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Modeling and Simulation Integration Framework
(Integrative Project C1)

Demonstration of an Urban Chemical Disaster Simulation for Preparedness and Response

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Presentation Outline

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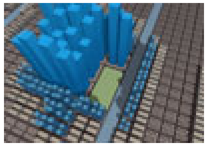
PACER Background

- **National Center for the Study of Preparedness and Catastrophic Event Response (PACER)**
  - **A University Center of Excellence (UCE) sponsored by the U.S. Department of Homeland Security (DHS)**
  - **24-institution consortium led by the Johns Hopkins University (JHU)**
  - **Awarded in December 2005**
  - **3-year grant period beginning July 2006**
  - **5 general areas of research**

PREPAREDNESS THEORY AND PRACTICE
The aim of this research area is to investigate the features that define an event as catastrophic and develop and deploy a Risk Ready "toolkit" for use by local and state emergency-operations planners.

RESPONSE NETWORKS
These PACER projects seek to determine the best means for formal networks to harness the considerable response and Surge Capacity of informal networks.



ANALYSIS, MODELING AND SIMULATION
The PACER researchers in this area are working towards integrating complex Modeling and Simulation platforms for simultaneous modeling of multiple effects and response strategies.

SCIENCE, TECHNOLOGY AND ENGINEERING
The goal of these projects is to identify best means of communications and means for data fusion to promote Situational Awareness and Critical Decision Making.

EDUCATION
These PACER investigators seek to understand the issues and principles of preparedness, and the science of education, sufficient enough to disseminate knowledge, cultivate future leaders, and develop effective educational and training programs.

Source: PACER web site: http://www.pacercenter.org/

Project Background

- Integrated Modeling and Simulation (M&S) Framework Project
  - One of several PACER "cross-cutting" projects
  - Focused on preparing for response to catastrophic events
  - 3-year period
  - Intended to provide a composable set of simulations that can be used as an aid to decision-makers in training/rehearsal
- Participating Institutions
  - JHU Applied Physics Laboratory (JHU/APL) – lead
  - University of Alabama at Birmingham (UAB)
  - Florida Atlantic University (FAU)
  - Florida A&M University (FAMU)
  - The Brookings Institution

Project Aims

- **Overall objective:**
  - Develop a unifying common simulation framework into which smaller, more focused, simulations can be integrated to address various multi-disciplinary problems associated with catastrophic, high-consequence events
- **Specific aims:**
  - Develop a unifying framework for integrating and applying the most promising M&S tools available
    - to address distribution and allocation of resources
    - to determine the effects and efficacy of interventions
    - 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
    - behavioral epidemiology
  - Make tools available to policy-makers, public health professionals, and other end-users in order to aid decision-making, and to identify specific training and educational needs

Key Products

- A web-based catalog of the variety of M&S tools appropriate for the study of preparedness and catastrophic event response
  - initial operation in the spring of 2007
- A Verification, Validation, and Accreditation (VV&A) process manual
  - produced in the spring of 2007
- Demonstration of an Urban Chemical Disaster (UCD) simulation federation based on the High Level Architecture (HLA) standard
  - to examine potential responses to chemical contaminant releases in cities
  - completed in January 2008
- Demonstration of a Bioterrorism Crisis Management (BCM) simulation federation
  - to examine the progress of, and response to, disease outbreaks from biological attacks
  - to be completed in early 2009

Urban Chemical Disaster (UCD) Simulation Objectives

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

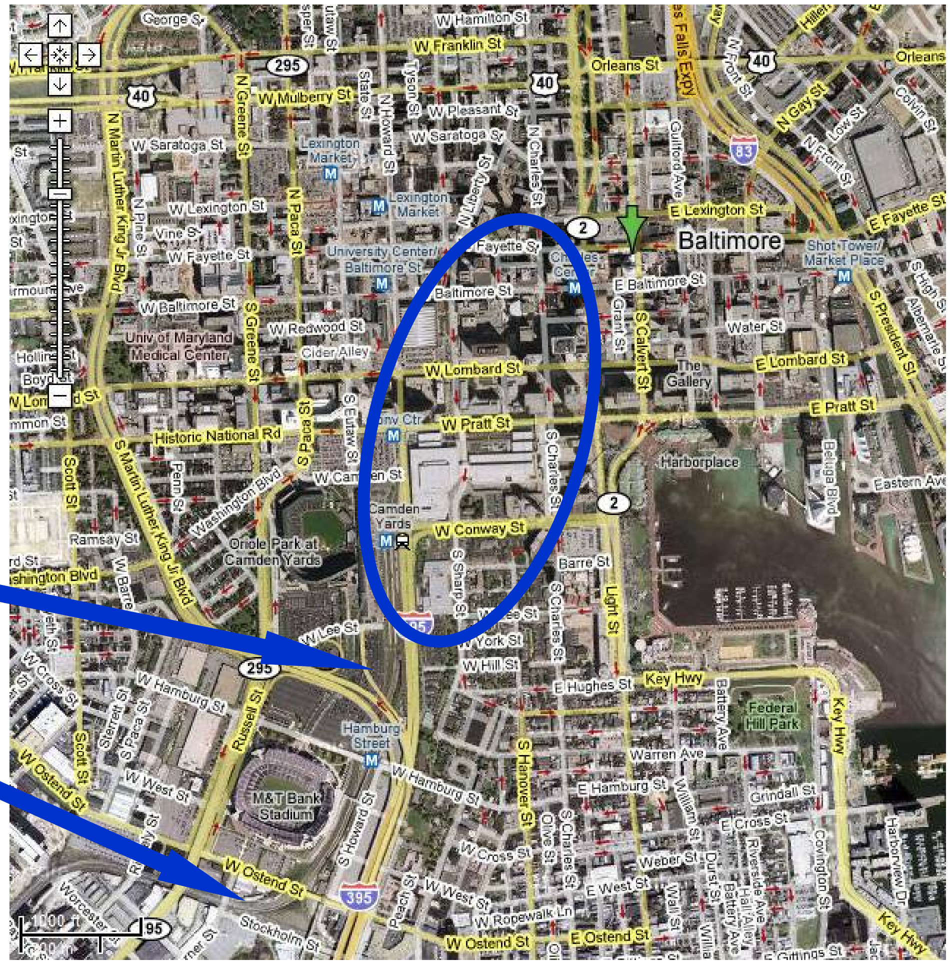
UCD Scenario – Downtown Baltimore

4. Chlorine cloud carried toward downtown by winds

3. Second explosion, 15 minutes later, southeast of baseball stadium

2. First explosion, south of football stadium

1. Train with multiple railcars containing chlorine approaches



Source: GoogleEarth

5. Emergency responders react

6. News reports issued

7. Local commanders order evacuation

8. Police in protective gear dispatched to intersections

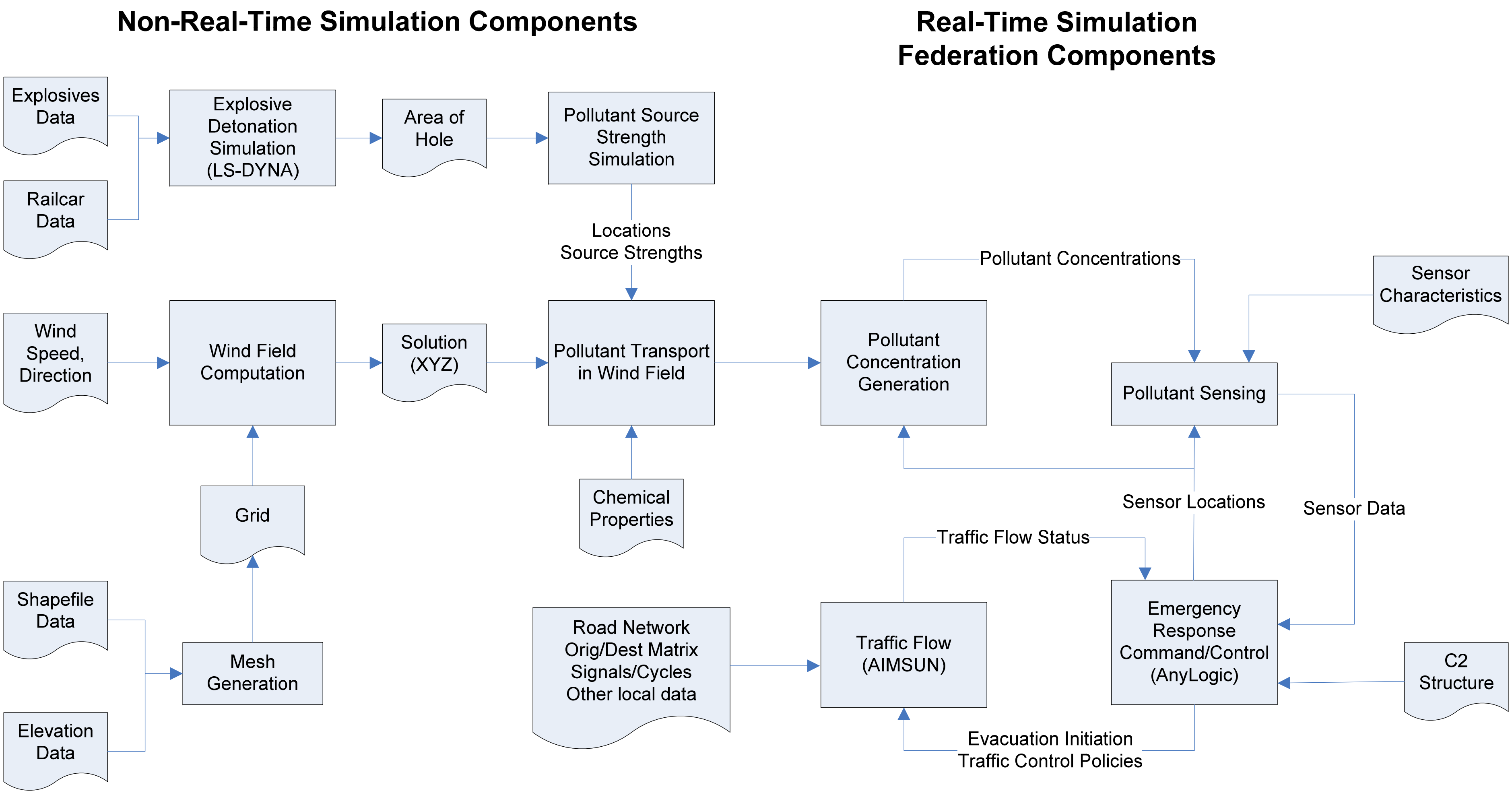
9. Chemical sensors deployed

10. Local populace reacts, traffic builds on roads

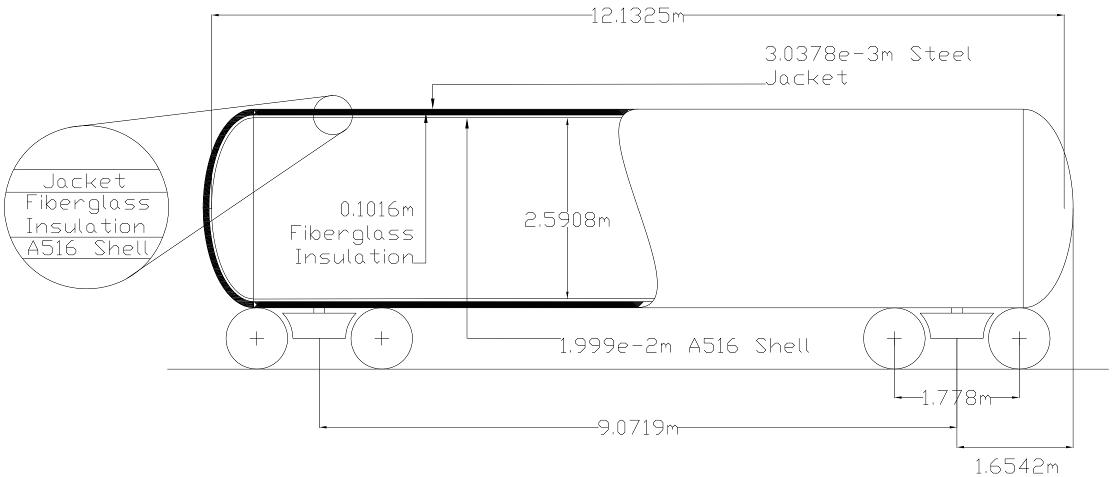
UCD Simulation Design Considerations

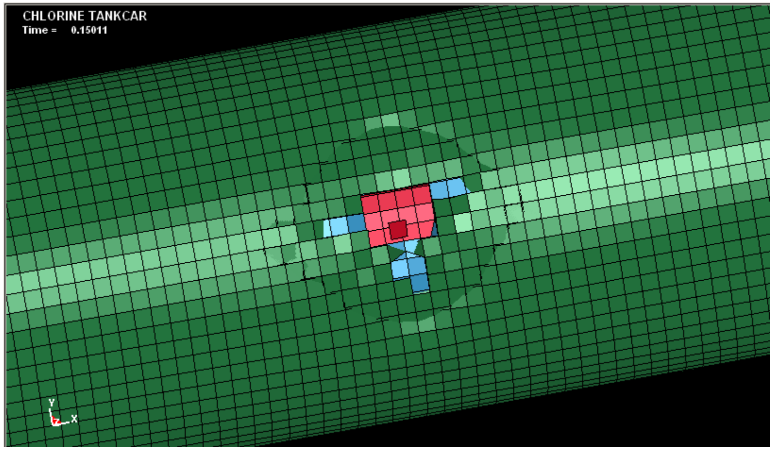
- **Railcar rupture** is virtually instantaneous
  - Serves only to trigger release of chlorine pollutant
  - No feedback interaction from any other simulation component
  - Can be executed in advance
- **Airborne transport** of chlorine through 3D cityscape is very complicated
  - Requires accurate data on size of buildings to calculate wind field
  - Transport of pollutant after release through wind field currently requires multiprocessor configuration, and cannot be executed in real time – decided to divide into three steps:
    - Generation of wind field (slower than real time)
    - Insertion of pollutant into wind field and transport as a function of time (slower than real time), forming data file of chlorine concentrations
    - Extraction of chlorine concentrations in real time from data file
  - First two steps need to be executed in advance of the real-time simulation federation
- Because pollutant transport depends on release rate of chlorine from ruptured railcar(s), the **chlorine release simulation**, although not computationally intensive, also needs to be executed in advance
- Remaining three functions (**sensing**, **command and control**, and **traffic flow**) can be performed in real time as part of simulation federation

UCD Simulation Block Diagram



Non-Real-Time Component: Explosive Detonation and Railcar Rupture





Explosive detonation simulation

- Performed by FAMU
- Using LS-DYNA simulation

Railcar data

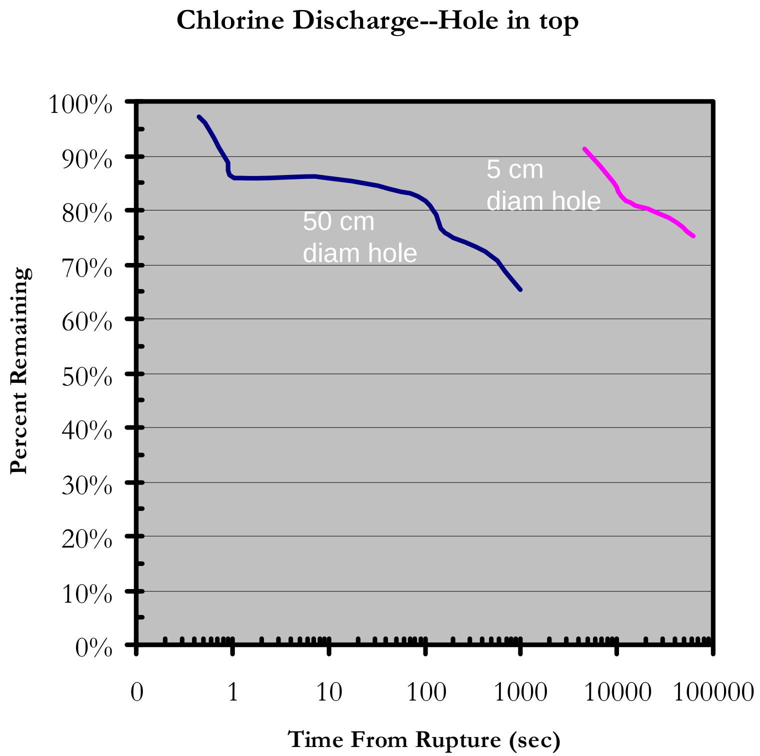
- DOT 105A500W
- Contents: 80,000 kg chlorine
- Inner shell: ASTM A516 grade 70 steel (.02 m)
- Outer jacket: ASTM A516 grade 70 steel (.003 m)
- Insulation: Fiberglass (.1016 m)

Explosives data

- Type: Dynamite
- Weight: 1.33 lb

Non-Real-Time Component: Pollutant Source Strength Simulation

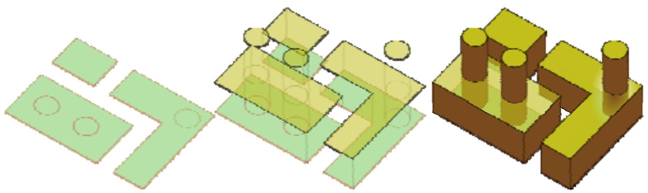
- **Source strength is computed using three fluid discharge sub-models**:
  - Model of liquid discharge through a tank rupture
  - Model of the release of compressed gas
  - Model of vapor released through a rupture above a boiling liquid
- **Input data for each time step**:
  - Atmospheric temperature, pressure and wind speed
  - State of the tank and its rupture
  - Critical properties of the chemical
- **At each time step**:
  - Appropriate sub-model is selected
  - Mass flow rate is calculated
  - Mass balance models are then used to calculate drop in pressure, qualities of two-phase flow and new evaporation rates to define new state of system for next time step
- **Final outputs are flow rates at every time step, aggregated together**



Sample output of source strength simulation

Source: 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)

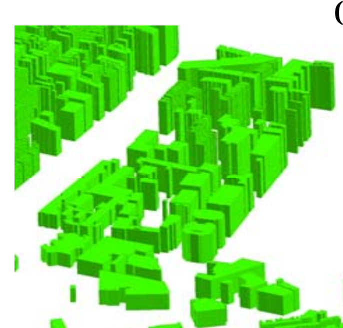
Non-Real-Time Component: Wind Field Computation – Schematic View



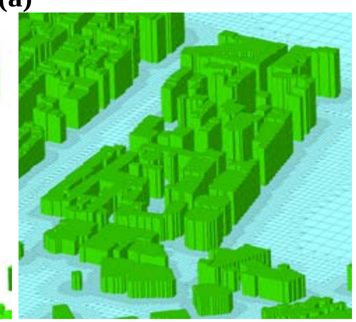
(a) (b) (c)

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

(a)



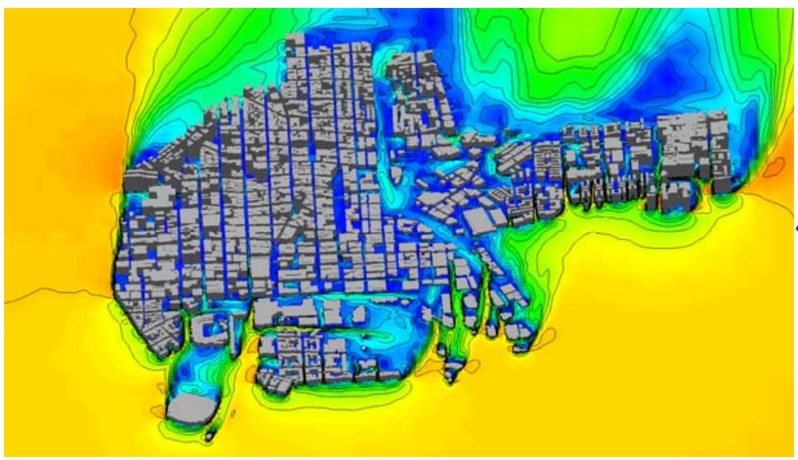
(b)



(d)

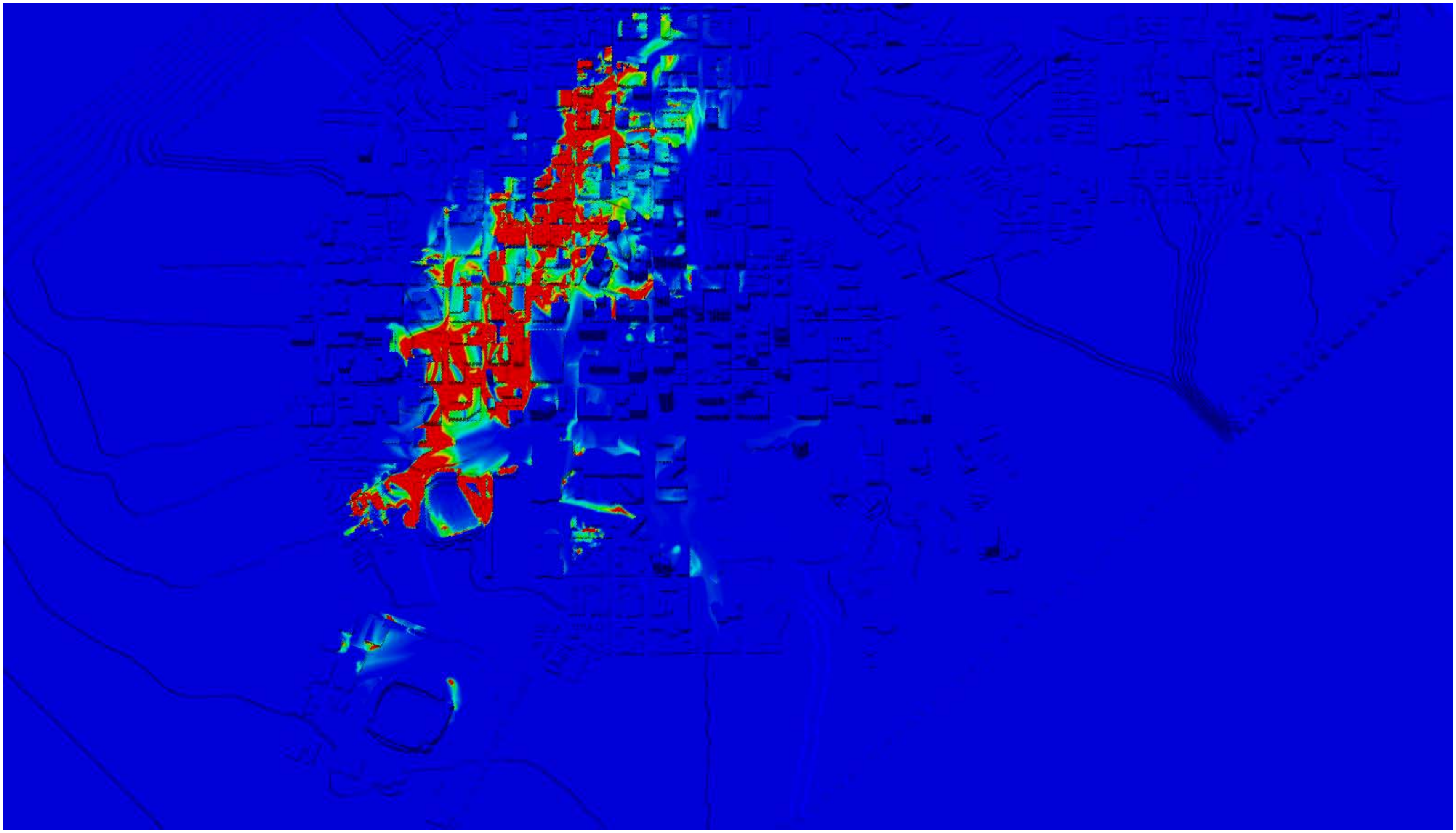
(c)

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



Computer simulated wind field in the city of Baltimore.

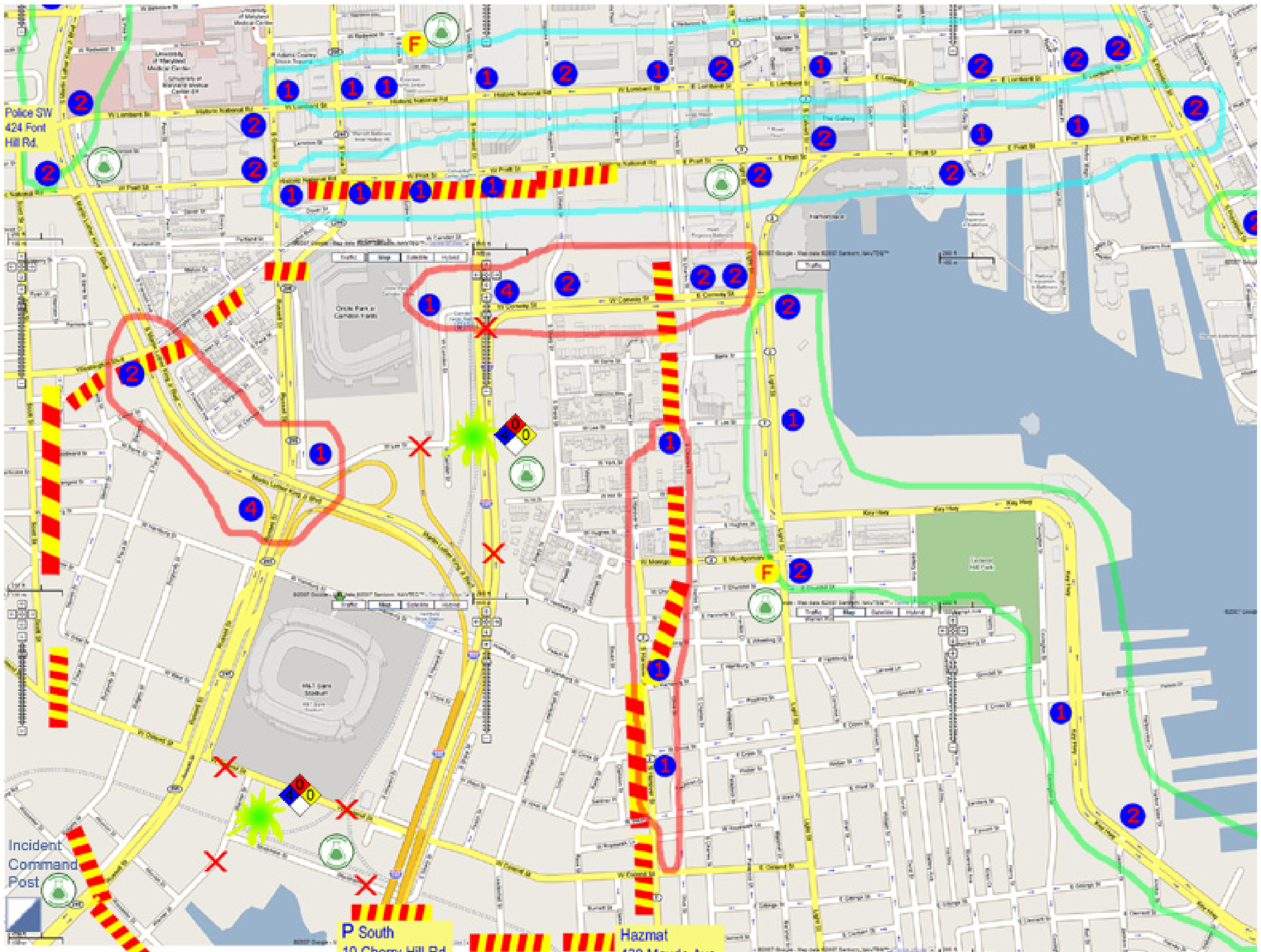
Chemical Plume Dispersion

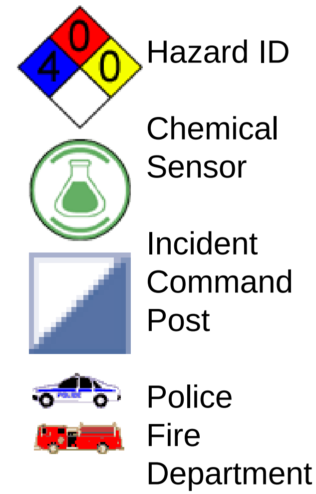


Emergency Management Command/Control

- Implemented by JHU/APL using the AnyLogic (version 6) simulation tool
- Command/control structures follow Federal guidelines in DHS National Response Plan
- Simulates actions called for in the Incident Action Plan (required by DHS National Incident Management System Framework) for the mission areas involved in the incident
- Simulates the activities of the various organizations involved
- Maintains a representation of the Incident Commander's situational awareness based on sensor data and field reports
- Receives pollutant detection information from the sensing simulation
- Communicates with the traffic simulation 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

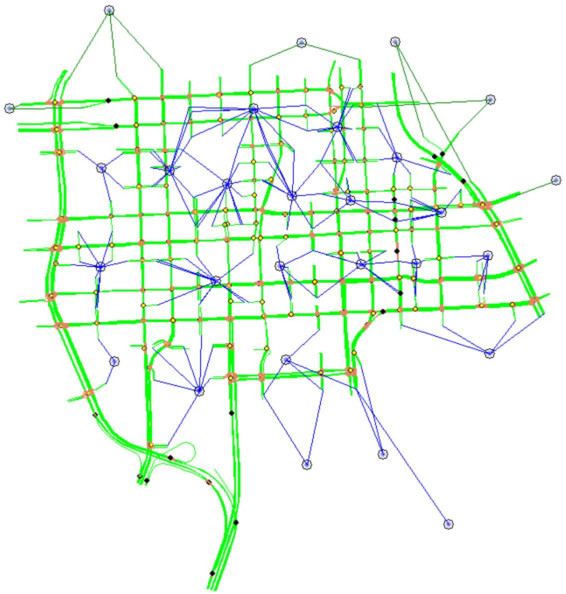
C2 Incident Situation Map





Traffic Simulation

- Implemented by FAU using the AIMSUN (version 5.1) simulation
- Signal timing and phase configuration from City of Baltimore
- Specific zones of affected area need to be evacuated in sequence
  - Area is divided, making distinctions between homogeneous socio-economic zones
    - Data provides information about the amount, characteristics and trip motives of the people in the different zones
  - “Transportation Analysis Zones” from Baltimore Metropolitan Council have been chosen
  - Use of origin-destination (O-D) matrices is dependent upon chosen safe zones established outside of the critical area
    - Matrices based on area population and estimated number of daily commuters during average work week



Road Network as Constructed in Simulation:

- 475 sections
- 156 intersections
- 37 km section length
- 97 km lane length
- 28 centroids (22 zones and 6 exits)

Traffic Simulation Display

UCD Simulation Potential Uses

- Training / mission rehearsal
  - Seminar gaming
    - For course-of-action development
  - Decision-maker training
    - For specific scenarios

- Analysis of alternatives
  - Automated traffic control systems
  - Deployable chemical sensors

JHU/APL Warfare Analysis Laboratory (WAL)