Disaster Forensics: Leveraging Crisis Information Systems for Social Science

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ABSTRACT

This paper contributes to the literature on information systems in crisis management by providing an overview of emerging technologies for sensing and recording sociological data about disasters. These technologies are transforming our capacity to gather data about what happens during disasters, and our ability to reconstruct the social dynamics of affected communities. Our approach takes a broad review of disaster research literature, current research efforts and new reports from recent disasters, especially Hurricane Katrina and the Indian Ocean Tsunami. We forecast that sensor networks will revolutionize conceptual and empiricial approaches to research in the social sciences, by providing unprecedented volumes of high-quality data on movements, communication and response activities by both formal and informal actors. We conclude with a set of recommendations to designers of crisis management information systems to design systems that can support social science research, and argue for the inclusion of post-disaster social research as a design consideration in such systems.

Keywords

Sensing, sensor-networks, context-awareness, social science, forensics

INTRODUCTION: THE ROLE OF TECHNOLOGY IN DISASTER

Humans have deployed technology to combat disaster since the beginning of recorded history. The cradle of Western civilization, the Tigris-Euphrates river valley, was settled and urbanized through an extensive flood control infrastructure that stabilized the flow of water to fields while also protecting fixed settlements. Nature provided the means of destruction, yet by developing a social structure complex enough to mount a large-scale response, man was able to harness it to produce a stable food supply.[1] In a sense then, the onset of disasters like flood and famine can be considered fundamental contributors to the development of civilization and cities.

Over the past centuries, the role of technology in disasters has expanded from mitigating the impacts of natural disaster to also emerge as the very means of producing disaster itself. The devastating effects of aerial bombardment of cities during wars in the 20th century may well have killed more people than all natural disasters in history combined. Chernobyl (1986) and Bhopal (1984) demonstrate the potential for chemical and nuclear industrial accidents to cause major disasters. Terrorist attacks mounted by Islamic fundamentalists in New York, London and Madrid during the 2001-2005 period demonstrated how urban technological infrastructure, targeted against itself, could be harnessed to destroy. Some experts argue that in the 21st century a biotechnological disaster is an absolute certainty.[2]

Yet while creating new kinds of technological disasters, the industrial revolution also provided vastly improved tools for post-disaster reconstruction. Despite the greater vulnerability of larger and more exposed settlements to both man-made and natural events, in the last two centuries virtually every city seriously damaged by disaster has been rebuilt. [3] Industrial resource extraction and mass production methods organized labor, capital and raw materials into massive reconstruction efforts that, for instance, rebuilt war-torn Germany and Japan into two of the world's wealthiest nations in just a few decades.

Today (at least in the developed world) industrial technologies and mechanical methods for protecting cities from disaster are highly developed.[1] Efforts to leverage technology to prepare for disasters now emphasize the development of more sophisticated planning and response techniques. Information and communications technology play a critical role in complex disaster response plans, which are becoming increasingly dependent upon these tools to improve disaster mitigation capability.

The argument we seek to advance in this paper is not about the role of technology in preventing or preparing for disaster, but rather in studying and reconstructing disasters *after* they have occurred. While a relatively small subfield within the social science research community, "disaster research" encompasses a large intellectual terrain of issues of critical importance: the social dynamics of evacuation, how people and organizations react to warnings and information during crisis, and how communities respond to and rebuild after disasters.

Current trends indicate that future information systems for crisis management will generate enormous volumes of information of interest to social scientists who study disasters. This paper examines the potentially revolutionary impact better sensing and recording of disaster phenomena could have on this nascent field of social research.

INFORMATION AND COMMUNICATIONS TECHNOLOGY IN DISASTER RESEARCH

Before we discuss future possibilities for the use of information technology in the sociological study of disaster, it is useful to review the relatively unrefined ways in which the field currently uses information technology in research.

Disaster research, as a multi-disciplinary field, lacks a commonly shared set of research tools and methods. It is therefore difficult to determine how new technologies are currently used as research tools. However, at least three broader trends in the social sciences are clear, and each has important implications for disaster studies. First, unprecedented access to sociological data and the computational power to analyze it is leading to a broad shift across social science disciplines to sophisticated quantitative techniques. Second, access to GIS and remote sensing technology has improved rapidly over the last two decades and is clearly impacting the way disaster researchers frame and execute studies. Finally, perhaps the greatest impact has been the way the Internet has provided a new platform for archival research, publication and dissemination of research, and collaboration.

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[1] While they may still infrequently fail, as occurred in September 2005 in New Orleans when several levees failed in the aftermath of Hurricane Katrina, the problems and solutions to these types of disasters are well understood. Also, largely unique cases like the construction of flood gates in protect Venice and London remain isolated cases.

The Mathematicization of Social Science

The spread of digital information technology in the 1990s has reinforced a shift in social science research methodology by providing tools for collecting, managing, disseminating and analyzing large volumes of quantitative data. One way many disciplines such as economics have adapted is by placing a greater emphasis on quantitative techniques for making sense of it all.

The extent to which new methodological and empirical techniques are used varies substantially both among and within disciplines. Economics has been at the forefront in using mathematical techniques while in political science the backlash has been visceral. [4] Disaster researchers are largely trained as sociologists, and rely on a multiplicity of research methods ranging from quantitative field work and case study approaches to more advanced statistical methods. Ambivalence about the choice of appropriate research technique has led to an inability to incubate advanced mathematical techniques inside the field itself. As a result, major recent breakthroughs in quantitative sociology have largely come from physicists and mathematicians interested in studying social systems. For example, the major advances in social network analysis in the late 1990s were almost exclusively the work of a handful of physicists applying the arcane mathematics of graph theory to human social networks. [5]

Desktop GIS

Desktop mapping and geographic data management software, or geographic information systems (GIS), have "created an explosion in the demand for methods and tools that allow the explicit treatment of space in empirical application." [6] Disaster researchers have extensively documented the use of GIS in disaster planning and management. [7] Yet a 1997 review found that "GIS has yet to be integrated into social science research on disaster". [8] For the most part, the use of GIS in disaster research has been for cartographic visualization rather than spatial analysis.

One obvious use of GIS in disaster research is remote sensing through satellite and aerial photography. Until recently, social scientists have not had easy access to timely post-disaster imagery due to cost and security constraints. This is rapidly changing - free satellite imagery services such as Google Earth were widely used by researchers after several disasters during 2005 to rapidly assess damage to the built environment, and the prospects for reconstruction and resettlement. [9]

The Internet and the World Wide Web

As in many fields, the Internet is a key enabler of collaborative efforts in disaster research. Electronic newsletters, listservs and a handful of websites are used to support exchange within the disaster research community. The University of Colorado's Natural Hazards Center serves the community's primary online gathering place for information and news. Operating listservs, newsletters and a database of thousands of research papers, conference proceedings, newsletters, and announcements from 1996 onward. [10]

The web is also growing increasingly important to disaster researchers as a source of historical and archived documents from past disasters.

Finally, the web is providing new capabilities for archival research and data collection. In recent years, a number of efforts have made large archives of historical documents accessible via the web. The *David Rumsey Map Collection*, for example, provides over 11,000 high-resolution scanned images of rare 18th and 19th century maps. [11] GIS tools also allow researchers to integrate historical maps with modern data layers such as satellite photography. Other sources of historical information include the Ellis Island passenger arrival records database [http://www.ellisisland.org] and the genealogical records of the Church of Jesus Christ of Latter-day Saints [http://www.familysearch.org]. These tools are increasingly used by disaster researchers to provide rich historical context to disaster investigations.

The Slow Adoption of New Technology in Disaster Research

New technologies have been essential to the development of disaster research, allowing for frequent and rich collaboration despite the small size and broad geographic distribution of scholars. However, by social science standards, this discipline has been relatively slow to adopt more advanced computational techniques for data analysis, visualization or spatial analysis.

Why is this so?

The small size of the field, and it's location at the fringes of established disciplines is clearly a major culprit. With many lone investigators scattered across many institutions, there has not been a critical mass of scholars in one place to develop long-ranging research agendas that can support technology-intensive methods and tool building. The field's highly inter-disciplinary nature also means there is a lack of methodological consensus required to build markets or constituencies that would support development of a specific tool or technique.

The second reason why disaster research has fallen behind in research technology – which brings us back to the central argument of this paper - is that the limits on data collection do not require it.

For the most part, the dominant method of data collection in disaster research - manual archival searching or ethnographic fieldwork – produce volumes of data that are manageable using conventional manual techniques. While software tools for analyzing larger sets of quantitative data are in use, the volume of data usually does not justify the expense of a computer-based analysis.

SENSING, SURVEILLANCE AND THE FORENSIC ANALYSIS OF DISASTERS

Disaster research thus finds itself in a challenging position. A lack of resources for high-volume sampling and collection of disaster observations has stymied the development of analytical tools, techniques and technologies. Yet this same technological stupor has helped deter new talent from invigorating the field with fresh approaches to data gathering and analysis.

New Sensing Networks

New sensing and surveillance technologies may offer an escape from this Catch-22. In recent disasters, our ability to reconstruct detailed timelines and maps of disasters has been augmented by the proliferation of sensing and surveillance devices in the built and natural environment. Digital communications networks leaving traces of social "nervous systems" like mobile phones and the Internet, in and around disaster sites. As these technologies diffuse widely and rapidly in the coming decade, each future disaster will leave a greater volume of data than the one before it.

Sensor networks are not a new concept in disaster planning; they have been used in weather forecasting and seismology for decades to improve warnings. In the next decade, ongoing research and development is likely to yield sensing devices with significantly reductions size and cost, longer operating life, and higher sensitivity. Ad hoc mesh wireless communications protocols, designed for rapid battlefield deployment, will allow sensor networks to be rapidly deployed in disaster settings. [12] "Lab-on-a-chip" systems will push sophisticated processing and actuation further towards the edges of sensor grids. [13]

Prototypes of future disaster sensing grids are underway. The vulnerability of transportation infrastructure has made it a particularly fruitful testbed. For example, Sandia National Laboratory has developed chemical sensing networks for the Washington D.C. Metro subway system. [14] In California, an extensive freeway sensor network will provide valuable data about vehicle movements during and after a major earthquake. [15] The states of Missouri has partnered with wireless telephone companies to randomly sample the location of mobile phone subscribers, and will use this data to model traffic movement both during normal and emergency situations. [16] In the future, we expect to see other infrastructure networks, such as the electrical grid, instrumented to a similarly fine level of detail. Researchers may be able to re-create evacuation patterns not only by tracking vehicle movements but by looking at electricity flows to individual homes.

Sensor networks are therefore building up an archive of data that can inform disaster research. In the natural environment, remote and on-site sensing networks are aware of changes in climate, weather, and contamination at greater and greater resolutions. In the built environment, sensors can provide real-time streams of data on energy consumption, structural integrity, and the people and objects moving about in buildings and on streets. In virtual spaces, activities such as communicating and browsing leave a trail of digital breadcrumbs and transcripts that can be recalled at a moment's notice.

A Forensic Approach to Disaster Research

The proliferation of new sensor networks and the data they produce during crises poses a challenge to disaster research: how can we use data about the physical world to understand social dynamics? We propose that disaster experts should begin to think about the post-mortem study of disasters as a kind of forensic pathology – what evidence can we collect about the physical world that allows us to infer the motivations and actions of individual actors?

Before the scientific revolution, the dominant investigative techniques used in criminal investigations were witness accounts and religious or spiritual ritual. By the end of the19th century, however, fingerprint analysis and techniques for identifying poisons had laid the groundwork for forensic criminal science. The 20th century saw a steady stream of new innovations in forensic pathology: the use of anthropologists in identifying skeletal remains, and the development of DNA fingerprinting. [17]

Compared to forensic pathology, the reconstruction of social dynamics during disasters is still rooted in the 19th century, dominated by anecdotal evidence.

The impact of widespread sensing and surveillance during and after disasters will transform data collection in disaster research in three main ways. First, the data collected will be objective rather than subjective. Much of disaster research is based on archival research of media coverage or through interviews with victims and responders days, months or even years after the fact. By relying so heavily on witnesses today, disaster researchers face the same challenges criminal investigators have historically - witness accounts are proven to be unreliable records of actual events. Second, sensing and surveillance systems will often provide overlapping coverage, providing multiple sources of data regarding the same phenomena. These accounts can be used as a diagnostic check to ensure data accuracy. Third, many types of phenomena that could previously only be measured qualitatively through witness interviews and informal sources can now be measured quantitatively. Among other things, this shift could enable a better understanding of evacuations or the performance of infrastructure networks.

The Role of Informal Surveillance

Surveillance systems and personal multimedia recording technologies may provide an even richer and more relevant source of data for disaster researchers than large-scale sensor networks. These devices will provide the immediacy of first-person accounts without the errors introduced as witnesses' memories fade and change over time. Also, the data they produce may be more relevant to social research questions than logs of quantitative sensor data of physical phenomena.

Surveillance camera networks played a major role in deconstructing many of the events of September 11, including the timeline of evacuation and structural failures at the World Trade Center. After the December 2004 Indian Ocean tsunami, teams from the University of Buffalo were able to rapidly capture "collect perishable information about building and lifeline damage characteristics" using a portable surveying system that integrates GPS, satellite photographic and personal video recording. [18]

Informal recordings of disaster are an increasingly important alternative source of information about disasters. The development of cinema photography and television in the twentieth century has transformed the way we record disaster. The earliest motion video recording of a disaster in progress that we have been able to identify is the the film of the structural failure and breakup of the Tacoma Narrows Bridge taken by F. B. Farquharson in November 1940. [19]

Throughout the post-war era, television networks became increasingly effective at recording the human experience of disasters around the world. However, it was not until the introduction of the personal video recorder in the 1980s, that we began to see the potential of widespread video documentation of disasters for research. Personal video recordings were used in many recent disasters to supplement and confirm timelines – the structural failure of portions of the San Francisco Bay Bridge in 1989, the collapse of the World Trade Centers in 2001, and the arrival of the 2004 Indian Ocean tsunami.

We expect the importance of personal, informal recordings for disaster research to increase dramatically in the next two decades. Consumer electronics companies expect to market "life recorder" devices that combine multimedia sensing capabilities with massive storage capacity. Such a device would likely incorporate 24 hour-a-day video and audio recording, annotated by telemetry from other instruments and context sensors like location, social setting (proximity of other people) and even emotional state. Ten years in the future and beyond, such devices will also increasingly be able to recognize objects and people in their field of view, and be able to communicate that information to remote locations via a wireless network. [20] Future disasters are likely to be inundated with swarms of amateur archivists documenting unfolding events from the bottom-up.

The final set of sensing and surveillance practices that will impact disaster research are the traces and transcripts of digital communications that are increasing being logged, recorded, and even intercepted and rebroadcast. This surveillance of virtual disaster spaces will provide perhaps the most important archive of research data for social scientists, allowing them to recreate the flow of interaction among organizations, and in many cases understand the content of the information being exchanged.

The value of informal recordings in re-shaping our after-the-fact understanding of disaster choreography were most clearly highlighted by the events in New Orleans in the aftermath of Hurricane Katrina in August 2005. Throughout the storm and bungled government response, Internet activists patched Louisiana State Police scanner feed to an Internet webcast. A self-organized group of volunteers then transcribed the transmissions into text on an Internet Relay Chat (IRC) channel. While official transcripts would surely have been produced during official investigations of the response months or years after the fact, new technologies allowed onlookers to immediately create an alternative version, instantly accessible across the Internet.[2] While we are not aware of any instances of their use, cellular telephone and SMS messaging records could provide deep insight into how both official responders, bystanders, and victims react to disasters – whom do they communicate with and when? Internet website statistics could also help us map the flow of information about disasters, and the geography of aid donations and other relief activity. Finally, combined with sensor network data and multimedia surveillance, researchers will have a much deeper picture of the broader context in which these communications took place.

The Potential of New Data

The focus of much disaster research today is on prevention and mitigation. However, technologies and scenarios described here do not hold much promise in helping predict or avert future calamities. They do promise, however, to improve our ability to make more sense of disasters after they occur, and understand how we react individually and collectively as social creatures in times of crises. Collection and analysis of vastly richer impressions of disasters through sensor networks, communications logs, and multimedia recordings will provide new opportunities in an area of inquiry where historically data has been scarce, or questionable quality, and subject to political manipulation.

If other fields are a good indicator, however, improvements in analytic techniques lag significantly behind advances in data collection. So ironically for such a data-starved field, our ability to sense and record data about disasters is increasingly likely to exceed our ability to make sense of the record. As we shift from a world of a single media format (text) created directly by human authors to one of many media created by machines, the sense-making challenge increases relentlessly.

BUILDING CRISIS INFORMATION SYSTEMS THAT SUPPORT DISASTER RESEARCH

Largely by accident, recent disasters have created new and detailed sources of data of value to social scientists. Formal sensor networks, informal bottom-up surveillance, and the logs of digital communications networks are generating a sea of data that can be archived and made accessible to researchers investigating the dynamics of human behavior during and after crises.

The goal of this paper has been to familiarize the crisis information systems community with the value and potential impact of new sensing and recording technologies on the social investigation of disaster. We now turn to the question of how this insight might influence the design of such systems to make them more useful to this process (of course, without compromising their main function). Put simply, how can crisis information systems support the important, but secondary, mission of providing detailed accurate data about sociological phenomena?

The first key considerations is that (for the most part), the recording of sociological data needs to be a background process. Recording such data about disasters is simply not a priority for victims or responders who are making life-and-death decisions. This principle has two caveats, however. The first would be in situations where such systems could serve as an early warning system of sociological phenomena such as discontent, riots, etc. that would have an immediate short-term impact on crisis management operations. The second would be in informal systems where

[2] See for example, http://www.metafilter.com/mefi/44746. The now-defunct website www.nola-intel.org operated during much of Katrina to provide links to the IRC and feeds. Transcripts are currently archived at http://carolinacomputingsolutions.com/nola/.

there is far less responsibility for crisis management, such as the camera phone photos of the London subway bombings. To the point where these activities can be conducted without interfering with crisis response, they should be encouraged and integrated with official information gathering networks.

A more general consideration, though, is what should the role of crisis information systems be in gathering, integrating and archiving data from various sources about disasters. What would an ideal "black box" at the city level look like for a large-scale urban disaster? A key issue here is around the balance between centralized and peer-to-peer mechanisms for sharing information. Today's disaster response systems largely fall into the first category but are rapidly shifting to enable more horizontal flows of information to respond to the realities of how disaster response communities function. How can the information-gathering capabilities of citizen first responders be leveraged be both real-time and archival use?

A third consideration revolves around security. The informal surveillance of response operations during hurricane Katrina in New Orleans exposed many of the intricate workings and failures the local, state and federal emergency response infrastructure. Clearly, this information is just as valuable to potential terrorists as it is to emergency planners.

Next, what kind of sensing infrastructures could disaster researchers deploy on our own, as individuals or in larger collaborations? These need not be vast and expensive, but could leverage the unique economies of "peer production" on the Internet. For instance, Eagle argues that next generation mobile phones – location-aware and connected to the Internet - provide a platform for measurement of sociological phenomena vastly superior to conventional methods. [21] Finally, disaster researchers need to initiate a larger conversation about what types of data need to be collected to inform the field. While it is unlikely that such deliberations will have major impacts on the design of third-party sensing networks, they will provide a basis for systematically thinking about how to engage the public and private sector, and individual research subjects.

A fourth consideration, and perhaps the most straightforward is simply to ask what information is being collected by current crisis management systems that could be exported in a form accessible to social scientists? For example, the bungled evacuation of Houston in the days before Hurricane Rita in September 2005 has not been adequately explained, and is likely to be repeated in future crises. Yet all major American cities, including Houston, in recent years have constructed large networks of high-resolution roadway surveillance cameras. While they are normally used to monitor traffic flows, how could this data be harvested and analyzed to gain insight into driver behavior during mass evacuations?

A fifth consideration has to do with identifying existing sensor networks that could be augmented, retrofitted, or re-tasked to record disaster phenomena. Communications networks are the most immediately obvious example. For instance, it might be prudent to put in place systems for more detailed logging of communications activity once a disaster has occurred.

Conclusions

As we point out in this paper, large disasters in modern cities stimulate our social, political, economic and physical infrastructure systems to produce an enormous volume of data. Historically, while it was of great value to researchers, there was no economical, reliable, and safe way to collect data about disasters as they unfolded. Crisis information systems process much of this data, but do not encode or archive it in ways that are useful for forensic analysis. They should, and we have outlined five general considerations that designers should bear in mind when creating new crisis information systems.

While we have argued strongly for the use of sensing technologies in recording disasters for sociological investigation, we also argue that the proper focus for considering information technology in disaster research is as a means to and end, not an end in itself. [22]

Social scientists too, face a major challenge in leveraging new flows of data provided by crisis information systems. An entire methodological toolkit needs to be developed for the forensic study of disasters that will be enabled by these new data collection techniques. What are the equivalent procedures, precautions, and standard evidence gathering techniques that should be conducted during and after a disaster to ensure that a factual record of key events can be recorded and archived? Most importantly, how can this data be encoded in such a fashion that it is comparable from one disaster to the next? How can contamination of evidence be detected and accounted for? How can systems and procedures be put in place to ensure that the needed data is collected, even during the height of a crisis?

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