Information Technologies for Civilian Bioterrorism Response

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***Abstract*— To improve the level of preparedness against potential bioterrorist incidents, civilian medical communities in the United States have much to do. Developing effective responses hinge on information technologies namely detection, isolation, communications and education. This paper describes our efforts in integrating these technologies at the National Bioterrorism Civilian Medical Response Center (CiMeRC) at Drexel University. Our particular focus involves scenarios where biochemical agents are released in the public transportation system of a major metropolitan city.**

***Index Terms*— bioterrorism, emergency response, preparedness, epidemiology, computer vision**

I. Introduction

Considerable progress has been made in readying major population centers to respond to biological terrorism, but the development of an effective response during the early stages of an attack, particularly in the civilian medical community, requires more attention. Today's advanced state of information technologies, communications, remote sensing and computing capabilities for predicting complex system dynamics permits developing effective systems for improved response. First, systems that detect and isolate the source and spread of transmissible diseases can be reliably constructed with computer simulation models. Such models have been credited for developing public health infrastructures and response protocols; epidemiological prediction engines that integrate real-time sensor data with statistical databases serve to prepare the health community on precise distribution of available personnel and resources. Second, communication systems that distribute information using off-the-shelf wireless handheld devices featuring a camera, telecommunications and display can be used to rapidly distribute information. Third, educational systems that integrate assessment, information dissemination and knowledge-building for pre-planning bioterrorist responses can be created and integrated to support a web-based distance learning and telemedicine portal. Instruction such as effective treatment techniques and containment strategies would be especially helpful to rural communities which often have limited computer network and telecommunication infrastructures.

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This paper describes our efforts at developing each system and endeavors to construct a civilian medical response network that integrates advanced telemedicine communications and computer network technology with the existing civilian medical infrastructure. In the event of a bioterrorist attack, we envision our network and repository of information concerning best practices to be readily accessible to healthcare providers. Our long-term goal is to provide an instantaneous resource to civilian medical providers who may suddenly be confronted with a biological crisis. Towards this end, system components that gather, synthesize and analyze clinical information from the field and hospitals are being designed. Our efforts are in response to the first recommendation out of the 1999 National Research Council (NRC) Institute of Medicine Report on Chemical and Biological Terrorism [11] which reads "there needs to be a system in every state and major metropolitan area to ensure that medical facilities, including the state epidemiology office, receive information on actual, suspected, or potential terrorist activity." This paper describes our efforts as follows: Section II discusses an assessment of the current preparedness levels of hospital emergency departments in Philadelphia and critical gaps in performance are discussed. An epidemiological dynamic engine that models the release of biochemical agents in the public transportation system is presented in Section III while Section IV discusses computer vision, wireless networks and handheld devices that were designed to automatically collect, process and distribute information. Section V discusses some future work on providing a web portal that integrates assessment, information dissemination and knowledge-building for pre-planning bioterrorist responses is presented. Our case study and test bed revolves around 30th Street Station, a major hub in Amtrak's Northeast Corridor railroad that connects Washington DC, Philadelphia, New York City and Boston. Such hubs also connect to regional rail systems that transport tens of thousands of people between the city and residential areas. To the best of the authors' knowledge, epidemiological dynamics involving the release of biochemical agents in public transportation systems have not be performed. As such, this paper hopes to stimulate research across multiple disciplines, create novel use and development of information technologies to enhance security and reduce vulnerabilities of catastrophic events.

II. Civilian Medical Preparedness

Following disaster incidents, a substantial number of patients may present to area Emergency Departments (EDs) within a relatively short period of time. As a consequence, the level of preparedness of hospital based emergency services to respond to disasters of any etiology is of paramount importance. ED preparedness specific to hazardous materials related disasters has been previously reported to be less than adequate (Cone et al 1997 [7]) In 1997, Burgess et al. [8] reported that only 44.2% (42/101) of hospital EDs had the ability to receive any chemically contaminated patients from Hazardous Material (HAZMAT) incidents and as many as 41.1% (39/95) had no designated decontamination facilities. The purpose of our study was to assess the level of preparedness of hospital EDs in a large metropolitan area to evaluate and treat victims of a terrorist biological or chemical agent release.

All hospital EDs open to the general public in the survey target area (Philadelphia, Chester, Bucks, Delaware, and Montgomery counties in Pennsylvania and Camden County, New Jersey) were included in this study (n = 61). An explanatory cover letter and four-page 38-query survey instrument were mailed to the Emergency Physician Directors (EPDs) of the EDs described above. The questionnaires were mailed between June 19, 2000 and July 5, 2000. The results of this survey indicated that the preparedness of EDs in the greater Philadelphia area, to evaluate and treat victims of a terrorist biological or chemical agent release, is at a low level. Currently, there are no generally recognized specific criteria that define ED preparedness for biological/chemical issues. A key starting point to raise preparedness is *education and training* using repositories of information concerning best practices [2] and telemedicine, distance learning and web-based information technologies [2].

III. Epidemiological Dynamics

From October 3, 2001 through November 16, 2001, there were 18 confirmed cases of inhalational and cutaneous anthrax, an additional 4 suspected cases of cutaneous anthrax, and 5 deaths due to inhalational anthrax (Bartlett et al., 2002 [5]). Although the number of cases of anthrax was smaller than previous estimates of infections and deaths resulting from a bioterrorist attack, this experience brought the threat of bioterrorism to the forefront of the nation's consciousness. By definition, bioterrorism refers to the intentional malevolent release of disease causing agents that can cause sickness or death. Should a bioterrorist attack occur, an awareness of the potential threat of these agents in terms of the number of infections and deaths that could occur in a community is of paramount importance in preparing the public health community to respond to an attack. The primary goal of biosurveillance is to minimize the impact of a bioterrorist attack. While most communities have disaster response systems, a major bioterrorism attack will produce a catastrophe that would overwhelm a community health care system (Flowers et al., 2002 [6]). Bioterrorism response requires precise distribution of available personnel and resources. This distribution of personnel and resources must be based on the expected severity of the attack for a given community. Poor distribution of personnel and resources could result in an increase in infections and mortality; therefore, reliable prediction of the expected severity is crucial.

Computer simulation models can serve as effective tools for developing public health infrastructure for detecting and isolating the source and spread of infections arising from a bioterrorist attack (Hupert et al. 2002 [1]). Independent extensions of these ideas to more sophisticated models which capture various nuances both with the population characteristics, such as movements of people, and the bioterrorism attack characteristics, such as incubation periods and appearance of infection, would provide more information for better bioterrorism preparedness and response. The NRC report specifies metropolitan areas [11]. Public transportation systems, integral to life in cities, to the best of our knowledge have not been incorporated in epidemiological dynamic models. Despite a rather extensive literature on the mathematics of epidemics, little effort has been made to take into account the spread of disease through infectious contacts among people while in public transportation systems (C. Mode 2000 [4]). Stochastic modeling and analysis of state transitions in an air space management systems, using computer intensive methods have been studied and can serve as a framework [12].

A. Epi-Engine

The Epi-Engine described in this paper a stochastic model with embedded deterministic difference and differential equations, can be formulated and has two components. The first models the public transportation system in the Philadelphia metropolitan region. Daily movements of people among the residential, public transportation and work sectors of the region are accommodated in the model. Ridership data can be estimated from daily revenue reports. The R3 is a regional rail line operated by the Southeastern Pennsylvania Transit Authority (SEPTA) and was studied as an example as shown in Figure 1 (top). The R3 travels from West Trenton in New Jersey to Amtrak's 30th Street Station in Philadelphia to the Elwyn-Media suburb in Pennsylvania and crosses both the Delaware and Schuykill Rivers. From revenue data SEPTA estimates that 5,085,465 passengers used the R3 line in 2001. With 248 workdays in a year and assuming most people ride the train in the morning and evening, this results in 10,253 passengers riding the R3 line per workday. Stations along this rail line were weighted in proportion to the scheduled amount of time the train spends at the station; a longer period suggests a large passenger flow at the station. The weights were normalized to form fractions and then multiplied by the estimate of the total number of people using the R3 line on a typical workday to obtain estimates by station and fare zone. The Elwyn/Media to 30th Street Station Segment of the R3 line has 3 fare zones. The West Trenton to 30th Street Station Segment of the R3 line has 5 fare zones. Thus, the component of the Prediction Engine for the R3 line would contain 8 modules. A similar procedure was used to define fare zones for each SEPTA line. Linking each fare zone to hospitals of response was based on hospital directories for Pennsylvania.

The second component of the Epi-Engine dealt with the dynamics of infectious and non-infectious diseases like small pox and anthrax respectively. Given an estimate of the number of people exposed to such agents at some location, one of the capabilities of the engine is to provide estimates of the number of people presenting with clinical symptoms as functions of time as shown in Figure 1 (bottom)).

The principal goal of the Epi-Engine's two components was to provide estimates of the number of people at risk of a terrorist attack in each of the stations on a 24-hour per day, seven days per week basis. The main motivating factor underlying this goal was to supply the health care community with estimates of the number of people needing care should a terrorist attack, biological or otherwise, occur at any time in each of the stations. Given these estimates, the health care community will be in a better position to allocate limited resources to treat the victims of the attack.

Our experience with developing a prototype of the transportation component of the Epi-Engine during the past year has made us keenly aware of the *need for research on information technology that would automate the flow of data into the engine.* As a rule, public transportation systems, whose main motivation for collecting data seems to stem from the desire to manage the flow of revenue, do not collect information in sufficient detail to satisfy the requirements of the engine, which operates on a time scale one hour, one half hour or even 15 minutes during rush hours.

IV. Computer Vision

Interviews with first response teams and site commanders were conducted and revealed that verbal communication between parties in dynamic environments like battlespaces or disaster areas are often misinterpreted. Using a two-way radio to convey information like situational awareness, tasking commands or resource availability can often be misunderstood or misinterpreted, because voice-based systems always have the possibility that questions and answers will be vague, subjective, ill-posed, incomplete, or ambiguous. A video acquisition and imagery distribution system was prototyped. Preliminary results demonstrated that complex instructions like ingress/egress routes can be communicated non-verbally by transmitting images (P. Oh 2003 [3]). Response teams would wirelessly download and view the imagery in real-time using a Palm Pilot-type handheld device. The system was based on ubiquitous and rugged wireless local area network (WLAN) and Internet technologies [13]. The prototype's initial infrastructure consisted of: (1) both wired and wirelessly networked video cameras acquire different perspectives of an environment; (2) a web server to distribute the imagery generated; (3) handheld devices like Pocket PCs and Palm Pilots retrofitted to operate wirelessly and programmed to both download and view imagery; (4) imagery creation software that processes video for example, count the number of objects in a scene, highlight streets observed in an aerial photo, overlay global positioning system (GPS) coordinates on photos or mosaic multiple images have been developed.

A. Image Mosaicks

Mosaicing is an image processing method that essentially "stitches" different images and aligns them into a larger one [10]. The net effect is a single large field-of-view picture that

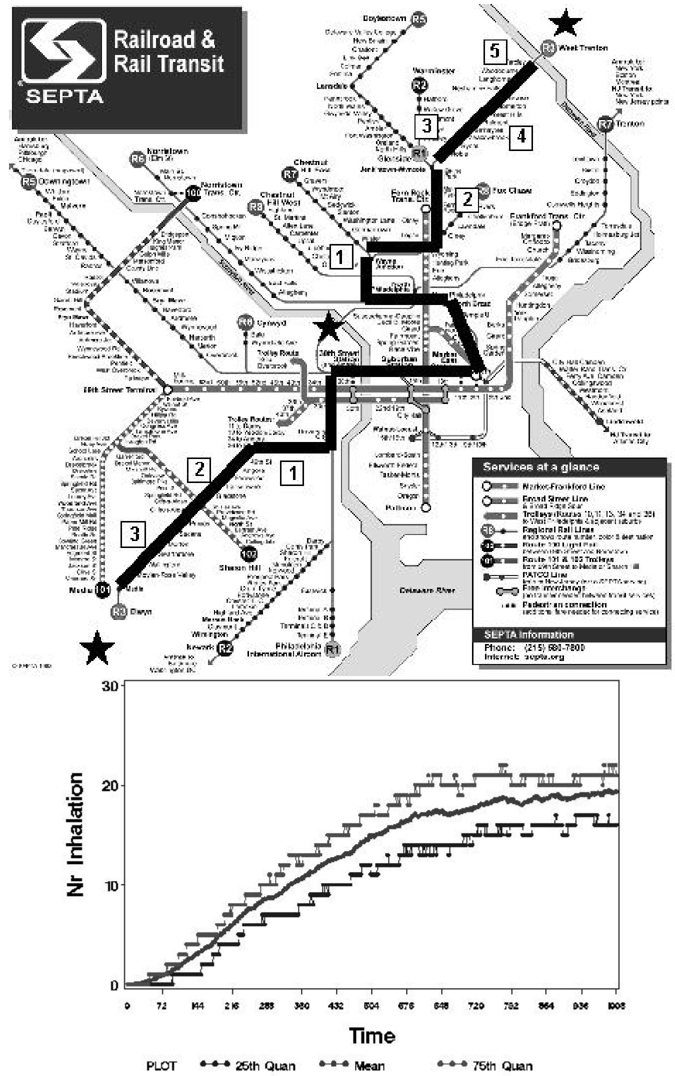

Fig. 1. Top: The approximately 2 hour rush hour commute on Line R3 (bolded) begins in West Trenton ($\star$ symbol in top right) and crosses the Delaware River enroute to Amtrak's 30th Street Station in central Philadelphia ($\star$ symbol in middle) then heads southeast to the Elwyn/Media terminal ($\star$ symbol in bottom left). Numbers in boxes denote fare zones where the number of area hospitals were identified. Bottom: Cumulative numbers of people needing care with inhalational Anthrax at each time in the projection.

permits more situational awareness. An example of mosaicing software we've developed is shown in Figure 2 (left). Here, various image stills were extracted from aerial video footage and mosaicked together. In Figure 2 (right), streets in an aerial photo were identified with edge detection image processing and were cross-referenced to global positioning system (GPS) coordinates we acquired from public databases. These coordinates and other useful text (like street names) were superimposed on the aerial photo. The resulting imagery can be distributed to medical response teams to geo-locate resources like triage sites.

B. Virtual Models 3D Reconstruction

Once acquired, the viewer is limited to whatever details are visible in the two-dimensional (2D) photo or video. Beyond magnification and cropping, the viewer cannot interact with the

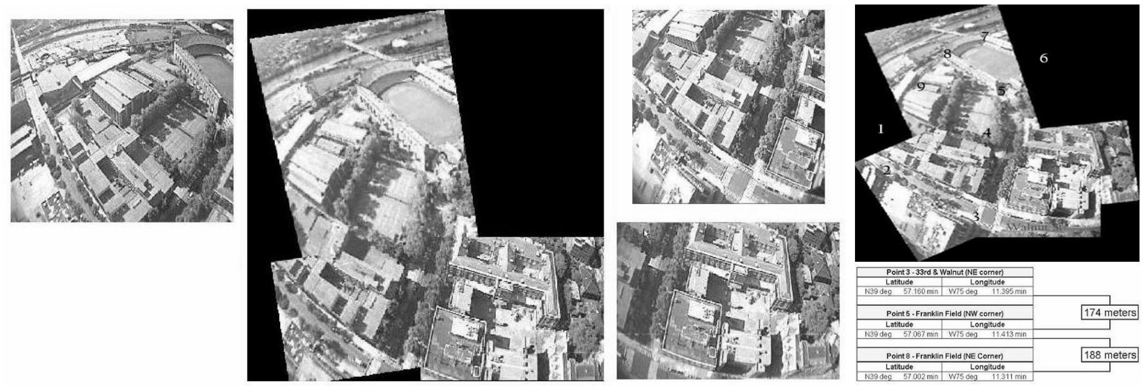

Fig. 2. Image mosaic created from disparate aerial images of area near 30th Street Station (left). Image geo-referenced with GPS longitude and latitude coordinates (far right).

image much. Figure IV-B (top) depicts a a potential terrorist target, namely 30th Street Station in Philadelphia. Such photos, like the two aerial views, would be typical of those captured during the an incident. The raw aerial photos show the station and surrounding architecture but beyond simple zooms and cropping, little information can be gathered or conveyed.

3D reconstruction (3DR) is the machine vision technique of creating a computer-generated graphical model from 2D images [9]. We created a model so that an incident commander can rotate, translate and zoom to identify and indicate key information. Figure IV-B depicts screenshots of the 3D model reconstructed (bottom two) from an aerial photo (top). This 3D model can be easily manipulated in a standard web browser like Netscape or Internet Explorer.

C2 could then highlight areas on screenshots to convey information to response teams. For example, ingress and egress routes can be ascertained after manipulating the model. Rather than verbal reports and orders, such 3DR imagery would enhance and augment C2 capability, more effectively and efficiently communicating information.

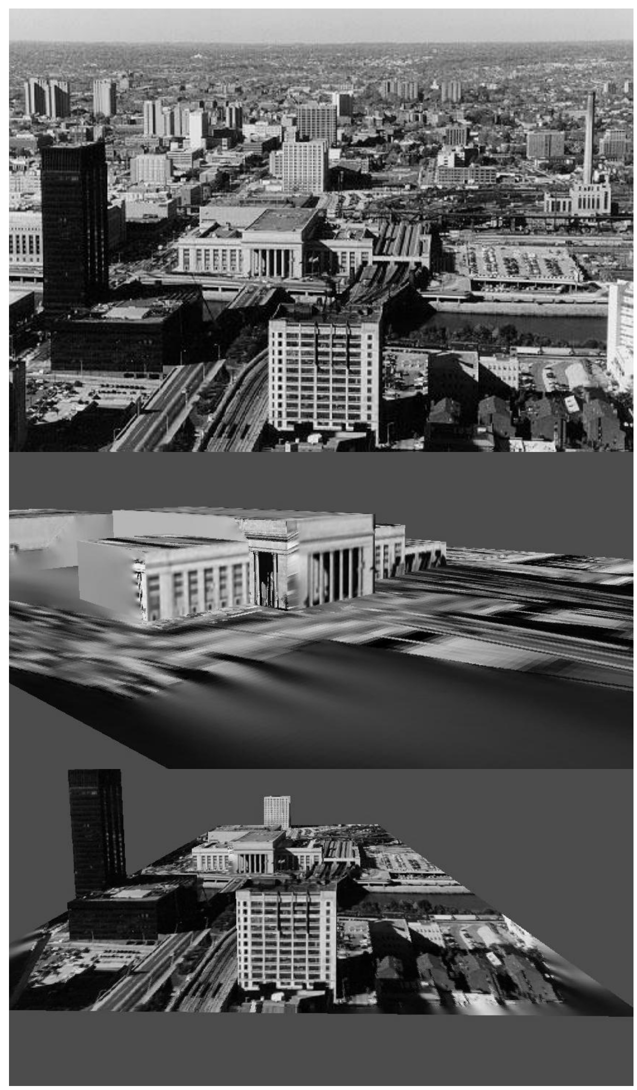

Fig. 3. Left: Aerial photo of 30th Street Station in Philadelphia. Middle and Right: Screenshots of 3D reconstructed model panned and zoomed

V. Future Work

The first goal under consideration is the development of a capability to automatically gather ridership data into the Epi-engine and generate visual representations of its output to points of need. The second goal is to derive a deterministic model given the stochastic model. Numerical solution of the deterministic model would provide information in assisting the response decision process. Our third goal is to use computer vision to gather data and process it for the Epi-engine. A secure, spatially distributed, real-time on-line data acquisition, communication, information retrieval, analysis and management system would be created for this.

Achievement of the first goal will provide the team with a collection of data that may be used to calibrate or validate existing statistic models used in assessing ridership patterns. It will also aid in the development of new or updated analyses procedures and modeling guidelines. Fulfilling the second goal, will lead to a greater understanding of the detection and isolation of biochemical agents released in transportation systems and help response communities to learn important lessons from such events. Lastly, success with the third goal will yield methods to rapidly transmit and convey information non-verbally. This is significant in that rural areas often resort to fax machines, lacking high-bandwidth infrastructures to process and access information [11].

The use of online learning communities, like WebMD for health professionals, has been shown to provide a scalable education program quickly reaching a very large audience and rapidly generating high quality content that is developed and delivered on an as-needed basis. As such, a web portal can be designed to foster cross-community learning and help physicians evaluate the readiness of a health care facility to respond to a bioterrorist attack. Physicians could use the information repository as well as the interactive services (i.e. Ask-an-Expert query engine) to build and maintain their competencies. The web portal could be used to retrieve Epi-engine results and serve the civilian medical community; physicians will have the opportunity to have a query answered automatically by an Ask-an-Expert service.

REFERENCES

[1] Hupert, N., Mushlin, A.L., and Callahan, M.A. “Modeling the pubic health response to bioterrorism: Using discrete event simulation to design antibiotic distribution centers”, *Medical Decision Making*, 22, S17-S25, 2002.

[2] Greenberg, M., Jurgens, S., Gracely, E., “Emergency Department Preparedness for the Evaluation and Treatment of Victims of Biological or Chemical Terrorist Attack”, *Journal of Emergency Medicine*, V22 N3 pp. 273-278, 2002.

[3] Oh, P.Y., Green, B,. “A Teleoperated Vision System for Acquiring Aerial Images,” *IEEE Int Conf Robotics & Automation*, Taipei, Taiwan, May 2003 (submitted)

[4] Mode, C. J. and Sleeman, C. K. Stochastic Processes in Epidemiology, HIV/AIDS, Other Infectious Diseases and Computers. World Scientific, New Jersey, 2000.

[5] Bartlett, J.G., Inglesby, T.V., and Borio, L. “Management of Anthrax”, *Clinical Infectious Diseases*, 35, pp. 851-858, 2002.

[6] Flowers. L.K., Mothershead, J.L., and Blackwell, T.H. “Bioterrorism preparedness II: the community and emergency medical services”, *Emergency Medicine Clinics of North America*, 20, p. 457, 2002.

[7] Cone D.C., Davidson S.J., “Hazardous materials preparedness in the emergency department”, *Prehospital Emergency Care*, pp. 85-90, V1, 1997.

[8] Burgess JL, Blackmon GM, CA Brodkin, et al. “Hospital preparedness for hazardous materials incidents and treatment of contaminated patients”, Ŵest Journal of Medicine V167, pp. 388-91, 1997.

[9] Debevec, P., Taylor, C.J., Malik,J., “Modeling and Rendering Architecture from Photographs: A Hybrid Geometry-and-Image-based Approach”, *Proc. SIGGRAPH 96 Computer Graphics Proceedings*, Annual Conference Series, New Orleans, pp. 11-20, Aug. 1996.

[10] Szeliski, R., “Video Mosaics for Virtual Environments”, *IEEE Computer Graphics and Applications*, Vol. 16, No. 2, pp. 22-30, 1996

[11] Chemical and Biological Terrorism: Research and Development to Improve Civilian Medical Response by *National Research Council*, Institute of Medicine, National Academy Press, 1st edition, 1999.

[12] Ringel, E.I., Mode, C.J., “A Stochastic Analysis of State Transitions in an Air-Space Management System”, *Journal of Operations Research* V42, pp. 262-273, 1994.

[13] Zhang, R., Tsatsanis, M., “Network-assisted Diversity Multiple Access in Dispersive Channels”, *IEEE Trans Communications*, V50 N4, pp. 623-632, 2002.