Technology foundation for a real-time distributed problem-solving environment applied to crisis and disaster scenarios

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Abstract

Disaster and crisis management is a global problem. Scenarios range from short-term localized events to those with widespread impact persisting for years or decades. From personal experience and research in the topic area, there is clearly a need for a technology "platform" that can integrate cross-disciplinary agencies, civilians, contractors, and any other conceivable stakeholder. These stakeholders (including the environment and the public) will benefit immensely from integration and standardization in a problem-solving environment, especially in light of the value of human life. This approach should lead to enhanced preservation of life and safety, reduced environmental impact, and overall improvement in disaster response and mitigation – irrespective of the disaster type or scale.

These images of the Deepwater Horizon oil spill disaster serve as a reminder of the impact an event of this scale can have upon our lives. The DH oil spill is one of many disasters that have recently affected the way we handle response and mitigation.

Contents

Section 1

Understanding Disasters

1.0 Understanding Disasters

This research will primarily describe events of interest as disasters or crises, but depending on the reader's frame of reference, many other words are suitable, e.g., emergency, situation, scenario, disturbance, extreme event, catastrophe, or accident. Whatever the terminology, dealing with disasters is difficult. My research will show that management of these crises can benefit from a distributed tactic that leverages modern technology paradigms such as social media, crowdsourcing, open source development[1], 3D game engines, and cloud computing. More importantly, the aggregation of existing platforms and technology building blocks depends on methodologies designed for large-scale projects. No such solutions currently exist, despite the presence of many viable building blocks. It seems the primary obstacle is the lack of vision and execution in pulling together necessary components into a unified platform. Therefore, I will develop an extensible technology architecture plan capable of improving distributed disaster response in a multidimensional synthetic environment.

1.1 Measurable Impact of a "Disaster"

A disaster could be described in many ways, depending on the viewpoint and context of the stakeholder. A citizen, for example, would

[1] The term "open source" has been in widespread use for quite some time and describes projects that are generally open to use free of commercial encumbrances and limitations. For more, see the Open Source Initiative's definition at: http://opensource.org/osd.html

have a different view of a hurricane (focused on the loss of a home or property) than would the Government (concerned with widespread economic loss and societal unrest). Developing a concrete working definition of "disaster" is not necessarily required for this research, but one description in particular does an excellent job of setting the context of this term for the remainder of our discussion:

> *"A disaster is a situation which overwhelms local capacity, necessitating a request to the national and international level for external assistance, or is recognized by a multilateral agency or by at least two sources, such as national, regional or international assistance groups and the media." (Senevirante, Baldry, and Pathirage 2010, 378).*

Furthermore, Dobel (2010) notes that "disasters unfold with little respect for human boundaries [and] agreements across stakeholders will become the cornerstone of modern approaches." We may often recall familiar disasters such as Hurricane Katrina or the Deepwater Horizon oil spill, but it is imperative to consider that the entire planet is vulnerable to a diverse spectrum of troubles – irrespective of race, religion, technological prowess, wealth, or social status.

The United Nations Office for Disaster Risk Reduction (UNISDR) issued a press release on June 13, 2012 explaining the massive cumulative effects of *natural* disasters since 1992 (UNISDR excludes disasters that are strictly *technical* such as a nuclear meltdown caused by an engineering failure). Figure 1 documents the findings, showing 4.4 billion people affected (1.3 million killed) and two trillion dollars in damage since 1992.

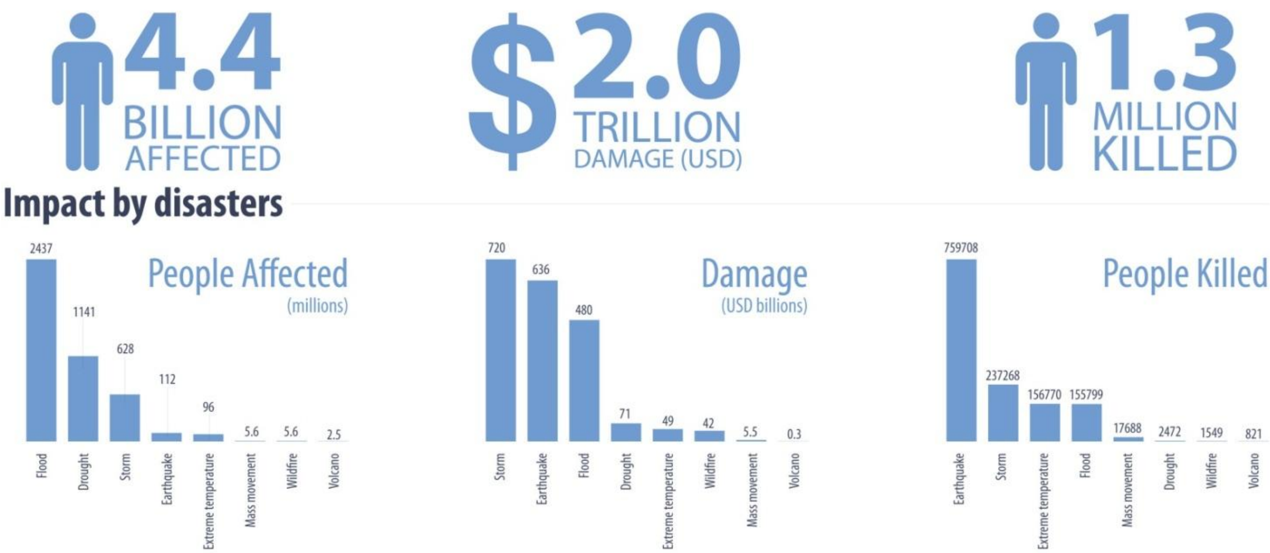

Figure 1 – Cumulative Impact of disasters since 1992. Adapted from the UNISDR June 2012 press release.

1.2 Complexity and Scope

Disasters, crises, events, situations – whatever terminology is preferred, when something goes wrong, the combination of variables is almost limitless. In a virus outbreak, for example, the social behavior of the population will be a critical factor. Do we need to keep the population indoors and isolated, or is the real problem with our drinking water? In Figure 2, the diversity of scope and complexity in natural disasters is easily imagined in the context of the complex disaster landscape (Guha-Sapir, Vos, Below, and Ponserre 2010). Technological disasters comprise a category all their own and are not depicted in the table. Examples of technological disasters are Chernobyl's meltdown, Three Mile Island, and the Deepwater Horizon oil spill. The recent tsunami in Japan is perhaps a hybrid disaster – one component being the massive destruction of the earthquake and tsunami and a secondary but equally important aspect is the technological complexity of the Fukushima Daiichi reactor meltdown. The lesson learned is that nothing happens as expected. Nearly anything can go wrong and, worse yet, will likely happen at the most inopportune time.

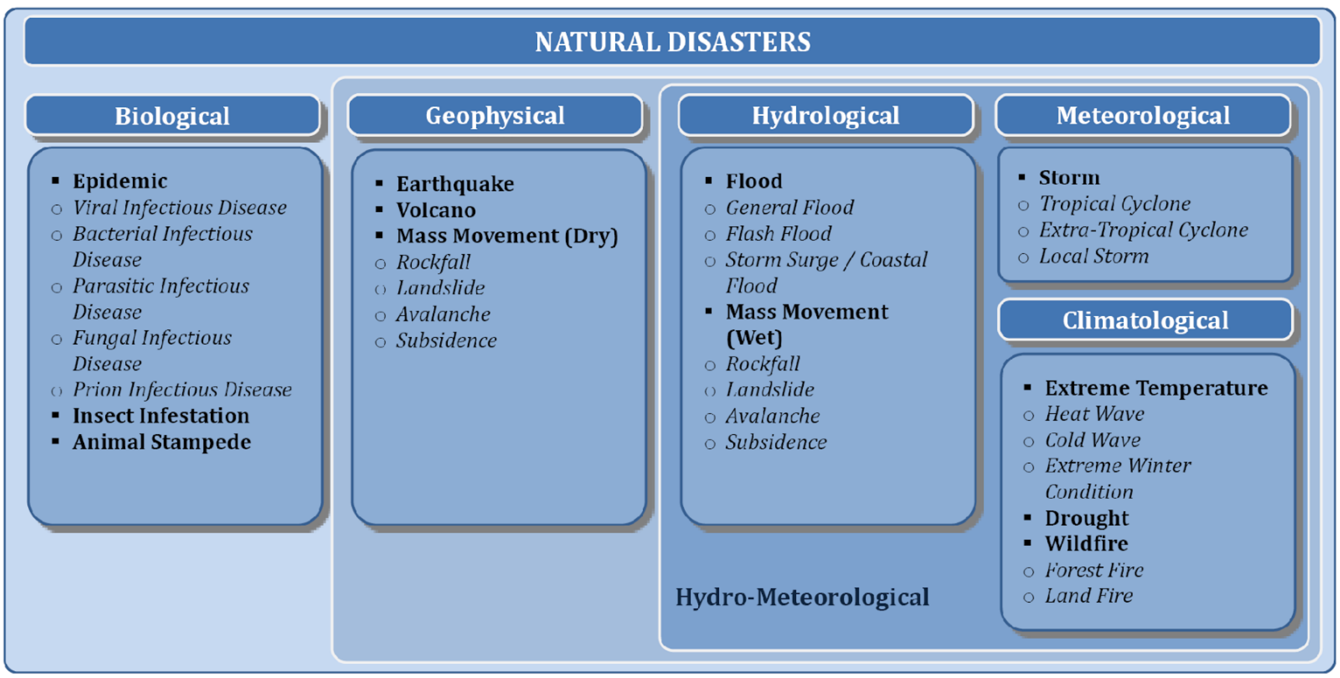

Figure 2 – Taken from Guha-Sapir (2010), the diversity of natural disaster scenarios is clear when considering the numerous classification types. Further complicating the notion of disaster management are "technological disasters," or those caused by humans (not depicted in table).

The financial impact of disasters is understandable, as is the loss of property and, to some extent, the loss of human life. However, the insidious aspect of disasters is their long-term impact in ways that most people are unaware. For example, the work of Julca (2012, 507-508) exposes often overlooked and unquantifiable effects such as the disruption of public services, the adverse effects on human wellbeing, disease, or disruptions to family life. Julca also notes many “cross-border” effects of disasters and gives the example of water rights during severe drought, stating that countries may be at odds with respect to usage and distribution (2012, 509). Zahran and colleagues (2011) account for “poor mental health” effects as the result of disasters, and are even able to ascertain a mathematical relationship between total financial damage and the number of poor mental health days following major disasters.

Section 2

Gap Analysis: Status Quo and Observations

2.0 Gap Analysis: Status Quo and Observations

Curiously, an article published in 1997 by Rhyne predicted that by 2002 (five years elapsed), "geographic information systems, digital cartography, scientific visualization, computational modeling, and videoconferencing will converge to support local and community decision making." Unfortunately, despite the passage of over 15 years since publication, no such convergence is yet obvious. The most advanced software programs in each of the disciplines mentioned by Rhyne have certainly adopted elements of one another, but no fully combined environment exists for use in disaster management. Even so, Rhyne's prediction excludes many components that a comprehensive problem-solving environment would require such as scalable IT infrastructure, data protocols, social network tools, or data mining software. Many attempts at combining two or three of the components do exist today and are in frequent use for disasters (e.g., Google Crisis Response, InciWeb, or Ushahidi), but these platforms all have significant disadvantages or shortcomings.

2.1 Commercial Off-the-shelf Solutions

A number of partial solutions exist for disaster management, but they have lost funding or ceased progress, or do not address the full spectrum of the problem area. For example, a project called

"Responsphere"[2] purports to be an "IT infrastructure test-bed that incorporates a multidisciplinary approach to emergency response." Made possible by funding from the National Science Foundation, Responsphere seems to be a robust approach to information dissemination, but funding stopped in 2008 and the website was last updated in 2009 (NSF 2004). The website and research therein seem an exciting start but there is no indication that developed concepts and technologies transferred to any real-world solutions. Regardless, if the Responsphere project came to fruition, it would still solve but one aspect of the problem space: information flow and networking.

Google crisis response. Google constructed a crisis response solution it shares with government and other authoritative publishers. According to its website, Google created event-specific response interfaces as early as 2005 (specifically for Hurricane Katrina). Google claims that to initiate a new event-specific interface, it first "assesses the severity and scope of the disaster" and subsequently choose what tools will be used for the situation (Google 2012).[3] Unfortunately, because Google chooses when to launch the platform and what modules to include, the platform goes unused by many who would otherwise be able to leverage its utility.

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[2] Responsphere is an effort by the RESCUE Project, the Center for Emergency Response Technologies and California Institute for Telecommunications and Information Technology.

[3] For quick reference, access the following links for the latest information: http://www.google.org/crisisresponse/ and http://www.google.org/crisisresponse/response.html

During the June 2012 Colorado wildfires, one of Google's disaster response engineers introduced the official Wildfire crisis portal with a blog posting and paradoxically said "you can also see *more authoritative*, local-level data from sources such as…" [emphasis added] (Geincke 2012). Sadly, this public "disclaimer" suggests that stakeholders in the disaster would be unable to rely on the Google response portal exclusively, and they may in fact consider that the data perhaps lacks *any* authority. Interestingly, one fire expert laments the lack of depth in the Google interface and states that it does little to educate the public about why the fires are occurring and what can be done to prevent them (Hopkins 2012). The Google interface depicted in Figure 3 includes data layers highlighting satellite imagery, burn perimeters, street maps, and a variety of other specific resources such as webcams, shelters, and evacuation notices.

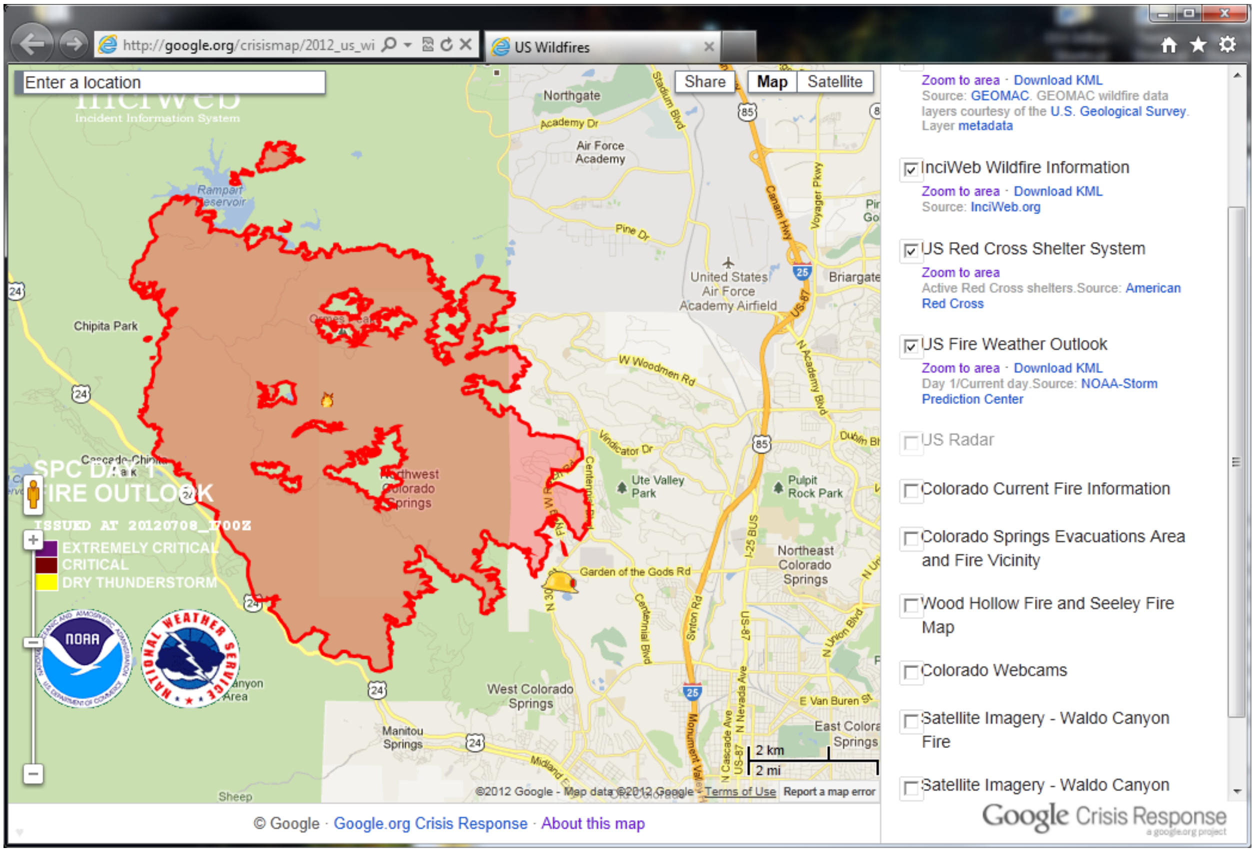

Figure 3 – Google's crisis response interface created specifically for disseminating information about wildfires burning across the country in June 2012. In this screen capture, the map shows information specific to the Waldo Canyon fire located near Colorado Springs.

Ushahidi. Another excellent tool is Ushahidi, an open source suite of tools focused on gathering information from data feeds such as Twitter[4], email, the web, and SMS (Figure 4 shows screen capture of the website).[5] Created in 2007 by David Kobia (then 29 years old), the tool was created

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[4] The reader is likely familiar with Twitter, the services is a public-facing Internet website that allows anyone to post 140 character bits of information (including links to other websites).

[5] Short Message Service is known to most people simply as "text messaging" and is the protocol of communication used on cellular telephone devices for exchanging typed information.

as a means of soliciting eyewitness reports of violence and unrest during the Kenyan presidential election (Greenwald 2010). Ushahidi includes a suite of advanced information filtering tools it brands as SwiftRiver. With SwiftRiver, it is possible to collect seemingly meaningless data from various sources and subsequently add semantic meaning and context (Ushahidi 2012). On the surface, one might suggest Ushahidi as a working solution to the overall disaster problem, as it does an excellent job at collecting and distilling information. Disaster problem solving, however, is a wide-open arena full of challenges and Ushahidi is but one of many information streams in the very large sea of information that must flow through a disaster management portal. A properly designed technology architecture will easily accommodate plug-in problem solving tools like Ushahidi.

Figure 4 – A screen capture of Ushahidi's homepage highlighting its central theme of "information flow." The Ushahidi platform is open source, real-time collaborative mapping.

InciWeb. A highly active information portal during the Colorado wildfires was InciWeb, an "interagency all-risk incident information management system." Typically deployed only for fire incidents, InciWeb (Figure 5) is a great case study in the area of interagency collaboration, considering that nine unique government agencies are responsible for its design and deployment.[6] The interface serves as an official distribution portal for the agencies. Citizens, the media, and other interested parties can go to InciWeb for a trustworthy current update on the status of an incident. During the Colorado wildfires, Inciweb proved to be a common denominator as the authoritative source for much of the information made public. For disasters other than fire, there should obviously be efforts by the appropriate agencies to collect information and alerts in an aggregated portal similar to InciWeb. On its homepage, InciWeb's primary logo reads "Incident Information System," suggesting it likely is suitable for a variety of usage cases.

[6] http://inciweb.org/about/ The nine agencies are: U.S. Forest Service, National Wildlife Coordinating Group, Bureau of Land Management, Bureau of Indian Affairs, Fish and Wildlife Service, National Park Service, Office of Aircraft Services, National Association of State Foresters, and the U.S. Fire Administration (a division of FEMA). A Whois record shows that the inciweb.org domain was first registered in 2004 and is held by the USDA Forest Service, but it is unclear from any source when the program was first conceived or successfully implemented.

Figure 5 – Screen capture of the InciWeb homepage. InciWeb is used almost exclusively by forest agencies for dissemination of data related to wildfire incidents. Individual incidents have news, photos, maps, and other associated data. [*http://www.inciweb.org*](http://www.inciweb.org)

Capaware. Touted on its website as a "3D multilayer geographical framework," the company's showcase video ironically features a wildfire demonstration scenario. The primary capabilities advertised are communication, analysis, simulation, education, navigation, and management. Capaware was "conceived as a system of 3D terrain representation with multilayer representation of diverse types of resource capabilities and application integration."[7] The first commercial deployment of Capaware is Sademer3D, an emergency aid decision-making system.[8] Sademer3D states that its mission is to "show data in a usable and intuitive way to eliminate noise and turn it into quality information." The tool seems to be a suitable product, especially for wildfire management, and it would be worth studying the operation of this and other similar software. The creators of Capaware published a paper in 2011 (Castrillon *et al*.), but it was actually authored in 2009 and unfortunately it seems work has ceased.

Changing the status quo. The quantity and type of existing products is motivation for applying an architectural approach. The existing solution components require aggregation into a suitable platform that is well known to citizens and trusted by experts and emergency responders. Fortunately, the surveyed technologies such as Ushahidi, Responsphere, InciWeb, and others seem very well suited for aggregation into a technology architecture. Creating the architecture so that it allows easy incorporation of preexisting products implies resources will not be wasted solving problems for which solutions already exist.

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[7] Capaware: http://www.capaware.org/index.php?option=com_content&view=article&id=55&Itemid=72
[8] Sademer3D: http://www.sademer3d.com/

2.2 Personal Experience with the 2012 Colorado Wildfires

The High Park fire in Fort Collins ignited early June (2012) and quickly grew to become the most destructive Colorado fire in history (259 homes destroyed) and second largest burned area in Colorado history (87,284 acres), with a total cost of containment of around $40 million. Within two weeks, the Waldo Canyon fire in Colorado Springs took over the "most destructive" position by destroying 346 homes with approximately 20,000 acres burned. The containment cost alone was $17 Million with a continuing daily expense of $25,000 as of July 17, 2012.[9]

Becoming self-informed. Despite my experience formulating queries with common search engines and my background in geospatial data, finding maps and knowledge pertaining to the fires was difficult – especially during the very early stages. Fire lines in the High Park incident eventually moved to within three miles of my home, yet there was still no authoritative single information portal and I found myself scavenging data from various places to uncover facts that were undoubtedly already examined in detail by experts. What roads are closed? What does the fire progression look like over the past seven days? What is my risk of evacuation?

Several data portals surfaced during the High Park fire incident, mostly presenting basic map and evacuation data. Undoubtedly, many

[9] Data from InciWeb pages: http://inciweb.org/incident/2904/ and http://inciweb.org/incident/2929/

were obfuscated by search engines and overall lack of popularity, but a handful seemed to take hold on Twitter and on news websites. The more prevalently shared maps during the first weeks were:

http://larimer.org/highparkfire/
http://inciweb.org/incident/2904/
http://www.cohighparkfiremap.org/
http://co.dtswildfire.com/home/Flex
http://activefiremaps.fs.fed.us/
http://www.fema.gov/news/event.fema?id=16493
http://www.geomac.gov/index.shtml
http://www.esri.com/services/disaster-response/wildlandfire/latest-news-map.html
http://www.eriaconsultants.com/documents/high_park_fire.pdf
http://blackicegeospatial.com/

Ineffective solutions. In surveying these many different interfaces and information sites, I observed several noteworthy characteristics and specific deficiencies that a technology architecture approach would correct:

- The variety of ad hoc interfaces are confusing and not standardized, making it difficult to interpret information.
- There is too much replication of data, and no indication of which sources are authoritative.
- It is difficult for citizens to locate data during the event – with heavy reliance on search engines, news broadcasts, or word of mouth. Further, the search engines will not understand which sources are authoritative until various sites get naturally cross-referenced.

- Lack of scalability and support infrastructure presents itself as slow or unusable interfaces to the users.
- Interfaces were developed primarily to serve/publish basic maps with no apparent effort made to actively collect data from users.
- The interfaces offer only basic measurement tools such as distance and area. A more robust design would publish data with protocols that open up the underlying datasets for analysis rather than pre-rendered map tiles. For example, I should be able to easily mark terrain data by slope or aspect – a trivial matter with a dedicated GIS[10] workstation but a potentially challenging task with a distributed system that is accessed by numerous people.
- Most likely, none of the interfaces used advanced aggregation tools to filter signals from the "noise" of input data. For example, simply adding a "Twitter feed" really doesn't add value, it pollutes the map with too much information.
- New and important data are difficult for the authors of the interfaces to discover; consequently, they are relying on tips from coworkers, discussion boards, and social media to "discover" data.

Status quo frustration. While the efforts of government agencies, corporations, and private citizens are noble, their variety of offerings served to paralyze the average citizen with too many choices and lack of

[10] Geographic Information Systems (GIS) is a term that broadly applies to mapping, cartography, and analysis of spatial datasets.

hierarchy. Without a single authoritative distribution point, many users had no means of finding answers to simple questions. A friend contacted me in the early days of another wildfire incident in Southern Colorado. He was frantically trying to ascertain the proximity of the fire to his family property in the area and had asked me to locate a recent satellite image of the burn. This was but one of many defining moments when I wondered to myself why Colorado is spending millions of dollars each day to fight fires but at the same time relying on good-natured private companies or individuals to educate us about the facts of the event. The lack of a disaster response infrastructure is not due to limitations of technology but arises, rather, from flawed implementation philosophies.

One person can make a difference. Google gained increased attention (popularity) when it publicized the web link to its wildfire map of Colorado Springs. The Google crisis response team builds disaster portals for selected crisis scenarios leveraging its technology infrastructure to serve vast amounts of map data. For the Waldo Canyon fire in Colorado Springs, Google added satellite images from DigitalGlobe to show post-fire damage.[11] I noticed a Twitter posting indicating images of the post-fire damage were available with the Google interface, but wondered why the excellent aerial photos taken days earlier had not yet been georectified[12]

[11] DigitalGlobe has provided overview images and a Google Earth file for download. Users can obtain the raw image data after a qualification process at: http://www.digitalglobe.com/waldocanyonfire

[12] Georectification is stretching and warping an image to fit known features (control points) on the earth's surface.

and released – *especially* considering their much higher resolution. It took approximately four hours of effort for me to contact the photograph copyright holder and subsequently publish a file to the Internet. Surprisingly, even this limited investment yielded more accurate information about the damage than previously available in this particular data format, as depicted in Figure 6. The particular value in my work was to put the aerial photographs into a format that anyone could use – a KMZ file. This data file opens natively in Google Earth, where the contents will overlay automatically on a composite map that includes street names and other localized data. Homeowners could glance at a map, zoom into streets they recognize (or even enter an address in a search bar), and instantly view the status of their homes – all of which is possible on a majority of the smartphones so prevalent today.


Image © 2012 DigitalGlobe
Googl

Figure 6 – Top half shows a DigitalGlobe satellite image of a destroyed area near Colorado Springs. The top image was the best-available georectified data until this author rectified aerial photos previously taken by Denver Post photographers (bottom). Note dramatic increase in available information.

Section 3

Information Communication: Ethics, Issues, Solutions

3.0 Information Communication: Ethics, Issues, Solutions

During the Waldo Canyon fire, the Denver Post collected aerial photographs of damaged homes in Colorado Springs. As a news agency, it elected to release this information immediately for the benefit of the public. Surprisingly, the city government was simultaneously withholding data about damaged houses until there was a complete and accurate survey of the neighborhoods (Handy 2012). Handy noted that the Colorado Springs Mayor "disapproved" of these photos being circulated. Ironically, this meant that homeowners came to rely on the Denver Post's journalism to discover the fate of their homes. Despite the city government's disapproval, the *Denver Post* reported (via Twitter) that it received emails from 200 homeowners expressing thanks for releasing the images (only approximately 350 homes were destroyed in total.) In this case, flow of information was negatively affected by one stakeholder (the government), and positively influenced by another stakeholder (a news agency). Ethical, legal, and political threats are all important factors to concede and mitigate when building a new disaster technology architecture.[13]

3.1 Withholding Data Could be Dangerous

While my personal experience with information politics during the High Park fire incident is edifying, a story from the Japan earthquake disaster gives an even more emotional look into how citizens use

[13] For more Twitter activity related to the damage photos: http://northlandfox.posterous.com/141984343

information. Noyes (2011) writes of his family's predicament during the early days of the reactor meltdown, noting in particular that he was "forced" to trust the information distributed by Japanese officials regarding the radiation levels. Noyes used extensive precaution with food and water handling to avoid exposure and noted that news on the Internet was at least several hours more current than available through traditional channels (2011, 6). Alarmingly, he concluded that Japanese media, motivated by financial reasons, would skew publicly released information to favor the nuclear industry – effectively downplaying the actual levels of radiation exposure.

While Noyes says that he knew the nuclear advocates were lying, he "didn't know who was right about radiation risks, and didn't know where to draw the line" (2011, 7). Noyes quoted one Japanese citizen as saying "we don't believe the government is telling the truth, *but we have no choice but to believe them.*" [Emphasis added.] This is an important reminder that the public will rely on published information to make decisions about safety and wellbeing.

It also happens in the USA. In the United States, many would believe that such an atrocity of misinformation (as in the Fukushima meltdown) would simply not occur. But there were major documented issues with the flow of information during the 2009 Deepwater Horizon oil spill incident – issues that undoubtedly contributed to the inefficient handling of the situation. Several stakeholders, including the White House, British Petroleum, and government scientists, all endured criticism for underestimating the amount of oil flowing from the breached underwater wellhead (McNutt 2010, PEER 2011). While it is understandable for humans (and corporations) to have a tendency toward self-preservation, we must realize that distribution of unaltered factual data is in our *collective* best interest when dealing with a disaster. One method to mitigate any misconduct is through a disaster data portal where various stakeholders can validate the flow and utilization of information. Any of the world's population can be involved in a disaster. In combination with a wide spectrum of environmental ecosystems, this diversity of life greatly increases the chance of unforeseen trickle-down effects when information is mishandled.

3.2 Innovative Solutions in Unlikely Places

An extraordinary solution to the absence of radiation data was born from the Japanese nuclear disaster. A private company called Safecast started up by using a crowdsourced funding website called Kickstarter (Figure 7). The founders of Safecast were "fed up with indefinite data" and decided to take the opportunity to build a radiation sensor network that would enable accurate radiation level sampling (Jamail 2011). The company makes all collected data publicly available and summarizes the results with a map interface (Figure 8). Safecast's company director noted during his discussion with Jamail, "Getting into this showed us there is a lack of data everywhere." The founders of Safecast and their unlikely means of acquiring funding proves the potential that lays in public resources.

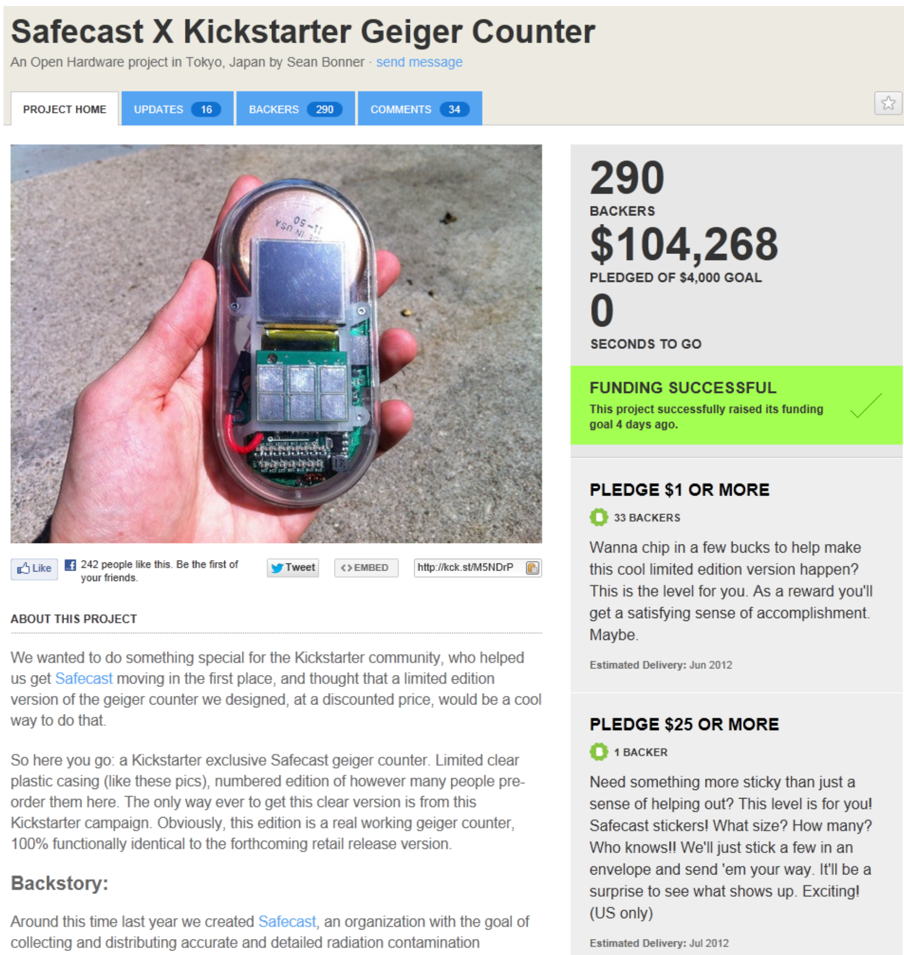

Figure 7 – Safecast, founded through Kickstarter, again used the platform this year to raise funds for building a new personal Geiger counter. Screen capture shown is from http://www.kickstarter.com

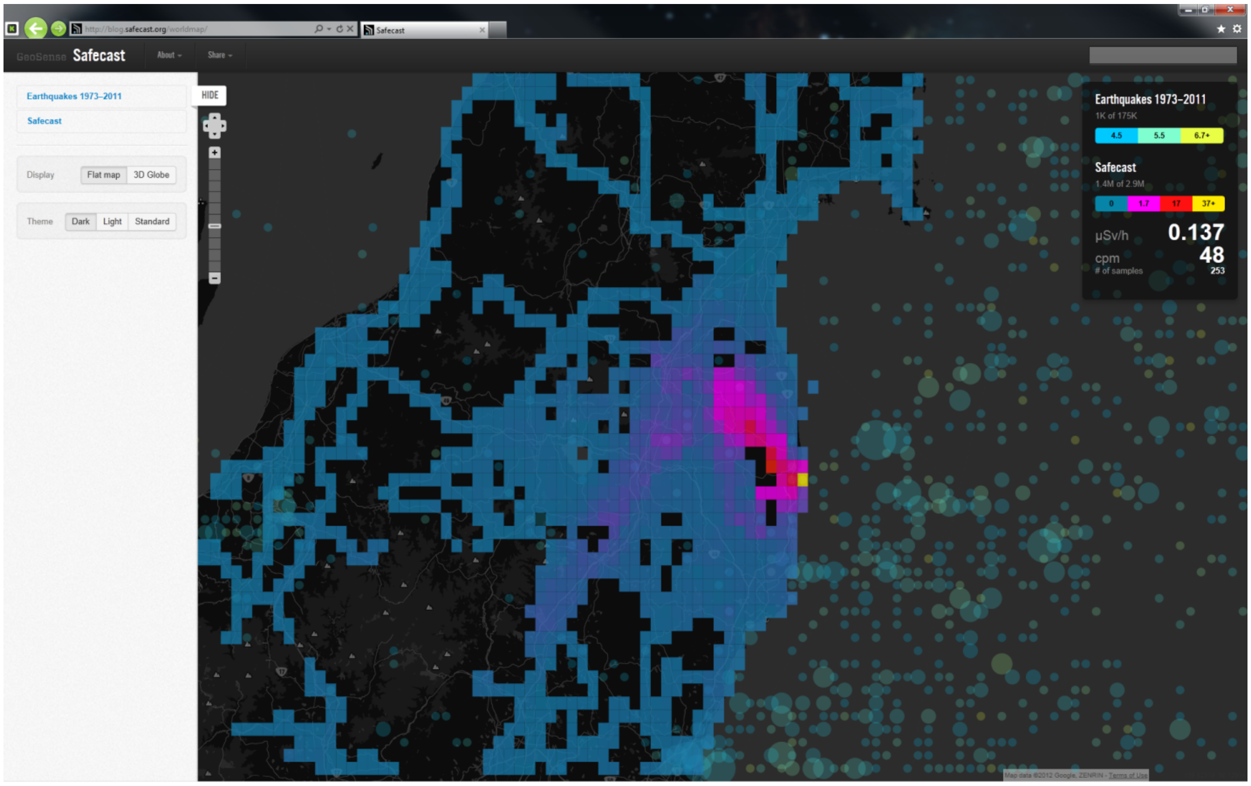

Figure 8 – The map interface on Safecast's website displays a "heat map" of radiation levels near the Fukushima reactor in Japan. Citizens using Safecast Geiger counters collected all data shown.

Social media. Another important type of "sensor" is the human. Humans are capable of observing complex situations and processing those observations into something we can share with others. Social media websites such as Twitter are an excellent way to gather information over a large network of human users. As Steiner (2012) writes, the majority of the stakeholders (public included) in the Waldo Canyon fire near Colorado Springs relied on Twitter for their information. I also found this to be true in my own research during the event – I used Twitter almost exclusively to uncover the most current news and other information by using the search keyword: #WaldoCanyonFire.[14] Steiner quoted the senior communication specialist for the city of Colorado Springs as saying "Twitter was the route that officials chose for immediate information, and [for] reining in any errors flowing across social media streams." Steiner also gives statistics from a tracking site indicating the search term #WaldoCanyonFire had reached 54.4 million people in 15 days with 119,000 total "tweets" (a tweet is a single posted message).

Unfortunately, Twitter's ease of use is not without consequences. The information stream from 54 million people is sure to contain noise and misinformation, but somewhere within lay the important facts that people need for health and safety (Boulos et al. 2011, 2). Steiner (2012) talked with an information officer from the Rocky Mountain Area Coordination Center who indicated misinformation can take "a lot of effort" to correct. Other social media sites such as Flickr (photo sharing) and Facebook also played important roles in the information streams going into and out of Colorado Springs. Such an assortment of data sources magnifies the possibility for misinformation. Complex filtering algorithms can mitigate this situation, but human intervention and supervision will likely remain a necessary means of oversight.

[14] The hash mark "#" is used on a Twitter posting when users want to add particular emphasis. As such, searching for a word that is a recognized "hash tag" will yield excellent results.

Section 4

Review of Literature and Survey of Technologies

4.0 Review of Literature and Survey of Technologies

Constructing a problem-solving environment capable of improving disaster response is predicated on a base layer of enabling infrastructure, the primary aspects of which are processing, storage, and communication. Built upon the infrastructure, various downstream software and sensor technologies make it possible to send email, analyze scientific data, place phone calls, or store information. Collectively, the entire pool of technology is termed Information Communication Technology (ICT), often shortened to just Information Technology, or even IT. My research goal is to identify and characterize the nature of existing and near future IT and to show how the various components can be woven together into an architecture that allows for extensibility and for scalability. The architectural approach will pull together solution "islands" into a unified working system – as opposed to a disparate collection of competing individual units, as seen in the status quo.

4.1 Disaster Mitigation Depends on Information Technology

A 1991 paper authored by Alexander effectively characterizes the role of information technology in disasters and gives us insight into the "state of the art" over 20 years ago. Surprisingly, even though written long ago, the conceptual role of IT remains quite similar today. The author proclaims, "The satellite and the microprocessor have revolutionized the way in which natural disasters are monitored and managed" (1991, 238). He goes on to remark that these technologies process a remarkable amount of information. Anyone today would agree that both the satellites and processors of 1991 would be woefully inferior compared to their modern equivalents. This is a unique insight into how our view of technology has evolved, with modern science exposing an almost limitless hunger for more processing capability. Alexander cites work in the early 1980s, where computers aided responders during emergency situations, thus establishing the long history and importance of information technology in disasters.

Alexander also writes, "With respect to natural disasters, technology designed to acquire and process large amounts of information has three basic uses: data retrieval and display, monitoring and prediction of events, and simulation for backcasting or forecasting" (1991, 239). Incredibly, it seems that in the case of the Colorado wildfires of 2012 that we completely neglected the third use of IT: simulation. At no point during the wildfires were the vast amounts of geospatial data and numerical modeling tools leveraged to model the fire (to my knowledge). Surprisingly, commercially available wildfire simulation software is available. Further, a handful of local Colorado researchers specialize in predictive wildfire modeling.

4.2 IT Architectures: Responding to Demand on a Large Scale

Digital information such as satellite imagery, social media data, numerical models, or any other conceivable source must be maintained on a base storage layer that is capable of rapid response and scalability to accommodate millions of users. In addition to storage, processing power must also be scalable – especially when approaching computationally intensive tasks such as machine learning or scientific modeling. Of course, to leverage processing and storage resources requires a suitable communication network. A modern development known as "cloud computing" is changing the IT hardware landscape by promising nearly unlimited scalability and ubiquitous accessibility.

The "as-a-Service" paradigm: Cloud computing. The evolution of modern computing environments has led to a service-oriented viewpoint of IT functionality. The first and most recognizable "as-a-Service" archetype is Software as a Service (SaaS). Software vendors traditionally sell licenses for installation on computers or networks local to the customer. Software as a service (SaaS) contrasts this approach by moving software and data to a centralized computing system often far-removed from individual users. This centralized system can be accessible over private networks, but when moved to public networks (the Internet), the term used is cloud computing (Brown *et al*. 2011, 390). Actually, many users may be using SaaS without recognizing it as such. For example, many people use Yahoo's webmail, electronic commerce, and other services as a routine part of domain hosting (Yahoo 2011, and Author). Even Facebook, which may not seem like "software," has become a commonplace SaaS application (Richard 2008).

A continuation of SaaS is Infrastructure as a Service (IaaS). Amazon Web Services (AWS) is a widely popular IaaS provider. Anyone can get an AWS account and subsequently pay an on-demand rate for running any number of computers using remote access to AWS facilities over the Internet. For example, rather than purchasing a second computer for home or small office usage (perhaps for storage or added computing power), one could instead pay Amazon a monthly usage fee for access to nearly any type of computer system, with virtually unlimited storage capabilities. The final "as-a-Service" buzzword is Platform as a Service (PaaS). PaaS is a still undefined midpoint between pure software (webmail, navigation maps) and infrastructure (which requires in-depth administrator level knowledge). Regardless, having access to as much (or as little) hardware as needed is a very powerful capability.

Recalling the work of Alexander (1991) mentioned earlier in this section, we benefit now from understanding how IT has evolved and how it is leveraged. Amazon Web Services (AWS) is one of many cloud service providers offering IaaS. Due to its popularity, AWS has many success stories. A few relevant case study metrics are as follows:

- Swisstopo, the office of topography in Switzerland, has eight terabytes of data transfer per month, 250 million preprocessed map tiles, and delivers 1,300 tiles per *second* on a typical day to its user-base (http://aws.amazon.com/solutions/case-studies/swisstopo/).
- NASA Jet Propulsion Laboratory is able to process 200,000 Cassini space images within a few hours at a cost of only $200 – without AWS JPL would spend 15 days completing the same task (http://aws.amazon.com/solutions/case-studies/nasa-jpl/).
- Foursquare, a popular social networking website, processes five million daily "check-ins" for users and leverages the elastic nature of AWS to grow and shrink its platform to match demand (http://aws.amazon.com/solutions/case-studies/foursquare/).
- Yelp (A local business feedback site) processes three terabytes of data daily and has seen over 39 million unique visitors to its site (http://aws.amazon.com/solutions/case-studies/yelp/).

The primary advantage of AWS and similar cloud computing platforms is that of "elasticity." A recent article by Jackson (2012) calls attention to the rapid growth of a social networking service called Pinterest (hosted on AWS). Launched in 2010, Pinterest now ranks 38th in global traffic and 16th

in the USA.[15] Jackson cites the company as "one of the fastest growing sites in the history of the Web." Pinterest leverages the geographic dispersion of AWS infrastructure to safely backup nearly 500 terabytes of data. The company exercises the elasticity of AWS by taking servers offline at night and adding more servers on weekends when traffic is high. During disaster events, network traffic growth and resource demands are keenly suited for this dynamic resource approach.

Finally, consider the story of Animoto, which developed an application for Facebook and experienced such growth that it expanded from 50 to 3,500 virtual machines in just three days (Economist 2008). This would be essentially impossible to achieve in the physical sense. Reliance on a preconfigured physical infrastructure such as AWS is the only means to expand so rapidly. Figure 9 depicts a typical data center modular container. A cloud provider such as AWS would likely have tens of thousands of these available on its network and dispersed throughout the globe at a dozen or more locations.

[15] http://www.alexa.com/siteinfo/pinterest.com

Figure 9 – A modular container filled with server computers is typical of the data centers powering Google, Amazon, and Facebook.

Cloud computing and the “as-a-service” paradigm is an effective model for many aspects of the disaster problem solving environment. Each stakeholder will have unique data and unique needs. The best means for these stakeholders to interact is to publish information as a “service,” to which anyone can subscribe. In the business vernacular, this is called a “service oriented architecture.” One common example of a published service is that of Google Maps. In addition to access via its portal maps.google.com, the company built a web mapping service (WMS) that anyone can use to pull live map data into a custom application. Twitter data are also available as a service – an application developer can add a small amount of software code to integrate this type of information feed. In the disaster context, publishing data with service layers can be highly effective in rapidly changing scenarios because transfer of static data files is unnecessary. Services are more agile than discrete data transfer because any subscriber will transparently receive updates in near real-time.

4.3 Communication Technology: Networks and Protocols

Network transport. Information flow is essential to disaster management and requires various communication technologies to convey different types of data (e.g., voice, digital, analog, optical). In addition to end-point hardware (modems, network cards, routers), the heart of communication lies in the long distance travel medium and signal technologies utilized. Examples (many cited by Alexander, 1991) are telephone, fax/modem, cable TV, power line, fiber optic, laser optical, two-way radios, HAM radio, AM/FM band radio stations, cellular or satellite mobile phone, microwave radio towers, satellite data links, and WiFi (short range wireless).

Diversity is a key aspect of communication within disaster stricken areas. Data and voice traffic can easily overwhelm local infrastructure, crippling the entire network. During the Colorado Springs fire, public officials posted messages on Twitter reminding citizens to avoid further use of overworked cell phone networks (Figure 10). In the figure, note that user "Bettie" has posted to Twitter using her cell phone but at the same time remarks that she is unable to make a phone call. This is due to dual-mode availability as well as ingenious protocol usage. Twitter is commonly used over wired Internet connections (e.g., cable TV or dedicated phone line in the household), but the service is also available over cellular phone networks using an efficient SMS protocol that can even automatically append location data (Boulos 2011, 6&17). Communication diversity is effective during disasters at times when limited infrastructure is operating at full capacity – especially when core infrastructure such as power and telephone landlines are crippled or destroyed. Luckily, the widely known "Internet" is not the only way to network a large number of systems.

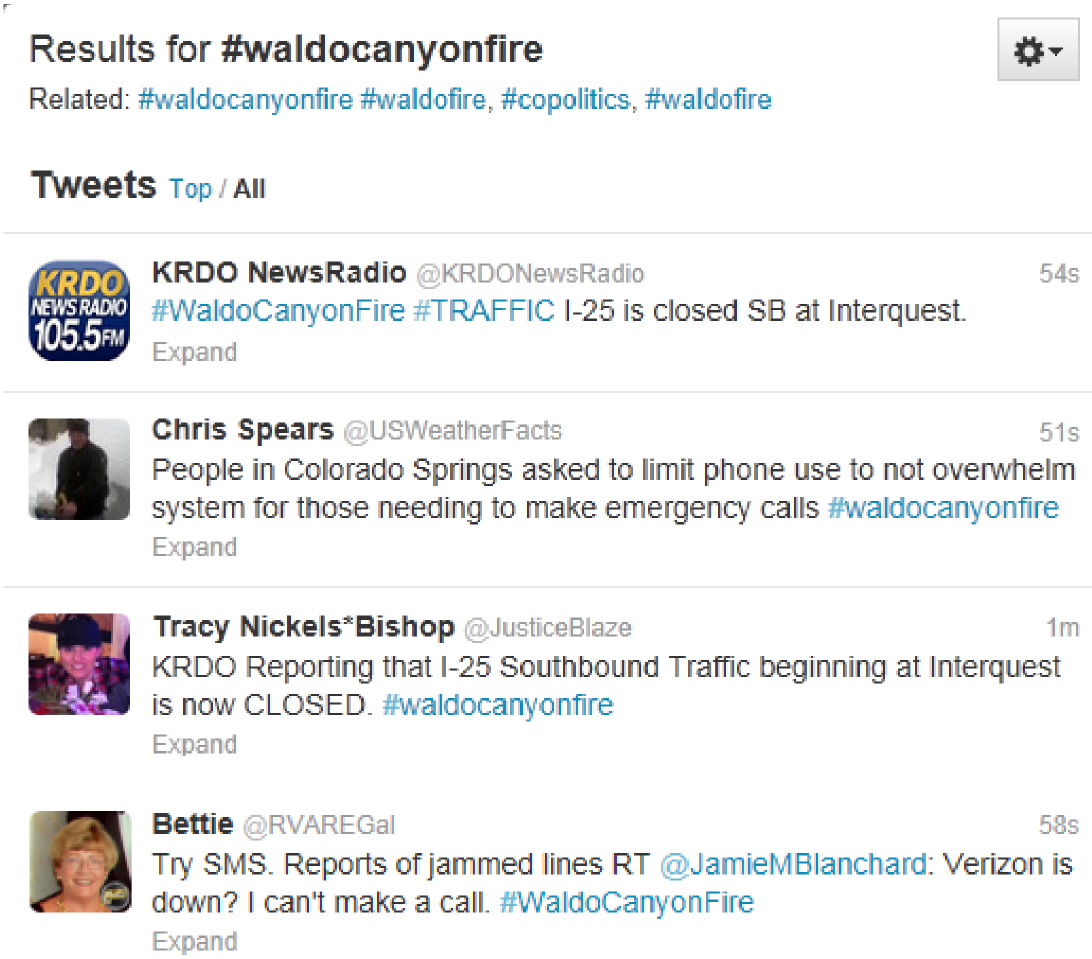

Figure 10 – Four selected "Tweets" (of thousands at this moment in time). Note the second and fourth entries both indicate issues with cell phone networks. User "Bettie" reports she is unable to place a call, yet is obviously able to send messages through Twitter.

The Internet is not the only network. Most readers of this work are likely near a large metropolitan area with massive power grids, effective telephone and cable networks, and even pervasive WiFi Internet. In parts of the USA and certainly many parts of the world, such infrastructure is not ubiquitous. When operating in these areas, responders would have difficulty with cellular reception – let alone functional Internet communication. Responsphere refers to these networks as "ground zero communication" and depicts what it views as a prototype configuration to include many network types as seen in Figure 11 below. The depiction again emphasizes the concept of diversity as it applies to communication modes.

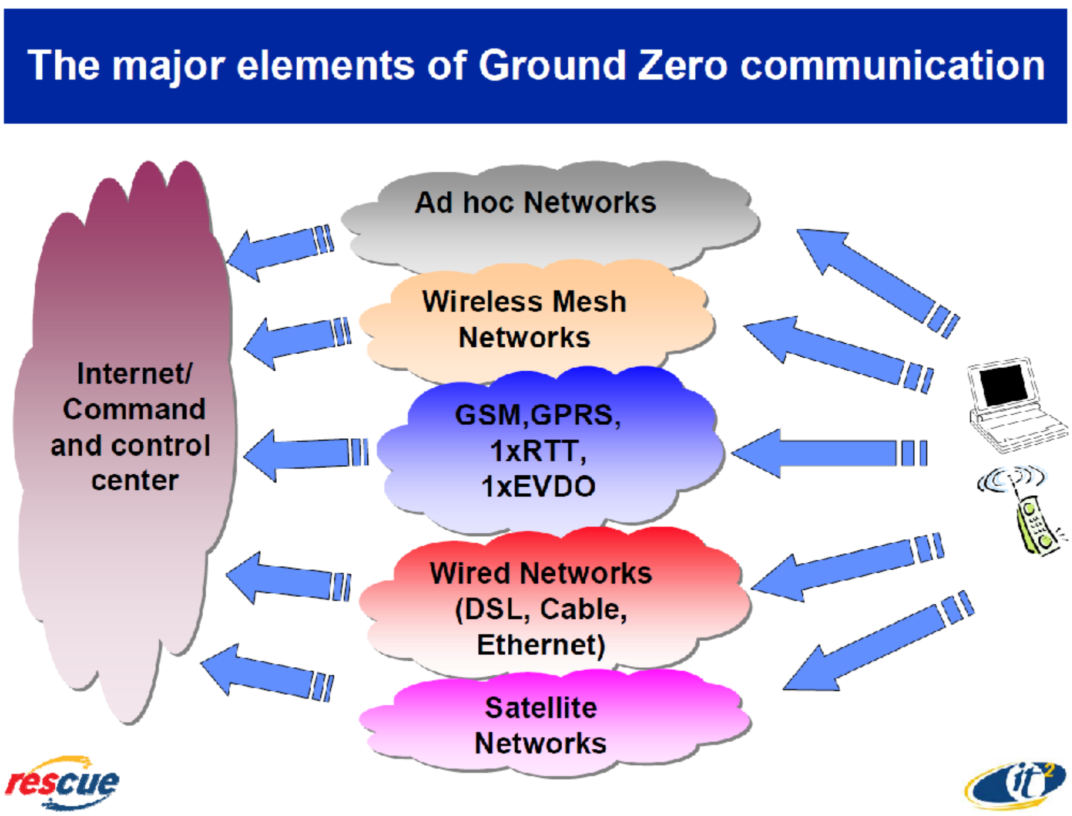

Figure 11 – Responsphere's view of the ideal "ground zero" network. The premise of this system is to deploy rapidly, operate with diversity, and maintain flexibility in deployment. (image source: www.responsphere.org)

Creating local ad hoc WiFi radio networks. The Internet is obviously the most popular and prevalent network, but widespread outages sometimes mandate the use of alternative technologies. An “ad hoc” wireless network is one such possibility, whereby hardware components (computers, routers, etc.) coalesce into a “local Internet.” Traffic control and monitoring is an essential component of this type of system, as user demand could quickly overcome network capacity. Arisoylu, Mishra, Rao, and Lenert (2005) have built an ad hoc network capable of functioning in locations where no functional networks exist. The novelty is in its independence; it functions as a stand-alone, peer-to-peer network. Because the work is slightly dated (now seven years old), it demonstrates that the underlying technology building blocks are likely pervasive in modern countries – as opposed to solutions premised on cutting edge protocols and hardware that have no market infiltration. A majority of the authors’ infrastructure operates on commercially available equipment, giving rise to a very adaptive capability in disaster scenarios (no reliance on proprietary hardware or access to specialized tools and infrastructure).

Adding diversity and distributing traffic. Most wireless communications use frequencies in the 100 to 5000 megahertz range, commonly referred to as “radio” waves. At much higher frequencies, those same radio waves become visible light. This can ease frequency congestion and creates unique opportunities for new methods of information exchange. Miyair and Matsuda (2011) term this technology "visible light communication," or VLC. They suggest VLC is a reasonable augmentation for cell phone connectivity and is possible using special LED[16] light fixtures installed in existing streetlights. They propose that a VLC-enabled communication link can feed enough supplemental data to cell phones to ease congestion on cellular network infrastructure. Their network technology is currently only capable of delivering downstream data – thus the public could easily consume published information much like watching a television, but they could not upload their own data using the VLC technology. This is an area they consider ripe for further development and they believe VLC has many possible applications including linking nearly any physical device to a network. Cell phone network saturation is somewhat common during disaster events. Miyair and Matsuda noted that cell phone networks were highly strained during the March 2011 earthquake, and they recognized the advantage of other communication modes such as Twitter, which transmits data with much smaller bandwidth requirements.

Data standards. Standardization of format facilitates communication of data by increasing interoperability among systems. For example, when sending a digital image by email, the most likely file format is JPG, a standard created in the mid 1980s by the Joint Photographer's Expert

[16] LED: light emitting diode

Group.[17] The PNNL gap analysis report noted in particular that the most challenging aspect of integrating data from various sources is the lack of standards. The report also notes, "Developing these standards can be a complex and time-consuming effort" (2011, 3.14). With cross-disciplinary stakeholders and global participation, the exchange of data is a fundamental requirement. The ability of the disaster interface to eliminate data format complications is a strategic advantage. Publishing data "service layers" could allow data subscribers (e.g., the public, another agency, or a responder at the scene) to access information without compromising the security of data. With careful design, the source data formats can remain proprietary and the service layer of the architecture would expose information in a consumable format to any stakeholder with sufficient security credentials. The service layer serves as an abstraction element by translating and allowing the upstream and downstream equipment to communicate easily.

XML. One popular data file format is the eXtensible Markup Language (XML). The language is an evolution of two previous standards, the first of which written in 1971 (Goldfarb 1996). Generally, the purpose of a markup language is to separate the information content of documents from their format. XML files are stored in human readable text (ASCII[18]),

[17] For more on the JPG image standard, refer to: http://jpeg.org/jpeg/index.html

[18] American Standard Code for Information Interchange – ASCII is a ubiquitous encoding scheme used to convert digital bits to human readable characters, first published in 1963. http://en.wikipedia.org/wiki/ASCII

with the exception of embedded binary data files used in the more advanced XML formats. A sample XML file might appear as follows:

```
<disaster_name>Waldo Canyon Fire</disaster_name>
<date>June 2012</date>
<resources>50 fire engines, 300 personnel</resources>
```

Each data entry is “tagged” with plaintext names that can be referenced in a tag library. In the above example, the tag “resources” refers to the deployed response units, in this case the 50 fire engines and 300 personnel. Despite the simplicity of the example, XML is capable of storing very complex information sets. The advantage of the XML design is the “extensibility.” Adding tags to the vocabulary and creating behaviors in the applications is a matter of supplementing the programming code with a new tag library (often referred to as a “schema”). Existing data would not need to modification, as new tags generally add supplemental functionality while maintaining backwards functionality.

CAP. An example XML filetype used in disaster response is the Common Alerting Protocol (CAP). According to Jones and Westfall (2010), CAP is a “simple but general format for exchanging all-hazard emergency alerts and public warnings over all kinds of networks.” The authors go on to say CAP “allows a consistent warning message to be disseminated simultaneously over many different warning systems, thus increasing warning effectiveness while simplifying the warning task.” Though Jones and Westfall are speaking of CAP, the reasoning extrapolates easily to any data exchange format. Publishing data in unknown or proprietary formats forces downstream users to reverse engineer the format or purchase expensive software to facilitate translation.

Open GeoSMS. Open GeoSMS is a standard that represents the piggybacking of two components, the popular SMS (Short Message Service) which we all use when sending text messages over cell phones, and a geographic standard developed by the Open Geospatial Consortium (OGC). [19] The standard is used on the Ushahidi platform as well in Shahna Disaster Management software and "has proven very useful in emergency and crisis management systems" Boulos (2011, 3). Clearly, there are many ways to build protocols and many specific applications for each. Open GeoSMS, for example, is designed for mobile devices and specifically facilitates adding spatial meaning to information.

Push/pull and publish/subscribe. In addition to data formats and networks over which data flows, much thought goes into the many methods of how authors and users become aware of services (Eugster, Felber, Guerraoui, and Kermarrec 2003, 114-115). Push, pull, publish, and subscribe are four words frequently used and well suited for grasping the fundamental concepts (117). For example, consider the difference between subscribing to a newspaper delivered to your door ("push" technology) and finding the news yourself through Internet search ("pull" technology).

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[19] To read the OpenGeo SMS standard in detail, see: http://www.opengeospatial.org/standards/opengeosms

Another common example is the emergency notification system that interrupts our television and radio broadcasts when needed during emergencies (or at predefined test times). This is a real-time "push" alert that allows no option to remove it from our television (except, of course, turning off the device). An alternative method might be a posted evacuation message on a website or bulletin board.

In the subscribe/publish interaction pair, authors and users have a mutual agreement of creating and consuming information. Eugster *et al*. (2003, 128) examined the phenomenon in detail and concluded that it is "well adapted to the deployment of scalable and loosely coupled systems." Most importantly, they have noted that the *method* of interaction can potentially affect the underlying infrastructure, especially when that infrastructure is not scalable (e.g., if communications consume more bandwidth than another more optimum method).

4.4 Data Technology: Sensing and Collecting Data

Without knowledge about a disaster, it is impossible to react. Many sources of information surface as events unfold; common examples are news media coverage, satellite imagery of a devastated area, scientific publications written specifically about the phenomenon of interest, eyewitness testimony, and commissioned field studies. Gathering such data is a careful science and when done improperly can undermine all systems downstream of the data gathering activity. Presented below, a sampling of the data types and collection methods hint at the complexity of combinations and possibilities. A later section of this paper covers data from social media sites in detail (known as "crowdsourcing").

Satellite imagery. Extreme events are typically associated with a particularly memorable image, and quite often the image is an overhead photo taken from satellite or aircraft depicting the aftermath (Wang 2007, 1-2). Gathering imagery after a disaster is fundamental to assessing damage and, though it might seem like just pictures, selecting a suitable pixel resolution for such information is sometimes a tedious process. Recording the highest resolution possible requires lengthy collection time and yields good post-acquisition analysis results whereas a coarse resolution may be unsuitable for interpretation (Wang 2007, 2). Designing this thought process into a disaster management platform is crucial to ensure data contribute to a healthy decision-making process. Stakeholders should be able to publish a data needs document and the data gatherers should be cognizant of post-acquisition requirements – thus the involved parties can all strike a balance. This concept extrapolates for many types of data collection – e.g., radiation levels recorded at certain spatial or temporal intervals or soil samples distributed over an area of interest.

Mortality data. Zolala (2010) has researched the collection of mortality data after earthquake incidents in Iran. The findings indicate that the basic problems with status quo data collection methods relate mostly to a lack of coordination among groups doing the collection. Zolala remarks that measuring effects of natural disasters requires "ongoing and routine data collection commencing immediately after a disaster" (2010, 542). The author concludes that poor infrastructure (mostly in undeveloped countries) can strongly inhibit effective data collection and that "multifaceted efforts in the global and national level" are needed to strengthen health information systems. Zolala's work exposes yet another portion of the extremely broad spectrum of issues faced when dealing with disasters across the globe.

Collecting field data. In any disaster region, there is a need for gathering information using humans equipped with sensors of various types. For example, a scientist might travel to various locations and measure air quality or observe animal species, or a citizen might discover an important location within a debris field. Lwin and Murayama addressed field data collection using GPS-enabled cell phones in moderate detail, having begun by stating "accurate, timely and handy field data collection is required for disaster management and quick response during emergencies" (2011, 382). The authors utilized off-the-shelf software and with some customization, successfully carried out field tests of a working system. They found that substituting cell phones for more expensive equipment such as portable computers was an effective approach, primarily because cellular coverage networks have broader coverage than WiFi access typically required for portable computer systems.

Machines that "tweet." While many regard Twitter as a primarily human-centric communication medium, Boulos discusses the important potential Twitter has for connecting machines to a network (2011, 2). Boulos believes Twitter would be an effective "publish-subscribe infrastructure for non-human sensors," allowing the sensors to automatically push data such as temperature, time, location, or other readings. The author also explains that similar machine communication could occur over Bluetooth wireless (or similar wireless infrastructure) using identity cards such as M2M (Machine-to-Machine) and SIM (Subscriber Identity Module). The eventuality of our technological world is that all objects will have embedded sensors, embedded connectivity, and likely a communications protocol that can be activated manually or automatically to facilitate the exchange of data among millions of devices.

4.5 Unconventional Data and Methods: Crowdsourcing

In our modern environment of nearly ubiquitous connectivity, our society has become a collective conscience and woven network of human sensors. The term "social media" is widely used to connote our digital relationships with each other and our sharing of information. Twitter and Facebook are two widely discussed social media web sites, but they are by no means the only interfaces that use tight human integration to add value. Social sites benefit from Metcalfe's Law, which states that the value of the network grows exponentially with the number of users. A new term, "crowdsourcing," has emerged to characterize the utility and possibilities of social media. Euchner believes that with crowdsourcing, we are now supplanting our trust in experts for the collective wisdom of the crowds (2010, 7). He also thinks crowdsourcing is a "transformative capability with wide application(s)" and cautions that use of the technology requires careful constraint and that it is by no means a "panacea." The most poignant wisdom seems to be that crowdsourced solutions typically do not proceed to completion because no one person can create a complete solution and typically the crowdsourcing platforms have performed poorly at allowing members to aggregate partial solutions. Euchner recommends creating an open platform where individuals "have access to the collection of partial ideas so that different parties can contribute unique expertise" (2010, 8). He also cautions not to solicit complete solutions from any one person, but rather to rely on individual expertise in areas of special knowledge.

Not just crowd*sourcing*. Several "crowd" terms have emerged in recent years. The most popular core term is crowdsourcing, with permutations such as "crowdfunding" that suggest a monetary result or "crowdsolving" which suggests the goal is to solve a problem. Consider the following working examples of human networks in the spotlight recently:

1) "Sourcing" – After the Japan earthquake, the crowdsourced network of radiation sensors launched by Safecast.com gathered more accurate data than local governments (Jamail 2011).
2) "Investigating" – The website HelpMeInvestigate.com, conceived by Paul Bradshaw, promises to change the flow of information concerning issues of local interest such as health, education, and welfare. The code for the website is open source (free to use by anyone).
3) "Journalism" – The Ushahidi.com technology for citizen mapping and journalism has proven the catalyst for change and awareness in many global events. The founder, David Kobia, was awarded "Humanitarian of the Year" in 2010 by Technology Review (MIT).
4) "Solving" – The Deepwater Horizon oil spill disaster response included a strong campaign by BP and the US Government to solicit solutions from the public, reportedly collecting over 20,000 ideas (Euchner 2010).
5) "Innovation" – InnoCentive.com has over 250,000 registered solvers from 200 countries who have collectively amassed over $35 million in award money, having solved more than 1400

challenges (Aron 2012). InnoCentive has a 300% to 600% higher success rate than most established R&D facilities.

6) "Funding" – Kickstarter.com has successfully funded approximately 28,000 of 65,000 potential projects, doling out $300 million in funding with seven of the projects each receiving over $1 million. [20]

Volunteered information. The Colorado wildfires in 2012 discussed earlier were not the first or only event to leverage the public for information dissemination (Twitter). Geospatial Today's article (2011) also mentions the extensive role of Twitter in the floods in Queensland Australia, emphasizing how the Queensland police used the website and a keyword "#qldfloods" (known as a "hashtag") to ensure the precise exchange of data and communication among citizens – with over 15,000 tweets per hour during the peak of the event. The author explains that crowdsourced volunteered geographic information (VGI) "plays a critical role in sharing real-time information during crisis management, especially when traditional sources of information are not accessible." The same statement is equally truthful when reduced to "volunteered information," it need not be "geographic" in nature. Many people carry a GPS enabled phone, lending to the geographic aspect of information gathering, but the reality is that many good ideas (information, perceptions, or even

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[20] Current stats are maintained at Kickstarter's website for public review: http://www.kickstarter.com/help/stats

measured data) come from the public and have no location-relevant aspect.

Trust but verify. The public may not be the best data warehouse – for neither collection nor processing of information. As pointed out earlier, the officials in the Colorado Springs Waldo Canyon fire had difficulty correcting the spread of misinformation through social media sites. One exemplary work investigating the use of social media in crisis management is quick to point out that data from the public "often contains variable amounts of 'noise', misinformation, and bias" (Boulos et al. 2011, 2). Boulos and colleagues state also that the noise will undergo "amplification" due to rapid rate of spread through social networks. They believe it requires filtering and verification before it is useful. Despite this, the authors believe human sensing is advantageous because of human ability to "contextualize, discriminate, and filter" (2011, 6). They suggest the combined use of expert analysis, crowdsourcing, and machine learning to facilitate rapid analysis of large datasets (2011, 7). Furthermore, with respect to crowdsourcing, the authors suggest that experts especially should work in peer networks to best facilitate effectiveness.

4.6 Wisdom from Knowledge: Heuristics and Machine Learning

Images, measurements, or any other types of data are meaningless until transformed into information; information is "some recognizable pattern or meaning that influences a user" (Messerschmitt 2000, 39). The most well known hierarchy (by Messerschmitt) is actually four levels of progression: data, information, knowledge, wisdom. In the disaster problem-solving architecture, each stage of the hierarchy needs representation and treatment. To transform data all the way into wisdom requires analysis, interpretation, and learning – all achieved with machines (using software programs), humans, or some balance thereof.

Heuristics: Making decisions. Heuristics is the art of making decisions. At times, we make calculated decisions, at other times we estimate and use rules to allow us to make a decision that otherwise is ambiguous. Defining the rules of decision making is difficult. Rolland, Patterson, Ward, and Dodin (2010) have investigated decision rules mathematically, specifically with regard to disaster response, and they remark "decision support systems used in disaster management must cope with complexity and uncertainty" (2010, 68). In their research, they note that an investigation into the aftermath of the hurricane Katrina disaster uncovered a lack of decisive action by all levels of government (federal, state, and local). In light of this, their goal was to develop tools to support the decision process in near real-time. Their findings indicate that it is possible for decision makers to provide key input data to a computational system and in return gain important knowledge about best-case options. In particular, interagency operational effectiveness and collaboration are both improved (2010, 74). The authors conclude that further research in this area is merited, and they believe the value of their approach is in “quickly assessing a disaster scenario and adapting to the dynamic nature of the situation in a timely manner” (2010, 76).

Machine learning. Humans learn from one another through interaction or training, and gain insight through individual experience. Unfortunately though, many of the difficult patterns or perceptions in large or complex datasets (such as during a disaster event) would require unwieldy human resources to interpret. In fact, some problems may simply be unsolvable without augmenting human knowledge with some degree of artificial intelligence. From a purely mathematical standpoint, hundreds of scholarly efforts attempt to address the task of building artificial “brains” to make decisions very rapidly, very accurately, or in extremely demanding situations. The work of Khouj, Lopez, Sarkaria, and Marti (2011) focuses on the use of machines for simulating disaster evacuation scenarios using software. They have constructed machine “agents” that individually attempt to make decisions based on situational data awareness. By exposing the agents to multiple scenarios, they hope to build artificial “wisdom” that can be transferred to future real disaster events. Murthy (2009) attempts a similar goal and cautions “human ingenuity can never be replaced.” Murthy attempts to solve large-scale rescue procedures in the hopes of “more predictable and planned results.” The author’s findings discuss several algorithms which represent a typical "capability module" that could be one of thousands of tools in the technology architecture proposed in my paper.

4.7 Human Gaming for Analysis and Simulation

The power of the human mind is extraordinary; it is capable of discerning patterns or moments of ingenuity, insight, or perception that no machine could ever hope to achieve. The use of gaming and simulation is relatively common in many industries and is a means to leverage human capabilities. The spectrum between "simulation" and "gaming" deserves an initial discussion. At one end, there lies pure simulation, in which parameters are fed into a computer model and the calculated result interpreted by users. At the other end lies gaming, where humans "play" in an interactive environment and are free to make decisions (most typically in a game involving many other human players). Somewhere between simulation and gaming lies an ideal compromise. For example, if a simulation has variable inputs, why not deploy the simulation to the public and allow each individual to experiment? In a sense, this is similar to pure "gaming" because individuals are competing for the best solution. In other words, gaming in the familiar sense is typically interactive, with many players, whereas we typically understand simulation to be a scientist or engineer using predefined parameters to analyze problems. My contention is that leveraging public input for mathematical simulations also qualifies as "gaming" in the sense because individuals are competing to find the best solution – perhaps the term "simulation gaming" best represents the idea.

Many authors recognize the value of gaming as a means to iterate potential scenarios in pursuit of an optimal outcome. Steward and Wan believe gaming allows for "adapting strategy and tactics" and that it can "support adaptive disaster response decision-making" (2007, 128). Taken to maturity, the use of games and simulation can be "connected to actuarial data for internal system and external context variables" and thus "*it is possible to monitor and mutate real-time system behavior while facing disaster*" (2007, 128) [emphasis added]. Steward and Wan also expect that "more productive outcomes and more measurable readiness" are possible when using matured game play in parallel with disaster decision making (2007, 129). Games have a long history in war and conflict training. Smith (2010) has a comprehensive treatment of the role "games" have played since the Stone Age. In his look into the future of "war-gaming", Smith finds that "games, simulations, and virtual worlds" are "becoming part of the global communication infrastructure …. They are tools that can be used to think about all kinds of problems and to orient dispersed audiences toward a shared problem in three dimensions" (2010, 18).

The IDSR (International Strategy for Disaster Reduction) created an online disaster mitigation game designed to engage children but it is equally effective at luring adults into play. Figure 12 is a screen capture from the beginning of a session showing the play interface. The user must build structures and modify the environment to best prepare for a disaster. Each cell of a mapped area is configurable – for example, a hospital added, the land raised as a levy, or even planting of trees is possible. The simulation will run to completion and give the user feedback on the quality of preparation for the disaster. With a sufficiently complex game, the simulation results could reveal novel methods for mitigation and response.

Figure 12 – An interactive game originally designed to engage children in simulated disaster scenarios. The user modifies every cell and will attempt to build relief housing and support infrastructure before disaster strikes. Game is available at http://www.stopdisastersgame.org

One online vendor, Linden Labs, has created a game so sophisticated as to establish an entire user ecosystem complete with the exchange of real money (users convert their currencies into "Linden" dollars), interpersonal relationships, and even land ownership. Called Second Life, users buy and sell objects to build and “live” in a world comprising restaurants, transportation systems, recreation, and nearly any other imaginable manifestation of real life (Figure 13). The Second Life project could serve as a reference design for building large-scale scenarios to model actual disasters. For example, it is conceivable to build a Second Life world mimicking the Fukushima nuclear reactor meltdown. Players would carry out their virtual lives in this world, perhaps divided initially into groups to explore different situations. In a sense, this would be an experiment involving the global community. Actually, the Second Life game has achieved such complexity that one group utilized it as an experimental laboratory for studies in human economic decision making. Duffy reviewed the experiment and concludes that virtual worlds are “potentially rich environments for experimental interventions” and that the subject pools are “more easily accessible to researchers” (2011, 61). Duffy also notes pitfalls in the use of virtual worlds for such testing, and cautions that using such media for human study can be risky. This type of large-scale simulation gaming seems a very promising utility for disaster scenario experimentation.

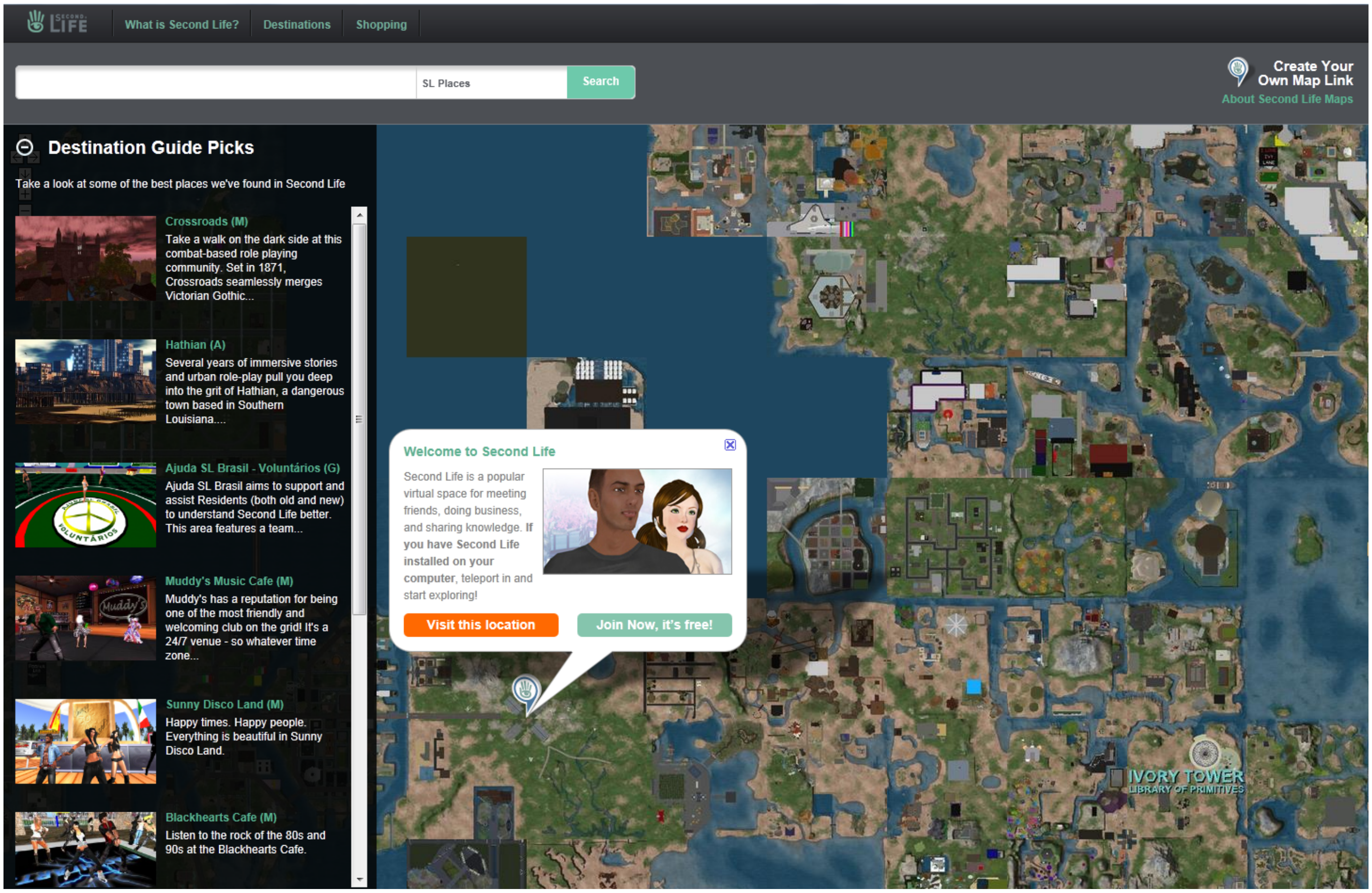

Figure 13 – Second Life is an immersive 3D environment built entirely by its user population. Users trade real dollars to buy objects, land, and goods and services. The entire world exists in 3D with objects having behaviors and utility – much like in real life.

Gaming has four primary purposes, as described by Walker, Giddings, and Armstrong: teaching, training, operations, and experimentation (2011, 167-168). Teaching and training are self-explanatory. Operational games investigate feasibility and review systems functionality. Experimental games focus on "human decision-making behavior" and in the case of crisis gaming can be used to "subject the players to a continuous process over time in which they are both making decisions and living with prior decisions" (2011, 168). Using humans to role-play in a reconstructed crisis scenario seems suitable for determining the best course of action for response and long-term remediation. Walker and colleagues created a "roadmap" of gaming, reproduced here as Figure 14. They foresee a future where it is possible to simulate a crisis in real-time and they are "convinced that the boundary between gaming and reality will become ever closer" (2011, 172). The authors also conclude that an open and distributed architecture is best suited for gaming and, further, the architecture should accommodate real world data feeds to facilitate augmented reality user interfaces.

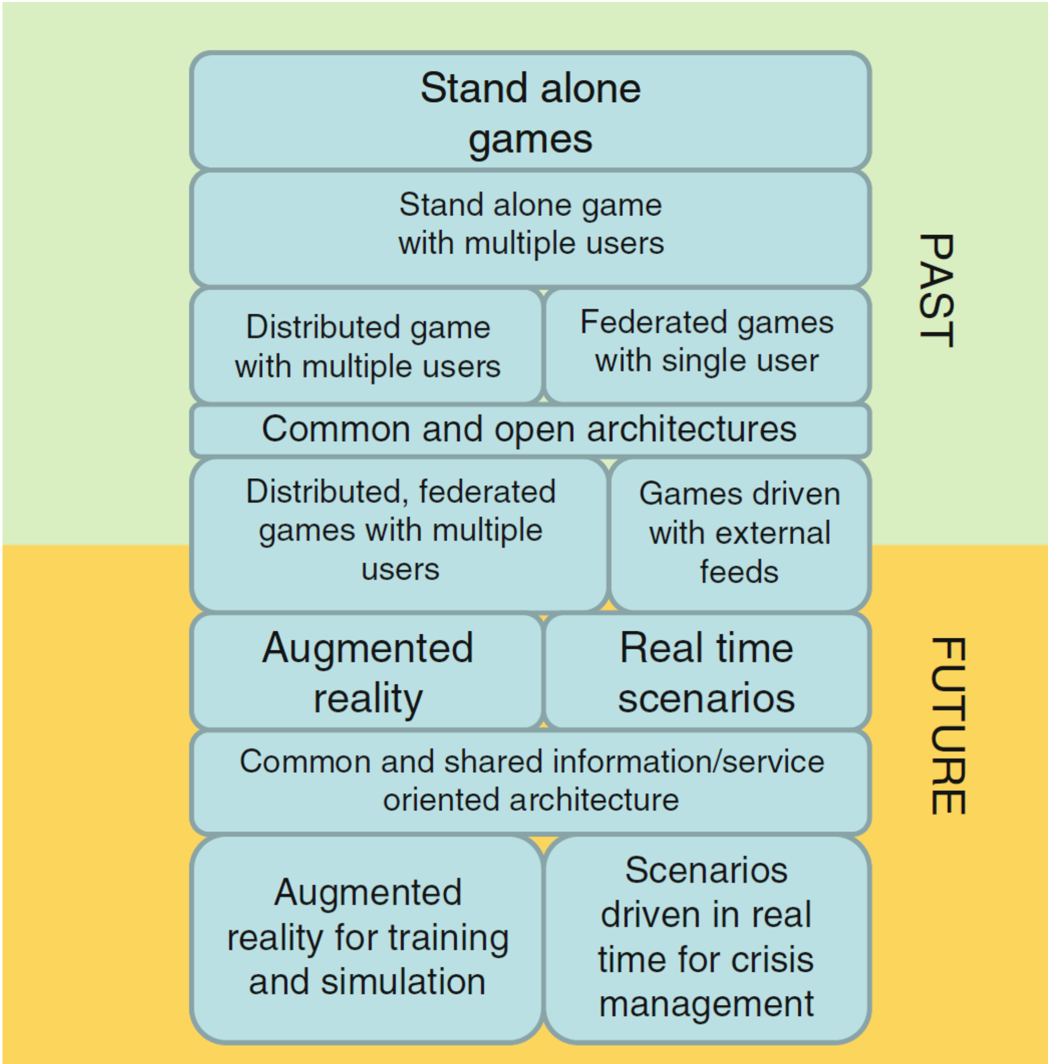

Figure 14 – A gaming technology roadmap with a particularly noteworthy prediction that real-time scenario gaming and augmented reality are integral to crisis management. From: Walker, Giddings, and Armstrong 2011.

4.8 Integration: Building Synthetic Environments

The culmination of disaster problem solving, and the key step lacking in the status quo, is in the integration of all available components of the technology landscape. With the architecture, stakeholders should have access to (at a minimum) a spatial component (i.e., the relationship to the earth or the walls of a building), a temporal component (timeline of events), a data input-output module, analysis tools, and a communication system capable of facilitating interaction among stakeholders. Integration will occur in a natural workspace where the user interacts two-dimensionally with flat data (news articles, for example) and three-dimensionally when data relate to the earth's surface (or in times when data analysis necessitates a 3D environment). Collectively, these concepts comprise what is commonly termed "situational awareness."

Vision vs. reality. More than 20 years ago, experts in disaster management predicted the aggregation of tools and techniques into a single interface. Alexander (1991) suggested this type of integration would "offer considerable potential for natural disaster management, especially if real-time uses are developed by integrating these technologies." Rhyne (1997) also predicted a convergence of systems, having predicted that geographic information systems (GIS), computational modeling, and video conferencing would merge by the year 2002. Based on these early visions of the future, it seems the industry remains in a limbo between idealization and reality.

Early steps in the status quo. Work at York University in Canada has recently demonstrated a real-time 3D environment premised on integration within Google Earth (GE). The system, called 3D Town, uses sensors to pass data to a standard GE interface where continuously updated visual objects represent the motion of vehicles, pedestrians, and other tracked objects.[21] The research team based the system on a four-layer design: a sensor layer for data acquisition, a protocol layer for homogenization of data, a data management layer, and a responsive layer that renders the environment (Boulos *et al*. 2011, 18-19). This tight integration and layered design methodology is a step in the right direction for building immersive problem-solving environments, but it is not yet comprehensive enough to include all aspects of the disaster management architecture.

A 3D wildfire environment. The design team who engineered the Capaware open source visualization tool mentioned in the earlier sections of this paper also authored a paper specific to wildfire forecasting. Castrillon *et al*. (2011) leveraged their Capaware software framework as a base tool and integrated a simulation module called "FARSITE" for modeling the growth of fires in three dimensions. The interface uses GPS tracking to draw objects such as deployed helicopters or ground vehicles in near real-time in the 3D environment. The diversity of resources involved and the complexity of the problem dictate the need for a very powerful support system (Castrillon *et al*. 2011, 392). They use an architectural approach whereby the base layer is an operating system followed by a core

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[21] Video "New eye in the sky at York University" http://www.youtube.com/watch?v=_RcdaIdRmHs

toolset layer and finally a plug-in and library layer. The authors promote a service oriented architecture approach, boasting the advantages of interoperability, simplicity, up-to-date currency, reliability, and functionality (2011, 392-393). Figure 15, taken from the authors' paper, portrays the high-level system design and service-oriented approach. Most importantly, they have focused on integrating the *simulation* capability into the *situational* graphic depiction, allowing stakeholders to predict and estimate fire behavior in the same interface that feeds real-time data about the actual scenario. It is surprising that this tool was not used (to my knowledge) during the Colorado wildfires, as this is precisely the system that would have allowed for improved situational awareness and even prediction of the fire's behavior.

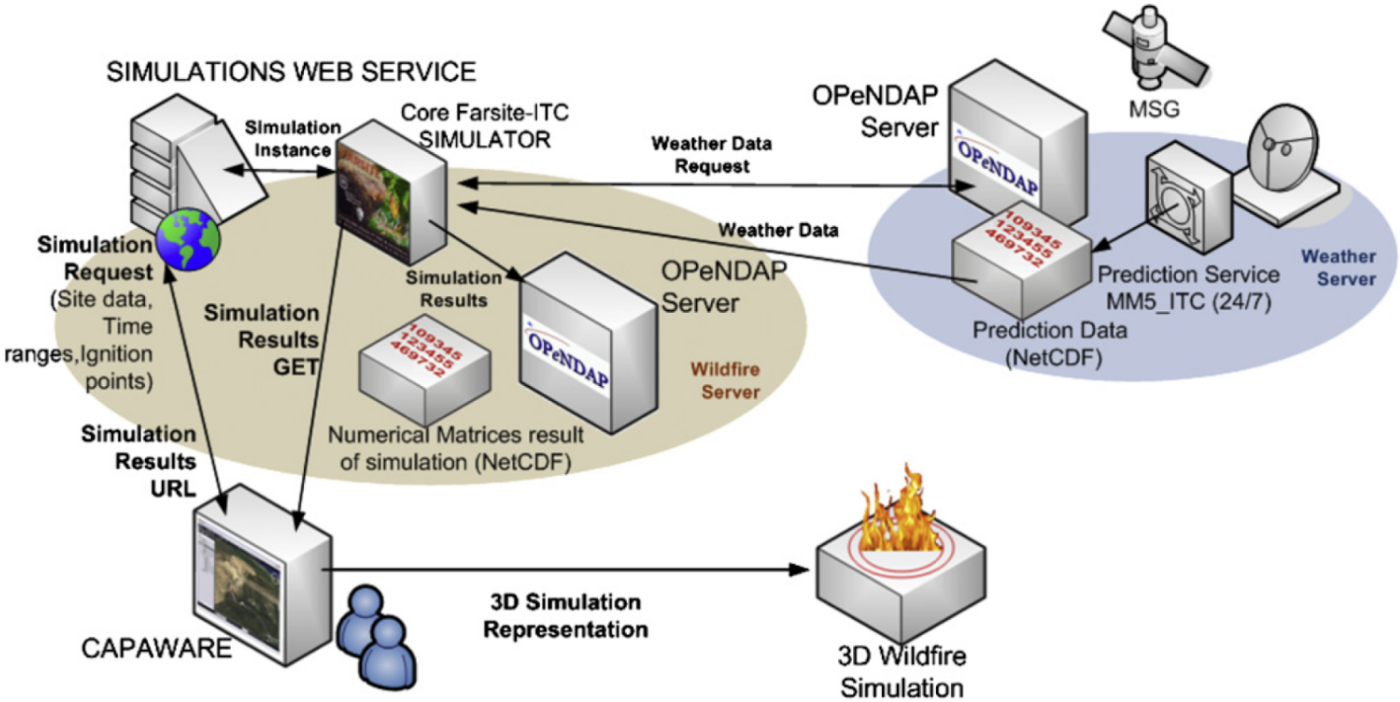

Figure 15 – A Conceptual depiction of an integrated simulation and monitoring system drawn by Castrillon et al. (2011). The system integrates real-time data from field equipment with simulation modules and a user interface.

Precision Information Environment. One extraordinary new conceptual interface design promises to link a network of sensors and systems into a user-centric Precision Information Environment (PIE), depicted in Figure 16. Under development at the Pacific Northwest National Laboratory (PNNL), the proposed PIE could revolutionize the way we interact with data in our environment.[22] A unique feature of the PIE is the profiling of users that allows automatic filtering and adjustment of

[22] PNNL's video "Precision information environments envisioning the future of emergency management" is hosted on YouTube at: http://www.youtube.com/watch?v=5tfnmhl-A54

incoming information streams, tailoring the data to each user. Furthermore, the PIE uses a Natural User Interface (NUI) design methodology. The NUI allows unfamiliar users to adapt to the system and facilitates a “desirable and engaging user experience” (Boulos et al. 2011, 23-24). Collectively, the design features of PNNL’s PIE are an accurate vision of an interface that immerses users in a multidimensional environment where spatial context is a central theme and each stakeholder has access to the appropriate information. PNNL has published an excellent gap analysis report (PNNL 2011) detailing the shortcomings of existing emergency management systems – an excellent resource for narrowing future research efforts.

Figure 16 – A screen capture from PNNL's video concept of a Precision Information Environment depicting stakeholders collaborating on a graphic table solving issues related to a wildfire. Video and more information available at http://precisioninformation.org

Isn't PIE good enough? Considering the very effective visuals in the PIE concept video, it would seem the efforts of my research paper are moot. In reality, this is precisely why I have assembled my research – technology and creative research efforts already exist to accomplish what I have envisioned. The missing component is the high-level architectural view and broad vision that considers technology and how to treat the disaster as a business so multiple agencies can collaborate free of encumbrances. Another missing component is a means to ensure engagement with the technology. In fact, many of the gaps discovered by PNNL are solvable by the foundational "architecture" approach proposed in this paper.

Where does this leave us? The concept of an integrated disaster management platform with time and dimensional functionality is obviously not unique. PNNL's PIE concept is quite similar to what this paper attempted to describe, but PNNL's execution is lacking – at least for now. Other efforts such as Capaware seem to have launched commercially but inexplicably remain undiscovered or perhaps abandoned by their authors.[23] Aggregating technologies onto an "architectural platform" is one way of allowing progress. Building an extensible foundation based on a service layer model will ensure that new research discoveries easily integrate into the system – something akin to a global "disasternet" that focuses on information flow, early response, and long-term problem solving.

[23] It seems Capaware, or its only known commercial deployment, Sademer3D, would have been a perfect tool for use in the Colorado wildfires but I have seen no indication that any such tool was ever used. Sademer3D could have predicted fire spread and fed information in real-time to responders and the public.

Section 5

Characteristics of the Ideal Disaster Solution Environment

5.0 Characteristics of an Ideal Architecture Platform

The optimum form of a distributed and extensible problem-solving platform will continuously evolve with technology, but the core design principles will hold true over time. Building on a foundation for execution (FFE) that models the disaster management problem as a large business, an assemblage of capability modules will integrate through a service oriented architecture and an open source design philosophy. This approach is capable of adapting to inevitable changes of technology over decades of time while continually aligning stakeholders' interests to ensure a collaborative philosophy.

5.1 General Characteristics Listed

- **Authoritative**: The interface should be widely regarded as *the* source of information. Stakeholders should trust and know the interface to eliminate ambiguity of authority in times of crisis.
- **Automatic**: When disaster strikes, quickly aggregating and disseminating information is important. If an event happens when nobody is prepared, the interface should trigger creation of a new problem workspace. To the extent possible, certain processes need automation to reduce human workload. For example, deploying a map, social media aggregator, and dedicated search engine module is appropriate for almost all disasters.

- **Adaptable**: Each crisis will have new challenges and needs; the interface should be pliable enough to accommodate variability. *No single design will be compatible with every disaster*. Stakeholders will have varying levels of design authority appropriate to their roles and needs. The design of the human interface could evolve over time by publishing slightly permuted configurations to a percentage of users – the most effective version thus incrementally winning over less desirable or less effective designs.
- **Extensible and Modular**: New capabilities emerge continually and new advancements will need tight integration with existing systems. Building services in an extensible manner ensures that new modules of capability remain compatible with previously deployed systems. Disasters can span decades, and so must the systems. A modular approach means that solution building blocks are reused and recombined in future scenarios.
- **Elastic**: The infrastructure and all systems built on the infrastructure must be rapidly scalable so that 1) resources are conserved in times of disuse, and 2) during rapid-onset crisis events, the system will respond to exponential growth needs.
- **Immersive**: Response and mitigation require awareness. The architecture will create a fully immersive environment capable of putting any information from any point in time in the hands of any

stakeholder. Using role-based game play coupled with advanced simulation techniques, the system could predict the outcome of complex social or political scenarios or even the progression of wildfires on an accelerated timeline – in time to react and alter the real world outcome.

- **Interactive**: The premise of this project is that a user needs to do more than just consume map data or public notices – the system architecture must have interactivity as a tenet. Rather than just glance at a map of a nuclear disaster, users should be able to click on their locations and receive routing instructions through the safest zones of radioactivity to the nearest shelters.
- **Open:** It is impossible for one stakeholder to address every aspect of a crisis scenario. The design and maintenance of an architecture must be open for all stakeholders' involvement. Contrary to a proprietary design maintained by a single entity, the open design approach ensures there are no hidden agendas or commercial motives.
- **Secure:** Different stakeholders must have different security levels and the system must be secure from malicious activity. Each layer of design will necessitate a certain level of protection, be it a password login requirement or physical security such as locked doors and tamper-proof equipment.

- **Ubiquitous:** Without access to this technology architecture, it is useless. Achieving ubiquity will be very challenging, especially in undeveloped countries or disaster stricken areas with completely destroyed communication networks. Connectivity must be diverse, leveraging analog and digital technologies as well as field deployable units that can capture data for later upload through backup infrastructure (even if that backup is as primitive as foot travel carrying USB flash drives or optical discs).

5.2 Service Oriented Architecture in Detail

The heart of this project is to approach issues in the status quo with a service oriented architecture (SOA). To understand the contextual meaning of services, consider a restaurant as a "food preparation service." Waiters take orders (the instruction set), the kitchen gathers food and prepares the meal (the service processes), and the waiter then delivers a meal to the hungry customer (a stakeholder). Common online "services" are web-mapping interfaces such as Google, Yahoo, or Mapquest – many have used these websites at least once to find a local restaurant or retail store. Rather than processing gigabytes of data and vector street networks, users provide only a simple instruction set (the "from" and "to" addresses), and the solution platform then returns a turnkey answer in the form of driving directions or perhaps a phone number to a business. Even just browsing such map interfaces is consuming a satellite imagery service.

In the disaster architecture context, many such services make sense. Satellite imagery is an obvious choice, but so is a current data service that for example would continuously publish the best available wildfire boundaries. In a public health disaster, the service could continuously publish the locations of known infections. A more complicated service in a disaster scenario might be an analytical solver module that processes user data. By leveraging cross platform well-known file languages such as XML, a researcher can build a plug-in module capable of processing data on a “subscription” basis. Stakeholders (present and future) would have access to the solving module by means of an advertised “solver service.”

What services are needed? Basic life support functions such as food, water, and shelter will be necessities. Other basic services are health (first aid, medicine, etc.) and transportation of goods. Beyond mere survival, however, lies an array of technological needs, the first of which is a computing infrastructure. As discussed previously, cloud service providers such as Amazon Web Services frequently offer “infrastructure as a service,” exposing users to a virtually unlimited resource pool of storage and processing capability. The second need is communications networks. Mobile phones are a critical tool, but as recent disasters have proven, they are only one component to a successful communication network. In times of overload, a secondary communication medium such as SMS texting, Twitter, or other social outlets has proven a low-bandwidth alternative to voice communication. When widespread power outages completely preclude such communication, alternative means are necessary such as ad hoc locally deployed network infrastructure. Comprehensively addressing communication thus necessitates a broad spectrum of readiness. It is conceivable, for example, that a creative software solution could patch together hundreds of computers over short-range WiFi connections creating a mesh network for a small city area.

Many technology service layers could exist and all have their applications. Just a sampling of these might be:

- **Data aggregation and filtering** – Data feeds, especially during unexpected events such as earthquakes, are notoriously noisy and typically are high volume. It is difficult to filter signals from the background chatter. Tools such as Ushahidi's SwiftRiver are just one example – including this type of processing through a simple query to the overall architecture allows anyone to leverage the algorithms.
- **Mapping** – No disaster portal would be complete without a comprehensive map interface. Within the map, many sub-services would exist, some of which may be: measurement and analysis interface, evacuation routing, weather data ingestion, user input and modification, or location-based messaging.

- **Citizen reporting** – The public should have the technology to submit photographs, text messages, and any other type of data or observation through a convenient and user-friendly interface.
- **Emergency messaging** – Citizens need warnings about life saving information by any means possible: television, radio, cell phone, email, bulletin boards, police broadcast, social media, and any other conceivable communication medium.
- **Weather** – It seems obvious, but integrating the most up-to-date weather as a service layer is a fundamental requirement for many analysis scenarios.
- **Situational awareness** – By sending latitude and longitude to a situational awareness service, users can navigate to safety, toward a predesignated meeting point with others, or learn about nearby radiation levels or infection rates. The service could augment a user's view of reality by sending information to a "heads-up" display or synthetic 3D environment.
- **Global search** – Not to be confused with a "Google search," this service would be a managed search portal that is situation-centric. Public search engines (e.g., Google, Yahoo, Bing, Twitter, and Facebook) will index almost everything, unfortunately including "noise" and misinformation as a side effect. A customized search service fine-tuned by stakeholders will keep information pathways

efficient. The service could leverage existing search engine technologies, but perhaps include human supervision or a special algorithm tailored to the event.

- **Publish and subscribe** – A service that aggregates data feeds and understands stakeholder needs to facilitate accurate and efficient exchange of information. For example, rather than choosing among Facebook, Twitter, or mass email notification, this service allows one posting to be delivered to any and all distribution portals depending on the intended audience and the preferences of the subscribers. A highly advanced version of this service might be predictive, in that it would possibly evaluate a stakeholder's interests in a given disaster before it was even clear to decision makers that involvement was necessary.
- **Data validation and weighting** – Providing a service that can evaluate specific data for validity is useful. If a citizen submits a photograph claiming damage in a certain area, the service could immediately cross-check other photos in the area and grade the validity of the claim. Likewise, another user who questions the validity of certain information might call a phone number, issue a spoken query concerning the validity, and in return discover if the information is correct. Adding location awareness to all information streams can strengthen validation algorithms. For example, a text

message coming from someone at the epicenter of a disaster might have more validity than one that is 100 miles distant.

- **Location-based push messaging** – Rather than subscribing to an emergency messaging service, users might receive notification on their mobile phones based on proximity to local threats or safety resources. When the user's latitude and longitude come within a certain area, a specific message would override the user interface – perhaps with a warning about radiation levels. If the user did not subscribe to a location-based service, it could still be possible to trigger messages if built-in hardware capabilities override the user's preferences. Of course, this type of intrusive messaging may be perceived as a privacy concern.
- **Crowdsourcing** – This service layer would facilitate requesting and consuming crowd-based resources. One example is financial, when a community is financially strained and needs to reach out for funding from neighboring regions. Perhaps a research team is unable to process a particular dataset effectively and wants to solicit public insight on methods to manipulate the data. Another scenario would be to solicit public interaction with a simulation (based on current data for a particular disaster) – perhaps leading to a novel understanding of the current event.

Service security. Individual stakeholders (companies, the public, homeowners, data collection agencies, government entities, etc.) need a robust method of publishing data that complies with a shared specification. This specification facilitates information sharing and aggregation and addresses usage rights, restrictions, and other factors. The Open Web Application Security Project (OWASP) has invested extensive effort into building security for web services; its work is an excellent starting point for this project. It is clear from just a cursory review OWASP's work that security will comprise a significant part of the final technology architecture. OWASP remarks on distributed system security saying, "If web services system designers do not understand those services and protocols … they cannot possibly design secure web services systems."[24]

5.3 Stakeholder Unification and Open Sourcing

Open design and consistent sharing among entities is an excellent way to encourage altruism in a community. My personal experience with the Colorado wildfires this year solidified my understanding that unified stakeholder involvement is in the collective best interest. During the fires, stakeholders were not operating with the big picture in sight; they focused on their own interests without a greater sense of how their information plugs-in to other stakeholders' viewpoints. Even though contributions were

[24] For more, begin at https://www.owasp.org/index.php/Web_Services_Architecture_and_Security

excellent, the work of individuals, government, and private companies seemed to be both repetitive and competitive … eventually leading to confusion about the true authoritative source. Despite potential criticisms and stakeholder rejection, an open design is the best solution with the most potential for leveraging ingenuity in untapped resources.

Open sourcing the project may eliminate or reduce financial barriers to implementation. Monetary backing will be necessary, but an open design could bypass traditional contract design processes and lead to vastly improved return on investment. For example, many of the tools mentioned in this paper are open source.[25] To contract the work represented just by these examples might easily cost millions of dollars (if not 10s or 100s of millions). As mentioned in an earlier section of the paper, the crowdsourcing company Innocentive has achieved three to six times better results than traditional research and development channels.

Unifying stakeholder interests will reduce parallel or duplicated efforts and would help promote peer review and collaboration among scientists in various disciplines. A disaster scenario tends to build a sense of camaraderie itself, but having the collaborator philosophy in place before and after will ensure that stakeholders work toward mutually beneficial goals.

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[25] For more background on the meaning of "open source", see the Open Source Initiative's definition at: http://opensource.org/osd.html or http://oreilly.com/catalog/opensources/book/perens.html

Section 6

Pulling Together a Technology Foundation

6.0 Pulling Together a Technology Foundation

The primary deficiency with disaster response portals in the present environment is their lack of a "foundation for execution" (FFE). This term originates in the business discipline, but extrapolates to the context of disasters by treating the disaster management system as a company or corporation (irrespective of whether or not the effort is commercial). FFE is a means of leveraging a company's technology to automate and optimize its *core capabilities* (Ross, Weil, and Robertson 2006, 3-4). A core capability is one that gives the company a specific advantage in the marketplace – it is essential to functional efficiency. Figure 17 shows a handful of core capabilities relating to disaster management. Because a disaster portal has numerous core capabilities dependant on technology, FFE is an appropriate viewpoint from which to begin overhauling status quo paradigms.

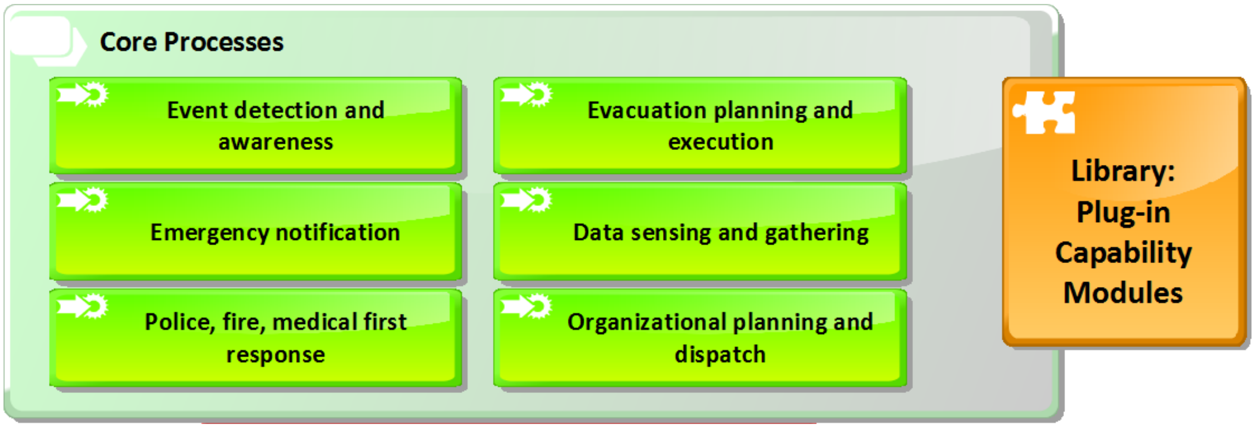

Figure 17 – A grouping of core capabilities (processes) for disaster management. Many auxiliary capabilities are available through an extensible library. Plug-ins from the library may eventually become "core."

Within this paper, many of the technologies discussed are core capabilities (or nearly so, with future refinements). Figure 18 lists several of these technologies grouped by capability descriptors. This listing is not comprehensive, but serves to demonstrate the FFE approach to "capability." Often, technologies are considered "solutions", but in the high-level view, solutions are just temporary remedies. A capability is developed extensively until it becomes integral to the system as basic functionality – irrespective of the underlying technologies utilized.

CORE CAPABILITY GROUP	TECHNOLOGY
Comprehensive integration	Sademer3D
Data filtering and aggregation	SwiftRiver
Data sensing and gathering	Ushahidi
	Safecast
Distributed resources	InnoCentive
	Crowdsourcing
	Kickstarter
Gaming simulation	Linden Labs Second Life
IT infrastructure and networking	Amazon Web Services
	Responsphere
	Ad-hoc Networks
	Internet
	Visible Light Communication
Organizational planning and dispatch	Capaware
	3D Town
	Precision Information Environment
Sharing and communication	Twitter
	Facebook
	Flickr
Standards and protocols	JPEG, XML, CAP, GeoSMS
User-centric interface	Inciweb
	Google Crisis Response

Figure 18 – A representation of many of the technologies discussed in this paper as they would be categorized into "core capabilities."

Three building blocks comprise the FFE: the operating model, the enterprise architecture (EA), and the information technology (IT) engagement model (Ross, Weil, and Robertson 2006, 8-10). An operating model is the high-level description that describes the degree to which the business process is standardized and how well its systems are integrated. The EA is the "organizing logic" and the overall map of how business systems and processes function. Finally, the IT engagement model ensures that individual projects align with overall business objectives.

6.1 Operating Model

A disaster management system's primary goal is to reduce impact to human life and the environment while balancing available resources. Much like a functioning large company, disasters span cultural and physical boundaries. Disaster stakeholders are like "business units" in an enterprise – geographically dispersed and typically capable of some degree of autonomous operation. Figure 19 depicts several of the more common disaster stakeholders. The operating model pulls together these business units and is a means of defining high-level system functionality. It gives an overall sense of how closely the various units are integrated and whether or not there is standardization of processes among them. The operating model is more than just strategy; it actually provides a "stable and actionable view of the company" (Ross, Weil, and Robertson 2006, 25-26).

Figure 19 – Part of a larger diagram, this graphic element identifies several of the more notable stakeholders in a disaster. Many of the elements would divide into sub-elements (e.g., "response agencies" would divide into police, fire, and medical).

Without an operating model, disaster stakeholders (i.e., business units) will function selfishly with reduced awareness of the benefits of collaboration and information exchange.[26] For example, during the Deepwater Horizon (DH) oil spill off the coast of Louisiana, highly advanced oil-skimming ships traveled from the Netherlands to assist the United States with cleanup. This equipment was far more efficient and capable than anything operated by the US – and the Dutch were eager to help because they had a vested interest in the health of the environment. Sadly, poor communication, a decades-old legal act, and a stubborn Environmental Protection Agency (EPA) all contributed to major delays and complications with deployment of the skimmers resulting in less than

[26] I witnessed this first hand throughout the wildfire incidents in Colorado this summer though my involvement with the GIS community, email discussion groups, and by extensive search and review of online news and data.

desirable oil recovery (Grundvig 2010). An operating model would have fostered coordination among stakeholders, ensuring these stumbling blocks would not exist and promoting an altruistic philosophy.

There are four operating models to consider, each with a different degree of business process standardization and integration: 1) unified, 2) diversified, 3) replicated, and 4) coordinated. Unification is the highest level of standardization and integration; the other models sacrifice some degree of process standardization or integration (Ross, Weil, and Robertson 2006, 28-29). Figure 20 shows the four models as well as a representative company for each. The choice and design of an operating model has a “profound impact on [implementation of] business process and IT infrastructure,” and businesses may transform to new models over time (2006, 26, 40-41).

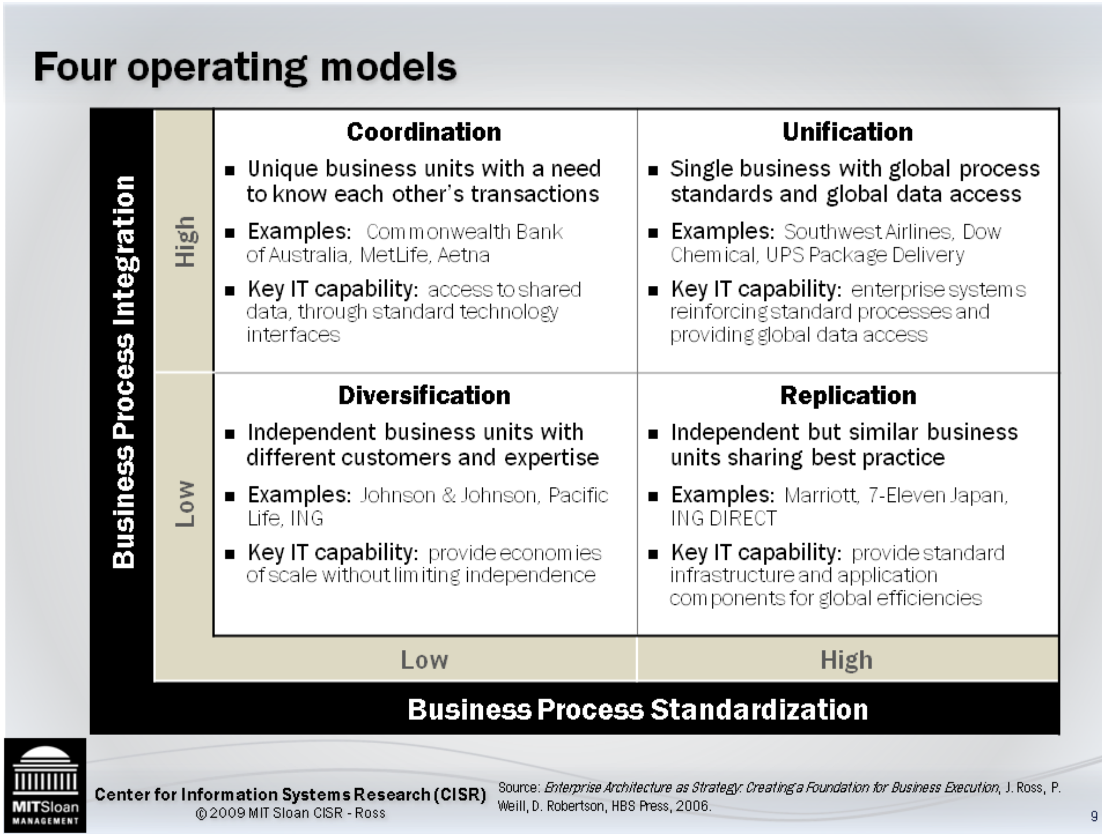

Figure 20 – The first component of a Foundation for Execution, the Operating Model, can have varying degrees of business ***standardization*** *and* ***integration****. Standardization means individual business units are identical (fast food restaurants) while integration implies tight data sharing.*

Choosing the operating model for a comprehensive global disaster platform is difficult. Luckily, as Ross, Weil, and Robertson have explained, a company need not adopt one model at all levels (2006, 39-40). The disaster management platform should strive to attain unification at local levels while functioning at a global level with a more diversified model. Business process integration (the vertical scale in Figure 20) represents sharing of data among business units. The service oriented architecture (SOA) discussed previously is the enabling technology for data sharing – it ensures that each business unit (stakeholder) has access to important shared data. Standardization will likely remain a difficult characteristic to define in a field as diverse as disaster management. During global events, the level of standardization needs to be much higher than local events.

Consider an example of nuclear contamination in the context of system scale. If global, the air sampling equipment and test procedures used in America should be identical to those used in Germany to allow comparison. But what is the probability that each country has identical equipment beforehand? In the case of two isolated incidents (one in the USA and another in Germany), each country can use its own equipment and procedures without adversely affecting the other because sharing of measurements has little meaning. No single operating model will work for every level of the system, but an operating model of some type is beneficial.

Geographic and cultural boundaries are a starting point for aggregating stakeholders into operational groups. Over time, natural groupings will likely evolve and may be dependent upon the nature of the disaster (e.g., hurricane versus earthquake). Eventually, a library of operational models will emerge, each particularly well-suited for a specific type of event. Collectively, these operational models will play a role in refining the top-level view of the disaster system.

6.2 Enterprise Architecture

The operating model alone will do little to implement the disaster management system. But the next level of the FFE, Enterprise Architecture (EA), leverages the model to define processes and integrating technologies that carry out core processes. EA is a widely used problem-solving approach that allows companies to integrate information systems, technology, security, governance, and other business operations into a unified and well-aligned whole (Ross, Weill, and Robertson 2006, 47-49). For upper-level decision makers to understand the very complex and detailed EA, architects create a simple one page "core diagram." The diagram becomes a "rallying point for managers responsible for building out and exploiting the EA" (2006, 50-51). Businesses having the same operating model often have similar core diagrams. Different operating models will manifest as different core diagrams; but irrespective of the model type, core diagrams typically emphasize:

a) **Core business processes**: those processes needed to execute the operating model and respond to opportunities. In the disaster portal context, one example would be emergency notification, or resource coordination such as police, ambulances, and other first responders.

b) **Shared data driving the core processes**: data shared across locations unifies processes. The technology architecture in this paper hopes to create a service oriented architecture (SOA) for publishing data to all stakeholders; sharing data is a principle of the design.

c) **Key Linking and automation technologies**: This is the technological "guts" of the disaster portal. Elements are networking infrastructure (wired and wireless), computing platforms, sensor technologies, user interfaces, data management, and sharing mechanisms.

d) **Key stakeholders**: In a disaster context, the stakeholders are quite diverse – likely more so than in even the largest of companies. Each core diagram at any particular system level will identify stakeholders and their basic roles.

Figure 21 depicts a core diagram "pattern" applicable to disaster management, comprising several elements of the four emphasis areas given above: stakeholders, core capabilities, shared data, and linking technologies. This diagram accentuates the link layer (networks, protocols, etc.) and its strong connection to the central data repository. Stakeholders interact with core processes through this link layer by means of a credentialed access firewall. The data engine handles storage management and additional security issues while maintaining transparency to the appropriately credentialed user. The core processes listed are only a sample of the entire process pool; the plug-in library facilitates the extensibility of the core capabilities. As new modules are developed, they will integrate either as new core functionality or as optional plug-in modules. The diagram represents one possible embodiment but not necessary the ideal form for *all* hierarchical levels of the overall system (local, state, federal, global).

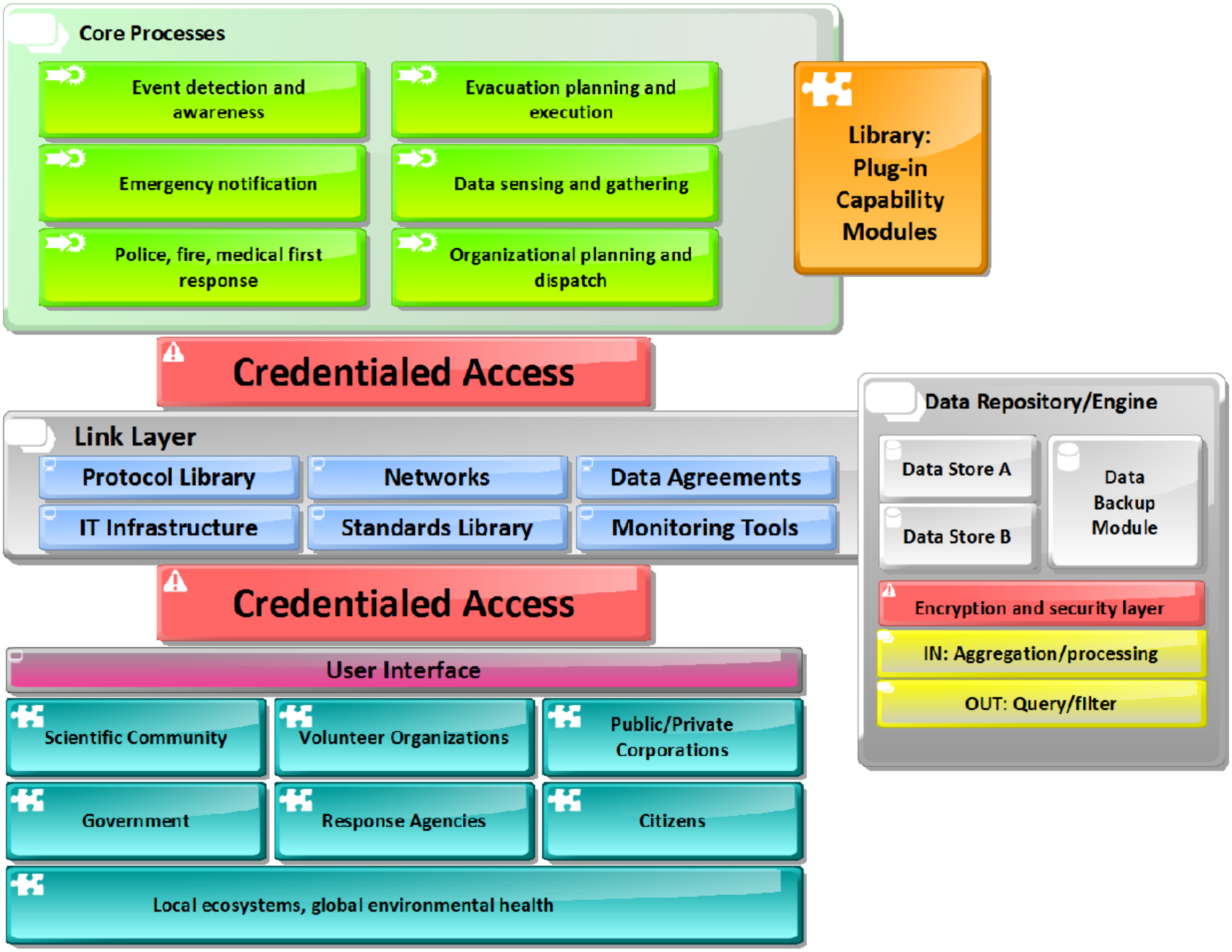

Figure 21 – Core diagram of the disaster response platform shows the high-level view of what will become a sophisticated enterprise architecture. Stakeholders (bottom) access core processes and plug-in modules through a security layer. A data repository is integrated with the linking technology.

A second form of the core diagram, depicted in Figure 22, shows the base architecture expanded to allow regional customization (e.g., city, state, federal). As discussed earlier, the operating model characterizes integration and standardization of business processes. Integration is accomplished with a horizontal “link layer” that is integral throughout all regions including the data repository. Stakeholders and core processes will differ based on scale – note the topology changes indicated among the red, green, and blue regions. The data repository has grown in size and includes additional elements to accommodate varying regional requirements. All stakeholders, core processes, and the data repository only connect through a security layer. Security measures give easy access to properly credentialed stakeholders and curtail malicious attacks against core processes and the data repository.

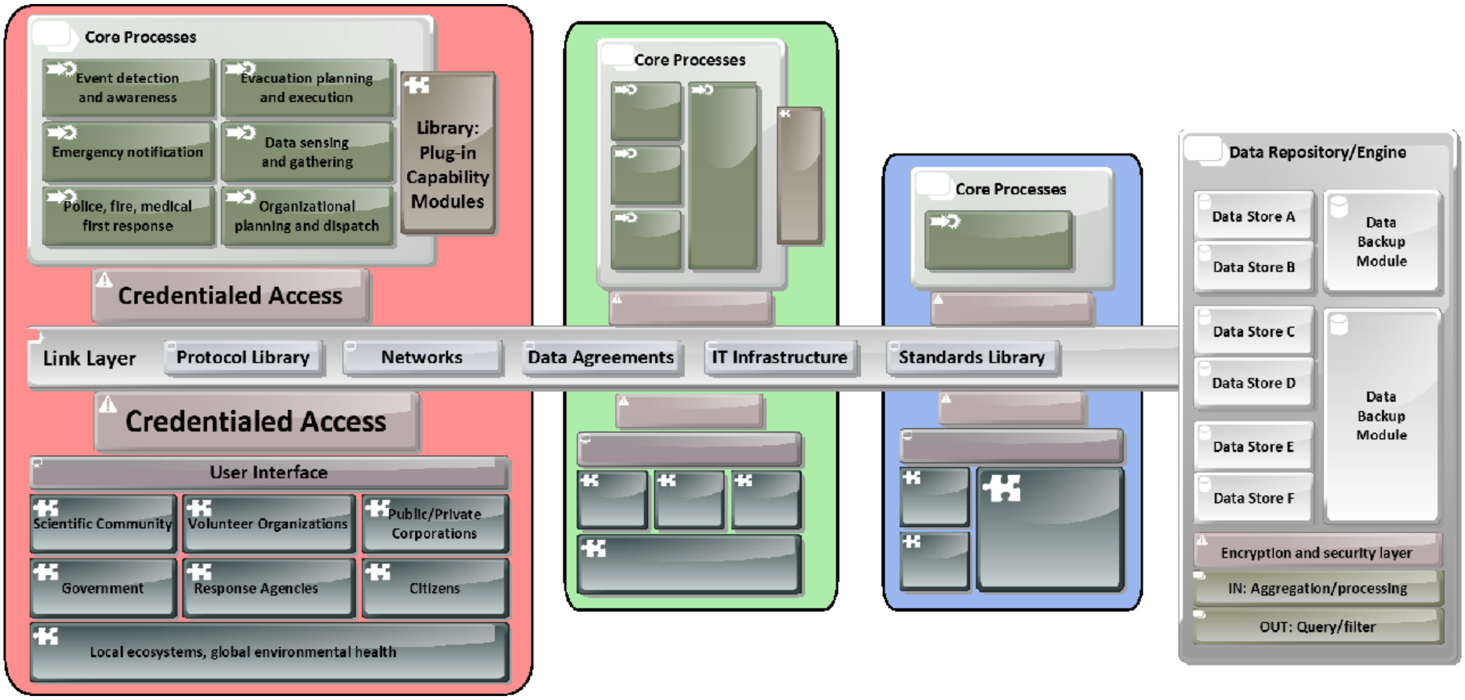

Figure 22 – Core diagram expanded with three similar groupings (shown as red, green, blue) representing system levels at global, national, and local scale. Multiple systems remain closely linked to a common data repository, which has expanded to accommodate growth (compare to Figure 21).

Defining region groupings (Figure 22) is a difficult task. Network-based infrastructure (cloud computing) is a key enabling technology which places few, if any, limitations on how regions are subdivided. The linking layer is best imagined as the ubiquitous "Internet," though as discussed previously, maintaining connectivity during disasters requires extreme diversity in communication media. The data repository appears as a single unit in the diagram, but is distributed geographically to prevent a single point of failure. Distributed infrastructure is feasible and is frequently used today for very large data-based companies (Google, Facebook, Yahoo, and many others).

A discussion of EA in disaster management by Janssen, Lee, Bharosa, and Cresswell (2009) concedes that many of the areas EA attempts to tackle are specifically lacking in modern disaster management efforts. They have concluded that individual agencies involved in disasters are "isolated, overlapping in function and content, [and] highly fragmented." The authors conclude that the lack of multi-agency collaboration remains a key handicap, despite major advances in technology. Their work underscores the importance and relevance of the *business of disasters*.

6.3 IT Engagement Model

The IT engagement model maps infiltration of information technology within the business. Development of the full IT engagement model is an enabling step to full EA adoption and focuses on pulling stakeholders together to facilitate extraction of value from IT investments. More policy and procedure than pictorial diagram, the best engagement models typically contain three primary components: governance, project management, and linking mechanisms. Governance ensures the accountability of decisionmaking and cultivates "desirable behavior in the use of IT." Project management formalizes resource allocations as well as the process of moving from beginning through completion. Finally, "linkage mechanisms" are the keystones that pull together the goals of project activities with governance (Ross, Weil, and Robertson 2006, 119).

The engagement model serves as framework from which to improve operations efficiency, in particular with respect to *leveraging* technologies. Without engagement, project leaders will execute in isolation, ignoring the operational model's goals of standardization and integration – typically by deploying localized solutions to IT problems. In a disaster management system, an earnest approach to IT engagement is advantageous especially due to the very diverse stakeholder population. Given the current state of disaster management and lack of alignment among stakeholders, IT engagement is a promising step to completing the FFE successfully.

Ross, Weil, and Robertson present an effective summary of IT engagement in their lengthy quote of Andre Spatz, who at the time was Chief Information Officer at UNICEF. Spatz remarks:

> *We face high pressures for synergy across UNICEF and at the same time, we have high pressures for local autonomy from the regional and country offices. CIO leadership in a global IT organization is not just command and execute. We need to continually empower people with a vision and execution strategy, and position governance elements within a global framework. Part of my role is to ensure that*

we do not centralize too much and that our IT organization adapts to the different cultural environments we work in (2006, 123-124).

The authors also ask and answer the question, "What is good IT engagement?" They believe good governance gives clarity about decision making and accountability, good project management limits risk and improves the chance of meeting goals, and linking mechanisms ensure that decision conversations can leverage the foundation for execution. In a case study of eighteen companies, they identified several key principles of successful engagement as follows (2006, 135-136):

- Engagement must identify clear strategic objectives that are specific and actionable (i.e., it is possible to actually achieve the objective).
- Incentives motivate unit leaders to achieve goals, especially at the project manager and project architect levels.
- In complement to offering incentive, enforcing performance builds credibility of a project. Enforcement allows change, adaptation, cancellation, or exception when a project is off track.
- IT engagement early can prevent bad solutions from evolving into something larger. Technology architects must be involved with business-level decisions as early as practical.

- Alignment and coordination between IT and business objectives is not *achieved*, but rather is *maintained*. Consistent two-way transparent communication is critical for leveraging technology effectively, especially considering that many high-level decision makers lack an in-depth knowledge of IT limitations or capabilities.

It may seem like oversimplification, but achieving good engagement seems to distill down to business common sense. How can IT professionals expect to build a successful mapping interface when city governments will not clearly explain their requirements? How can the general public be expected to rely on an emergency messaging system when a large portion do not have television or radio, but instead rely on smartphones for the majority of their information? Is it reasonable to expect a scientist to build an analysis module capable of predicting fire propagation with no incentive to do so accurately or efficiently? Most likely, using common sense is not the core problem. The real issue lies in the interagency aspect of applying common sense; it is vastly more complex to act when multiple stakeholders have difficulty collaborating toward a common goal.

Section 7

Funding Model

7.0 Funding Model

The defining characteristics of an "ideal interface" presented in an earlier section are technically feasible, but many of the implementation barriers to actually constructing such an interface could be large. Some of the technologies are candidates for federal funding through research and development grant programs. Other technologies may be better suited for crowdsourcing or even private development. Once operational, continued funding is required to support the IT equipment and personnel for system operations. Using scalable cloud-based infrastructure, the system could operate on standby using a very small team of people with relatively low equipment costs (perhaps $1,000 to $5,000 per month). In the wake of a large-scale disaster, however, IT operational costs may increase to $100,000 per month or more with a commensurate increase in personnel expenditures.[27]

How many zeros? Statistics noted earlier in the paper show natural disasters alone have affected 4.4 billion people, killed 1.3 million, and caused $2 Trillion dollars in damage since 1992 (UNISDR 2011). This averages approximately $270 Million dollars per day – a staggering number that underscores the value of building better management architecture. Factor in the cost of human life and other intangible costs, and the stakes grow exponentially. The value of seemingly imperceptible improvements

[27] The dynamic scaling of the disaster response portal closely matches the usage models advertised by cloud computing providers in which the infrastructure behaves elastically and can respond to times of massive growth while shrinking during periods of disuse.

could be in the billions of dollars. Consider the year 2011 in which the Japan earthquake and Tsunami alone cost approximately $210 Billion, with the total yearly cost of disasters nearing $400 Billion (CRED Crunch 2012). Even a one-tenth of a percentage point (just 0.001 of the whole) could fund a massive $600 million effort. Furthermore, considering the value of human life in the USA approximated at $7 million, saving just one life is significant – saving tens of thousands of lives would represent an astronomical value.[28]

Funding paradigms. Other means of revenue and funding are:

- From the standpoint of human life, we can all appreciate the value of health or life insurance. Perhaps stakeholders in a certain geographic region would consider funding a technology architecture program as a type of "disaster insurance."
- Similar to the Safecast revenue model, the project could be funded by the public in advance or on-demand during events. With over 4 billion people affected by disaster in the last 20 years, even a small contribution from a portion of those individuals would amount to significant revenue. A recent game console crowdfunding project raised over $1 million in eight hours, $2 million by the end of the first day, $5 million after approximately

[28] The Environmental Protection Agency has taken on the problem of "value of a statistical life" and has settled on a number of $7.4 million in 2006 dollars.

five days, and leveled around the $6 million mark after two weeks. [29]

- Stakeholders could be "billed" after the technology architecture has delivered results – perceived or actual. This would be difficult in that investment capital would be required in advance, but it could be a basis for future insurance models once baselines of value are established.

Non-traditional financials. However funding is secured, the economic model is likely to diverge from that of a typical corporation or enterprise. Scope and complexity of each disaster will dictate who stakeholders are, a proposition that could range from citywide to global. Crossing political and social boundaries will be a trying scenario when dealing with economic burdens. Capital investors must absorb the development costs or propose a reasonable model for amortizing the initial expenses over the course of future events. From this perspective, the extensibility of the platform is fundamental – rather than spending billions up front to create the "ultimate" technology architecture, clever design allows the system to start small, then continue building additional value and functionality over time.

Capital investments. Government funding for initial capital requirements is likely, especially due to government's almost ubiquitous

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29 http://arstechnica.com/gaming/2012/07/oh-yeah-ouya-receives-over-1m-in-crowdfunding-in-less-than-8-hours/

involvement in disaster mitigation at city, county, state, and federal level. For example, the National Science Foundation (NSF) offers grants to disaster mitigation research.[30] The NSF has a division called Infrastructure Management and Extreme Events (IMME) that still actively disburses funds for projects focusing "on the impact of large-scale hazards on civil infrastructure and society and on related issues of preparedness, response, mitigation, and recovery."[31] Some of the larger private companies may express interest in capital investment as well. Companies like Google, Amazon (AWS in particular), Comcast, Oracle, and other technology "giants" may be interested in donating infrastructure or intellectual capacity in exchange for tax benefits (donation write-offs) or even improved public perception and involvement.

Global opportunity. Because disasters are a global issue with no regard for social or political boundaries, funding opportunities are abundant. One example is a donation-driven organization known as the Global Facility for Disaster Reduction and Recovery (GFDRR). GFDRR focuses on reducing *susceptibility* to natural hazards, not necessarily the response and mitigation after disaster events. Regardless, its goals are certainly in alignment with those of a disaster technology architecture, as the architecture prescribed in this paper is not limited to a certain disaster phase. On its homepage, GFDRR currently indicate the receipt of $332

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[30] The Responsphere interface mentioned earlier was awarded nearly $2 million over a four-year period. Review the National Science Foundation at: http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0403433

[31] For more on the IMME division of NSF, see: http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=13353

million in pledged funds.[32] The GFDRR has an innovative program of "*risk financing*," which has demonstrated excellent results in recent history. While the program seems focused on helping individuals, the concept could extrapolate to involve stakeholders at many levels.

[32] The GFDRR homepage is located at http://www.gfdrr.org/gfdrr/

Section 8

Further Research

8.0 Further Research

The goal of my research was to approach high-level concepts rather than deal with the details of technological processes. I have concluded that it is both feasible and advantageous to approach disaster management from a business viewpoint and to aggregate technologies through an architectural paradigm – in particular, to implement service oriented architecture where practical. Continuing research should primarily concentrate on applying a "foundation for execution" (FFE) business approach to disaster management with particular effort directed at improving interagency collaboration and stakeholder participation.

The way forward: Funding. An important area to investigate further is procurement of long-term funding. No matter how excellent the proposed technology architecture, investor backing is required to acquisition infrastructure and human resources. The simplistic funding model proposed in the previous section of this paper is only the proverbial "tip of the iceberg" and needs further development. Realistically, this project in its current state is capable of securing just enough funding to *find more funding*. With a small amount of private backing or even a small government grant, the first area of focused research would be how to secure this long-term financial backing. Perhaps local governments have a budgetary allowance that would support further work, or maybe surveys of private companies would uncover interest in backing the project.

Linking technology and business. Extensive research is already in motion concerning the underlying technologies (e.g., broadband wireless, self-assembling networks, wearable computing, simulation gaming, etc.). Calling for additional effort in these areas is pointless because they are already motivated independently of the disaster management problem. My review of literature exposed hundreds of these burgeoning technologies, all of which are candidate plug-in modules for a larger architecture. But I have found little research concerning the integration of these existing and emerging technologies into a disaster-centric architecture. Treating disasters as a large enterprise opens up an entirely new research area. Consequently, study areas are abundant on the topics of stakeholder interactions, interagency collaboration, data sharing ethics, and information ownership (and many others, of course). Combining technology-centric research with business-centric is an important area of future work related to this project.

Dissolving boundaries. Political, legal, and cultural issues present major roadblocks by inhibiting open collaboration and information sharing. This area of future research presents many issues in actual execution. The primary goal is bridging boundaries that separate stakeholders, b y ensuring adequate representation of all entities involved (citizens, government, scientists, victims, local ecosystems, the earth, private companies). Hands-on interviews and focus group discussions are a recommended study area to assist in understanding this phenomenon. Existing collaboration models seem to allow these stakeholders to operate somewhat autonomously – without regard to their effects on others and with no particular motivation to work jointly. This unfortunately creates islands of knowledge, lack of central authority, and many other detrimental side effects. Designing mutually beneficial working agreements could potentially encourage stakeholders to behave altruistically – holding the interests of others above their own in hopes of achieving an overall improvement in outcome. Many agencies will be particularly sensitive about releasing information, especially from a standpoint of legal protection in instances where misinterpretation of data can lead to loss of life or significant financial loss. Research and practical interaction with these agencies is required to ensure that the operating model and resulting technology architecture address key concerns.

Learning from missed opportunities. A pivotal lesson learned in my review of literature was discovery of the Sademer3D tool based on the Capaware platform. Touted as an emergency management decision-making interface, its creators claim the tool shows data in a "usable and intuitive way" while "eliminating noise." Their wildfire case study seemed the perfect proof of concept for application to the Colorado wildfires. But there is no readily available evidence that anyone involved in the Colorado incidents even knew of the tool's existence. If Sademer3D had been published as a capability module as part of a larger "technology architecture," Colorado stakeholders could have immediately put the tool to use. Documenting other disasters and the technologies that *could* have assisted in response and mitigation is an excellent way to secure the future of this project. For example, retrospectively examining the Fukushima disaster from the standpoint of missed opportunities could demonstrate how technologies were available but were not used to their potential (or not used at all). Such case studies might be a proving ground for the proposed technology architecture and foundation for execution approach to disaster response.

Section 9

Conclusion

9.0 Conclusion

The underlying philosophy that began this work was that technologies exist that are capable of drastically improving disaster response and long-term problem solving. My personal experience with a local disaster (the June-July wildfires in Colorado) and the review of literature both support the initial hypothesis and suggest that the core problem is lack of high-level thinking capable of guiding development. Another area of concern is open collaboration among stakeholders.

The technical challenges faced during disasters have similarities to those faced by large companies – especially concerning collaboration and management of IT resources. Enterprise Architecture (EA), or more broadly the "foundation for execution" (FFE), is a business tool used to manage large geographically dispersed companies. The companies that most benefit from an FFE approach have many characteristics in common with the stakeholder population typical of disaster events. Treating disasters as a large enterprise is the logical means to realize an effective response, mitigation, and problem-solving environment.

This project has exposed an excellent opportunity for applying business philosophies to disaster response and mitigation. An initial round of funding will allow a serious investigation into means of securing long-term funding as well as resource allocations by large corporations or government entities. If the next steps are successful, a team of experts could begin working with stakeholders to identify requirements and build working agreements among those stakeholders. With stakeholder buy-in, work would progress methodically through typical design-build-test iterative cycles. Overall guidance from existing frameworks (FFE, EA, and others) will promote a successful implementation.

Collaborative philosophies will be crucial to the success of continued work on this project. Selfless participation on behalf of all stakeholders is necessary for handling disaster events. System designers must not only find and deploy advanced technology systems, but also must help build working relationships among stakeholders. The business-centric FFE view of disaster management may seem an awkward application, but it is a proven and highly effective means of ensuring stakeholders operate in the best interest of the whole, not solely on their own behalf.

Fortunately, many of the problems documented in present-day disaster systems are not intentional, or planned, but rather are an unfortunate lack of awareness. Enabling technologies exist but are encumbered by stakeholder isolation (intentional and unintentional). A business view of disasters and a guided developmental process will improve disaster preparation, response, and mitigation. Implementing a technology architecture will leverage IT for the disaster stakeholders and ultimately lead to reduced financial loss, lessened environmental impact, and decreased loss of life.

Section 10

References

10.0 References

Alexander, David. 1991. Information technology in real-time for monitoring and managing natural disasters. *Progress in Physical Geography* 15, 238:260 (September).

Arisoylu, Mustafa, Rajesh Mishra, Ramesh Rao, and Leslie A. Lenert. 2005. 802.11 Wireless infrastructure to enhance medical response to disasters. *AMIA Symposium Proceedings*.

Aron, Dave. 2012. InnoCentive positions itself as a challenge marketplace. *Gartner, Inc.* Executive Programs. June 27. https://www.innocentive.com/files/node/casestudy/gartner-report-innocentive-positions-itself-challenge-marketplace.pdf (Accessed July 25, 2012)

Boulos, Maged N Kamel, Bernd Resch, David Crowley, John Breslin, Gunho Sohn, Russ Burtner, William Pike, Eduardo Jezierski, Kuo-Yu Slayer Chuang. 2011. Crowdsourcing, citizen sensing and sensor web technologies for public and environmental health surveillance and crisis management: trends, OGC standards and application examples. *International Journal of Heath Geographics* 10:67.

Brown, Carol V., Daniel W. DeHayes, Jeffrey A. Hoffer, E. Wainright Martin, William C. Perkins. 2011. *Managing information technology.* 7th Ed. Upper Saddle River, NJ: Pearson Education.

Castrillón, M., P.A. Jorge, I.J. López, A. Macías, D. Martín, R.J. Nebot, and A. Trujillo, et al. 2011. Forecasting and visualization of wildfires in a 3D geographical information system. *Computers & Geosciences* 37, no. 3: 390-396.

CRED Crunch. 2012. Disaster data: A balanced perspective. *Centre for Research on the Epidemiology of Disasters (CRED).* Issue No. 27. February. http://www.cred.be/sites/default/files/CredCrunch27.pdf (Accessed June 21, 2012)

Deam, Jenny. 2010. Colorado scene: From aerial photos, a ray of hope amid wildfires. *Los Angeles Times.* June 28. http://www.latimes.com/news/nation/nationnow/la-na-nn-colorado-fires-photos-20120628,0,5017543.story (Accessed July 9, 2012)

Dobel, J. Patrick. 2010. Mission integrity in disaster management. *Public Administration Review*. December (special Issue).

Duffy, John. 2011. Trust in Second Life. *Southern Economic Journal* 78:53-62.

Economist. 2008. A survey of corporate IT: Let it rise. *The Economist Newspaper*. From the print edition, October 23. http://www.economist.com/node/12411864/print (Accessed July 23, 2012)

Euchner, James A. 2010. The limits of crowds. *Research Technology Management* 10: 7-8. December.

Eugster, Pathrick Th., Pascal A Felber, Rachid Guerraoui, and Anne-Marie Kermarrec. 2003. The many faces of publish/subscribe. *ACM Computing Surveys* Vol 35 iss. 2: 114-131. June.

Geincke, Pete. 2012. US Wildfires: New Google crisis map, Colorado imagery and more. June 29. http://google-latlong.blogspot.com/2012/06/us-wildfires-new-google-crisis-map.html (Accessed July 1, 2012)

Geospatial Today. 2011. Disaster management: Social media to the rescue. *Geospatial Today* (November 9).

Goldfarb, Charles F. 1996. The Roots of SGML – A Personal recollection. http://www.sgmlsource.com/history/roots.htm (Accessed July 23, 2012)

Google. 2012. Google crisis response: Past response efforts. Webpage. http://www.google.org/crisisresponse/response.html (Accessed July 8, 2012)

Greenwald, Ted. 2010. Software that helps populations cope with crises. *Technology Review*. September/October 44-46.

Grundvig, James Ottar. 2010. The Odyssey of the Dutch oil skimmers. *Epoch Times*. July 8. http://www.theepochtimes.com/n2/united-states/gulf-oil-spill-netherlands-38810-print.html (Accessed August 8, 2012)

Guha-Sapir, Debby, Femke Vos, Regina Below, and Sylvain Ponserre. 2010. *Annual Disaster Statistical Review: The numbers and trends.* Centre for Research on the Epidemiology of Disasters (CRED). Universite catholique de Louvain. Brussels, Belgium. http://www.cred.be/sites/default/files/ADSR_2010.pdf (Accessed June 21, 2012)

Handy, Ryan Maye. Waldo Canyon fire homeowners still in dark. *Colorado Springs Gazette.* June 28. http://www.gazette.com/articles/homes-140948-officials-fire.html (Accessed July 9, 2012)

Hopkins, Curt. 2012. Google tracks hellish wildfire season in the American West. *Conde Nast*. July 4. http://arstechnica.com/security/2012/07/google-tracks-hellish-wildfire-season-in-the-american-west/ (Accessed July 6, 2012).

Jackson, Joab. 2012. Amazon cloud set stage for rapid Pinterest growth. *IDG News Service*. April 19. http://www.networkworld.com/news/2012/041912-amazon-cloud-set-stage-for-258485.html (Accessed July 11, 2012)

Jamail, Dahr. 2011. Citizen group tracks down Japan's radiation. *Al Jazeera.* August 10. http://www.aljazeera.com/news/asia-pacific/2011/08/2011810142915166342.html (Accessed June 24, 2012).

Janssen, Marijn, JinKyu Lee, Nitesh Bharosa, and Anthony Cresswell. 2009. Advances in multi-agency disaster management: Key elements in disaster research. *Information Systems Frontiers* 12:1-7. May 9.

Jones, Elysa and Jacob Westfall. 2010. Common alerting protocol version 1.2 *OASIS (Organization for the Advancement of Structured Information Standards)*. July 1. http://docs.oasis-open.org/emergency/cap/v1.2/CAP-v1.2-os.pdf (Accessed July 8, 2012)

Julca, Alex. 2012. Natural disasters with un-natural effects: Why? *Journal of Economic Issues.* 46-2: 499-510. June.

Khouj, Mohammed, Cesar Lopez, Sarbjit Sarkaria, and Jose Marti. 2011. *Disaster management in real time simulation using machine learning.* IEEE CCECE 001507. Niagara Falls, Canada.

Lwin, Ko Ko and Yuji Murayama. 2011. Web-based GIS system for real-time field data collection using a personal mobile phone. *Journal of Geographic Information Systems* 3: 382-389.

Messerschmitt, David G. 2000. *Understanding Networked Applications: A First Course.* San Francisco: Morgan Kaufmann.

McNutt, Marcia. 2010. Email to "Plume Team." Publicized email document dated May 28th. http://peer.org/docs/noaa/1_23_12_Email_WH_pressure.pdf (Accessed June 25, 2012)

Miyair, Kantaro and Shunsuke Matsuda. 2011. Multi-use of urban infrastructure: Wireless light curried digital communication based on LED street lighting. *8th International Telecommunications Society Conference*. Taiwan. June. http://hdl.handle.net/10419/52333 (Accessed July 23, 2012).

Murthy, Sapna Guniguntla. 2009. Disaster recovery heuristic. Thesis. *Rochester Institute of Technology.* UMI Publishing. August.

National Science Foundation (NSF). 2004. An IT infrastructure for responding to the unexpected. NSF Award #0403433 granted September 3, 2004. http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0403433 (Accessed June 20, 2012)

Noyes, Matt. 2011. Tokoyo letter: After the disaster. *Against the Current* 153:5-7. July/August. Also available in online version: http://www.solidarity-us.org/current/node/3311 (Accessed June 21, 2012).

PEER. 2011. Allegations of scientific and research misconduct. Public letter of allegation dated January 23. http://salsa.democracyinaction.org/dia/track.jsp?v=2&c=UbL6kFuMbaiiq5iphELTefZNDfJAZqwx (Accessed June 24, 2012)

PNNL. 2011. *Gap assessment in the emergency response community.* Pacific Northwest National Laboratory. Batelle. February. http://precisioninformation.org/?p=24 (Accessed April 15, 2012)

Rhyne, Theresa Marie. 1997. Going virtual with geographic information and scientific visualization. *Computers and Geosciences* 23:4, 489-491.

Richard, Bryan. 2008. Facebook puts its SaaS where its mouth is. *QuinStreet Inc.* June 2nd. http://www.linux-mag.com/id/6094/ (Accessed 23 Oct 2011).

Rolland, Erik, Raymond A. Patterson, Keith Ward, Bajis Dodin. 2010. *Decision support for disaster management.* Operations Management Research 3:68-79. March.

Ross, Jeanne W., Peter Weil and David C. Robertson. 2006. *Enterprise Architecture as strategy: Creating a foundation for business execution.* Boston: Harvard Business School Press.

Rushe, Dominic. 2012. BP sues Halliburton for Deepwater Horizon oil spill clean-up costs. *Guardian News.* January 3. http://www.guardian.co.uk/business/2012/jan/03/bp-sues-halliburton-over-deepwater/print (Accessed June 21, 2012)

Senevirante, Krisanthi, David Baldry, and Chaminda Pathirage. 2010. Disaster knowledge factors in managing disasters successfully. *International Journal of Strategic Property Management* 14, 376-390.

Smith, Roger. 2010. The long history of gaming in military training. *Simulation Gaming* 41: 6-19.

Steiner, Matt. 2012. Waldo Canyon fire: Social media dominates flow of fire info. *Colorado Springs Gazette.* July 6. http://www.gazette.com/common/printer/view.php?db=colgazette&id=141309 (Accessed July 7, 2012)

Steward, Duane and Thomas T.H. Wan. 2007. The role of simulation and modeling in disaster management. *Journal of Medical Systems* 31:125-130.

UNISDR. 2012. UNISDR Counts the cost of 20 years of inaction on climate change and risk reduction. *United Nations Office for Disaster Risk Reduction.* Press release. June 13. http://www.unisdr.org/files/27162_2012no21.pdf (Accessed June 21, 2012)

Ushahidi SwiftRiver. 2012. Two-page information brochure. *Ushahidi*. http://ushahidi.com/uploads/docs/SwiftRiver_1-Pager.pdf (Accessed June 20, 2012)

Walker, Warren E., Jordan Giddings, and Stuart Armstrong. 2011. Training and learning for crisis management using a virtual simulation/gaming environment. *Cognition, Technology, and Work* 13:163-173.

Wang, Jiayu. 2007. A Cognitive assessment of post-disaster imagery requirements. Thesis. *University of South Carolina.* UMI Publishing.

Yahoo Inc. 2011. Small business home page.
http://smallbusiness.yahoo.com/ (Accessed 23 Oct 2011).

Zahran, Sammy, Lori Peek, Jeffrey G. Snodgrass, Stephan Weiler, and Lynn Hempel. 2011. Economics of disaster risk, social vulnerability and mental health resilience. *Risk Analysis* 31-7: 1107-1119.

Zolala, Farzaneh. 2010. Data collection after massive natural disasters. *Disaster Prevention and Management* 19:5, 541-547.

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