2.5 Pollutant Transport in the Wind Field

The computation of the chlorine pollutant in the wind field is also being performed by researchers at UAB.

The general form of a species equation for the transport of chlorine through the urban area can be expressed as

$$\frac{\partial}{\partial t} \int_{\Omega} f dV + \oint_{\partial\Omega} f \vec{U} \cdot \vec{n} ds = \oint_{\partial\Omega} k \nabla f \cdot \vec{n} ds + S$$

where f and k are species concentration and diffusion coefficients, respectively, and \vec{U} is the velocity vector that is calculated using the wind field simulation code. The first term on the left side represents the rate of change of the species concentration inside the control volume Ω , the second term on the left is the rate of species changes due to convection through the control surface, the first term on the right is the diffusion term, and the last term is the source terms. The treatment of different terms in the transport equations and their modeling are carried out in the same way as the discretization of various terms in the Euler equations.

The diffusion coefficient used in the transport equation becomes a binary diffusion coefficient and can be calculated using the formula,

$$D_{AB} = \frac{10^{-3} \times T^{1.75} \times \sqrt{M_r}}{P \times (V_A^{1/3} + V_B^{1/3})^2}$$

where D_{BA} represents the binary diffusion coefficient of species B (Chlorine) in species A (Air) at a temperature of T (K) and pressure of P (atm). M_r is given by $(M_A + M_B) / (M_A M_B)$, where M_A and M_B are the molecular weights and V_A , V_B the molar volumes of species A and B , respectively.

As the simulation for chlorine transport in Baltimore has not yet been performed, the results from the simulation of phosgene transport through the City of New Orleans from

a previous study are presented here for illustration purposes. In this simulation, phosgene sources are placed at five different locations inside the city, and the predicted pollutant concentrations and migration from these locations are shown in Figure 3.7. In this simulation, it is assumed that phosgene is emitted from these source locations for the entire period. The results are presented at 120 seconds after the release of phosgene from the sources. The zoom-in view of one of the phosgene source locations with different iso-surface values of phosgene concentration is shown in Figure 3.8. The concentration levels vary with the different transparencies, with the darker iso-surfaces representing the higher concentration regions and lighter ones for the lower concentration.

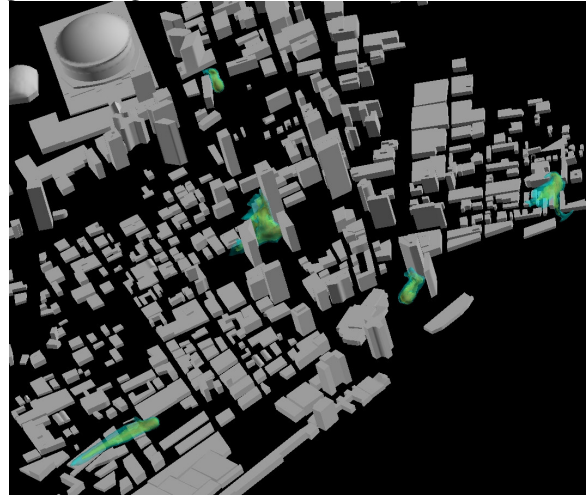


Figure 3.7 Phosgene transport from five sources after 120 real-time seconds.

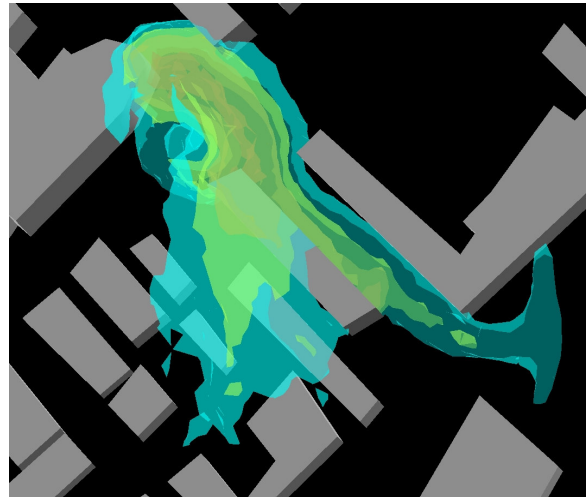


Figure 3.8 Zoomed-in view of one of the source locations.

3.3 Real-Time Simulation Federation Components

3.3.1 Introduction

Once all of the computations required to be done in advance have been performed, the real-time UCD simulation federation can be executed. There are four principal simulation components in the federation (in addition to simulation management, data logging, and visualization):

- the generation of chlorine pollutant concentrations in three dimensions as a function of time;
- the sensing of chlorine concentrations at selected locations
- the command and control of emergency response actions; and
- the generation of traffic flows as a result of the response actions taken.

Each of the above is discussed in the sections that follow.

3.3.2 Pollutant Concentration Generation

The real-time generation of chlorine pollutant concentrations in three dimensions as a function of time is being done by researchers at UAB, using the results of the computations of the wind field and the pollutant transport done in advance.

Detailed modeling of chemical, biological, and radiological (CBR) agents through an urban area is a computationally intensive process and is not practical for real-time implementation. In order to incorporate the simulation results into real-time emergency management simulations, prediction of pollutant transport in, or faster than, real time while maintaining a certain level of accuracy is required. Therefore, a set of wind fields and pollutant concentrations in the City of Baltimore will be pre-computed based on different prevailing wind conditions, and saved in a database where they can be accessed and utilized by the real-time simulation federation. A data interpolation algorithm to be developed will retrieve the cached wind field data and perform fast interpolation to provide an estimated path of the CBR agents through the urban environment. Since the flow field is highly nonlinear, new interpolation algorithms need to be explored. This data interpolation algorithm will be incorporated as a component in the real-time simulation federation.

3.3.3 Pollutant Sensing

The modeling of pollutant sensors is being performed by researchers at JHU/APL using the AnyLogic version 6 simulation tool. The Anylogic application program interface provides a “StepHook” function that will be

used to integrate the simulation tool with an HLA wrapper. The sensor model requests pollutant concentration data from the pollutant concentration generation model at locations that represent sensors in the field, which may be mobile. The model simulates the performance characteristics of various sensor technologies for detecting gaseous toxic industrial compounds, primarily gas chromatography. Sensor capabilities include identification of toxic substances and comparison of concentration levels to toxicity thresholds. Sensors require a minimum dwell time and can generate false positives – in an urban environment, diesel exhaust can interfere with sensor accuracy. The sensor simulation publishes results to other federates. Sensor results are used to identify toxic substances, to establish a safety perimeter, and to measure the effectiveness of decontamination efforts.

3.3.4 Emergency Response Command and Control

The modeling of the command and control (C²) of emergency response actions is being performed by researchers at JHU/APL, also using the AnyLogic version 6 simulation tool. The command and control structures in the model follow the Federal guidelines defined in the Department of Homeland Security (DHS) National Response Plan [15]. The DHS National Incident Management System (NIMS) Framework [16] requires that jurisdictions adopt the Incident Command System (ICS), a standardized, on-scene, all-hazard incident management concept, as a condition of receiving Federal preparedness funding.

The ICS standard calls for the establishment of an Incident Command Post (ICP), from which the Incident Commander oversees all incident operations. The ICS also provides common terminology for organizational functional elements, position titles, facilities and resources. The ICS places considerable emphasis on developing an effective Incident Action Plan (IAP). The C² model will simulate the actions called for in the IAP for the mission areas involved in the incident. These mission areas include:

- Establishing, planning, and operating incident command;
- Dispatching of response resources;
- Hazard assessment, prediction, monitoring, and sampling;
- Alerts, activation and notification;
- Evacuation and/or sheltering of downwind populations;
- Traffic and access control;
- Victim treatment and transport;
- Protection of special populations; and

- Public information activities.

The IAP allocates responsibility among various government and private agencies. The C^2 model simulates the activities of the:

- Fire Department (FD);
 - Hazmat response;
 - Coordination of rescue and ambulance service; and
 - Coordination of hazard monitoring.
- Police Department (PD);
 - Disseminating warnings;
 - Traffic control; and
 - Managing evacuation.

The C^2 model maintains a representation of the Incident Commander's situational awareness based on sensor data and field reports. The C^2 model subscribes to the pollutant concentration information published by the sensor model. It also obtains traffic flow status of evacuation routes from the traffic model. The C^2 model communicates with the traffic model to:

- Initiate evacuation plans for parts of the affected area;
- Prevent traffic from crossing within the safety perimeter;
- Dispatch police officers to traffic control locations;
- Dispatch fire and emergency medical resources to the incident site; and
- Dispatch Hazmat team to the incident site.

The traffic model communicates with the C^2 model to indicate the time required for police, fire, emergency services and Hazmat units to arrive at designated locations and to report traffic flow status.

A constructive simulation is used to model the incident from the initial reporting to the 911 communications center through several hours of incident response activities.

3.3.5 Traffic Flow Modeling

The modeling of traffic flow as the result of the emergency scenario is being performed by researchers at FAU using the AIMSUN version 5.1 simulation. In this simulation, various inputs need to be incorporated, as described in the following paragraphs.

Currently, the geometric design is being based on the combination of multiple detailed satellite images and 3D-shapefiles, and is being confirmed by a correspondent in city of Baltimore. From this data, the length of streets,

turn pockets, and lane configurations are determined. More accurate methods are currently being explored and analyzed regarding the simulation flow model.

The road network shown in Figure 3.9 has the following characteristics:

- 475 Sections;
- 156 Intersections;
- 37 km Section Length;
- 97 km Lane Length
- 28 Centroids (22 zones and 6 exits)

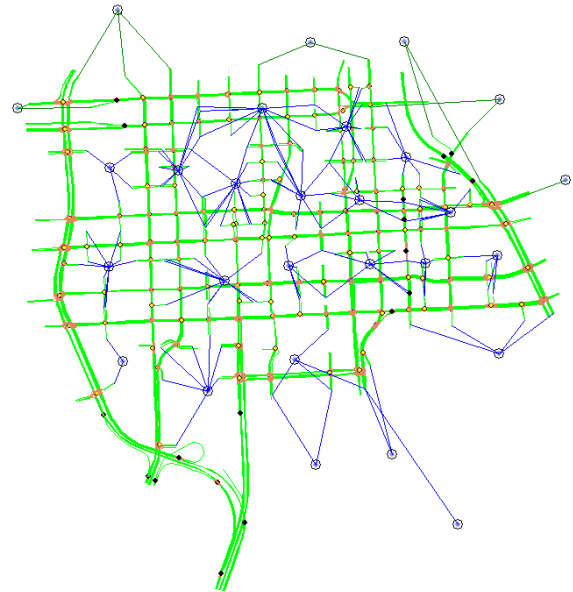


Figure 3.9 Road Network as Constructed in Simulation.

The signal timing and phase configuration were received from the city of Baltimore. Most of the signals are pre-timed, which means that the signals have to be reconfigured in any evacuation plan. Because the research area is part of the Central Business District, the 11:00 am traffic conditions and Signal Timing are the appropriate ones. In addition, the signal timing was extracted and will be calculated again using the traffic software Synchro7 to calculate the most efficient phase configuration for this particular scenario.

Due to the nature of the disaster, specific zones of the affected area need to be evacuated in sequence. To produce a manageable model, the area needs to be divided into different zones. The goal is to make a distinction between homogeneous social-economical zones. The "Transportation Analysis Zones" from the Baltimore Metropolitan Council, is chosen as a valid and reliable distinction. Social-economical data can provide information about the amount, characteristics and trip

motives of the people in the different zones. In addition, the use of origin-destination (O-D) matrixes is dependent upon the chosen safe zones that have been established outside of the critical area. Currently, different travel demand methodologies and tools are being researched for the accurate calculation of these matrixes. Nevertheless, the matrices will be based on the population of this area and the estimated number of daily commuters to the region during the average work week. One of the important issues that must be dealt with is the four hospitals and twenty schools that occupy the area. Minor inputs such as road side parking and other street maintenance have been accounted for as well.

4. Summary

This paper has presented the design of the Urban Chemical Disaster (UCD) simulation being constructed by the National Center for the Study of Preparedness and Catastrophic Event Response (PACER). Testing of the simulation federation is expected to begin in the fall of 2008, leading to final integration at JHU/APL in December, 2008.

Upon its completion, the potential uses of the UCD simulation fall into the three functional areas of training/mission rehearsal, analysis of alternatives, and system acquisition.

The training/mission rehearsal area is envisioned to be the primary use of the UCD simulation federation. This is the reason that objective 6 deals with the need for real-time execution. Within this functional area, there could be two specific uses: seminar gaming to perform course-of-action development, and decision-maker training for specific chemical release scenarios. Once a course of action has been established for a specific type of scenario, the UCD simulation federation could then be used to train first-responders for preparedness purposes.

The UCD simulation federation could also be used to support analysis of alternatives and related system acquisition decisions. For example, a postulated automated traffic signal control system could be overlaid on the traffic flow simulation, and various strategies could be analyzed to determine optimal signal timing under various conditions. Similarly, postulated fixed or deployable chemical sensors could be placed at various locations and densities to determine the number required to provide an adequate set of measurements to enable decisions.

5. References

- [1] Office of Naval Research BAA Announcement #05-008, Department of Homeland Security Centers (DHS Centers) Broad Agency Announcement: Center for the Study of High Consequence Event Preparedness and Response (2005).
- [2] Coolahan, J. E., "Planning for an Integrated M&S Framework for Catastrophic Event Response," in *Proc., 2007 Spring Simulation Interoperability Workshop*, Norfolk, VA (Apr 2007).
- [3] Saat, M. R., and Barkan, C. P. L., "The Effect of Rerouting and Tank Car Safety Design on the Risk of Rail Transport of Hazardous Materials," in *Proc., 7th World Congress on Railway Research*, Montreal, Canada (Jun 2006).
- [4] Belore, R., and Buist, I., "A computer model for predicting leak rates of chemicals from damaged storage and transportation tanks," Report EE-75, Ottawa, Ontario, Canada: Environmental Emergencies Technology Division, Environment Canada (1986).
- [5] Environmental Systems Research Institute Inc., *ESRI Shapefile Technical Description*, ESRI, NY (1998).
- [6] Ito, Y. and Nakahashi, K., "Surface Triangulation for Polygonal Models Based on CAD Data," *International Journal for Numerical Methods in Fluids*, Vol. 39, Issue 1, pp. 75-96 (2002).
- [7] Yerry, M. A., and Shephard, M. S., "Automatic three-dimensional mesh generation by the modified-octree technique," *International Journal for Numerical Methods in Engineering*, Vol. 20, Issue 11, pp. 1965-1990 (1984).
- [8] Koomullil, R. P., and Soni, B. K., "Flow Simulation Using Generalized Static and Dynamics Grids," *AIAA Journal*, Volume 37, Number 12, pp. 1551-1557 (Dec 1999).
- [9] Koomullil, R. P., and Soni, B. K., "Wind Field Simulations in Urban Area," AIAA-2001-2621, Available on CD ROM, presented at the 15th AIAA Computational Fluid Dynamics Conference, Anaheim, CA (Jun 2001).
- [10] Roe, P. L., "Approximate Riemann Solvers, Parameter Vector, and Difference Schemes," *Journal of Computational Physics*, Vol. 43, pp. 357-372 (1981).
- [11] Venkatakrisnan, V., "On the Accuracy of Limiters and Convergence to Steady State Solutions," AIAA Paper 93-0880 (Jan 1993).

- [12] Barth, T. J., and Jespersen, D. C., "The Design and Application of Upwind Schemes on Unstructured Meshes," AIAA Paper 89-0366 (Jan 1989).
- [13] Whitfield, D. L., and Taylor, L., "Discretized Newton-Relaxation Solution of High Resolution Flux-Difference Split Schemes," AIAA Paper 91-1539 (Jun 1991).
- [14] Karypis, G., and Kumar, V., "METIS: Unstructured Graph Partitioning and Sparse Matrix Reordering System, Version 2.0," Department of Computer Science, University of Minnesota (Aug 1995).
- [15] Department of Homeland Security National Response Plan (Dec 2004).
- [16] Department of Homeland Security National Incident Management System (2004).

Author Biographies

JAMES E. COOLAHAN is a Program Manager and the Supervisor of the Modeling and Simulation Group in the National Security Analysis Department at the Johns Hopkins University Applied Physics Laboratory, where he also served as the Assistant to the Director for Modeling and Simulation from 1996 to 2001. In his 35 years at JHU/APL, his technical activities have included modeling and simulation, test and evaluation, and the development of oceanographic data acquisition systems. Dr. Coolahan served as a member of the National Research Council (NRC) Committee on Modeling and Simulation Enhancements for 21st Century Manufacturing and Acquisition from 2000 to 2002. He is currently the Principal Investigator for the Modeling and Simulation Integration Framework project being performed as part of the National Center for the Study of Preparedness and Catastrophic Event Response (PACER) for the Department of Homeland Security (DHS). In SISO, he has been the chair and vice-chair of the System Acquisition and Product Development (SAPD) Forum, the vice-chair of the Test and Evaluation Forum, and a member of the Research, Development and Engineering Forum Program Review Panel. Dr. Coolahan holds B.S. and M.S. degrees in aerospace engineering from the University of Notre Dame and the Catholic University of America, respectively, and M.S. and Ph.D. degrees in computer science from the Johns Hopkins University and the University of Maryland, respectively.

MICHAEL T. KANE is on the Senior Staff of the Modeling and Simulation Group in the National Security Analysis Department at the Johns Hopkins University Applied Physics Laboratory. Mr. Kane has supervised a Software Engineering Section in the Department and has served as the technical lead for projects involving DoD

High Level Architecture (HLA) simulations, C4ISR architecture modeling, management information systems and knowledge management. He served as chairman of the Design Steering Committee for the Department of Transportation nation-wide vehicle database management system and as manager of the Advanced Computing and Visualization Laboratory. Mr. Kane holds a B.S. degree in industrial engineering from the University of Pittsburgh, an M.S. degree in operations research from the George Washington University, and an M.S. degree in computer science from the Johns Hopkins University.

JOHN F. SCHLOMAN is a Software Engineer at the Johns Hopkins University Applied Physics Laboratory. In 2003 he completed his Master's in Computer Science at Michigan State University. In 2001 he received a degree Cum Laude in Systems Analysis from Miami University in Oxford, Ohio.

ROY P. KOOMULLIL is an Assistant Professor of Mechanical Engineering at the University of Alabama at Birmingham (UAB). Dr. Koomullil received his doctoral degree in Aerospace Engineering from Mississippi State University in 1997. Before joining UAB, he worked as an Assistant Research Professor at the NSF Engineering Research Center (ERC) at Mississippi State University (MSU). Dr. Koomullil's area of expertise includes compressible and incompressible flows, computational fluid dynamics, finite volume upwind schemes on generalized grids, unsteady flow simulation, six-degree-of-freedom (6-DOF) rigid body simulations, overset meshes, and high performance computing. He is a Senior Member of the American Institute of Aeronautics and Astronautics (AIAA) and a Member of the American Society of Mechanical Engineers (ASME).

ALAN M. SHIH is a Research Associate Professor and the director of the Enabling Technology Laboratory (ETLab) in the Department of Mechanical Engineering, UAB. He is also an Adjunct Associate Professor of the Department of Computer and Information Sciences, UAB. Dr. Shih received his Ph.D. degree in Aerospace Engineering from Mississippi State University in 1994. His areas of interest include numerical geometry, mesh generation, computational graphics, scientific visualization and virtual environments. He is a Senior Member of the AIAA and a Member of the ASME and the Institute of Electrical and Electronics Engineers (IEEE).

YASUSHI ITO is a Research Assistant Professor of the Department of Mechanical Engineering, UAB. He has been working on mesh generation methods for computational simulations and has published more than twenty journal papers. He has received B.S., M.S., and

Ph.D. degrees in Aerospace Engineering from Tohoku University, Japan. He is a member of the AIAA.

EVANGELOS I. KAISAR is an Assistant Professor at the Florida Atlantic University. Prior to joining the University he was a Projects Manager of the Traffic Engineering division in the Maryland Transportation Authority (MdTA). In MdTA, his technical activities included traffic and congestion pricing studies, simulation and modeling, and safety studies. Dr. Kaisar served as a member of the Transportation Research Board (TRB), Committee for Intermodal Terminals, Port Operations, Network Equilibrium and Safety and Security. He is currently the Principal Investigator for the following projects: a) Simulation Modeling project being performed under JHU/APL for the Department of Homeland Security (DHS), b) Intermodal Safety and Security project being performed for the Federal Transit Administration, and c) Congestion impact study for the Port of Miami. Dr. Kaisar holds a B.S. degree in civil engineering from the University of Maryland and National Technological University of Athens, Greece, and M.S. and Ph.D. degrees in Civil Engineering, minor in Logistics, from the University of Maryland.

KENNETH K. WALSH is a Visiting Assistant Professor in the Department of Civil and Environmental Engineering at the FAMU-FSU College of Engineering and also serves as Co-Director of the Wind Hazard and Earthquake Engineering Lab. Dr. Walsh's research interests center around structural vibration control with particular focus in the areas of semi-active control, smart materials for improved structural performance, and vibration absorption and isolation of mechanical systems. Dr. Walsh holds a B.S. degree in Civil Engineering from Florida State University and M.S. and Ph.D. degrees in Civil Engineering from Florida A&M University.

MAKOLA M. ABDULLAH is a professor in the Department of Civil and Environmental Engineering at the FAMU-FSU College of Engineering and also serves as the Director for the Wind Hazard and Earthquake Engineering Lab. Dr. Abdullah's research interests center around the vibration control of civil engineering structures. In particular, the interests include the placement and design of output feedback controllers, optimization algorithms for discrete location placement, robust control design, and minimization of structural pounding. Dr. Abdullah holds a B.S. degree in Civil Engineering from Howard University, and M.S. and Ph.D. degrees in Civil Engineering from Northwestern University.