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MONTEREY, CALIFORNIA

THESIS

**IMPROVING INFORMATION SHARING IN THE
NEW YORK CITY HOMELAND SECURITY
COMMUNITY**

by

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June 2018

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**IMPROVING INFORMATION SHARING IN THE NEW YORK CITY
HOMELAND SECURITY COMMUNITY**

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ABSTRACT

Information sharing during complex large-scale emergencies continues to challenge New York City (NYC) agencies. Despite both local and national mandates for emergency response after 9/11, information sharing between and within agencies is limited. A conceptual model-based approach is proposed for multi-agency information-sharing challenges during large-scale emergency incidents.

A case study of the 2017 Hurricane Maria response in Puerto Rico by NYC agencies within the larger federal response to evaluate the current information-sharing environment highlights the need for more effective information sharing during large events. The case study used the Urban Search and Rescue New York Task Force 1, the New York City Fire Department Incident Management Team, and the NYC Department of Buildings as representative NYC agencies. The case study provided the opportunity to evaluate both the current technology and organizational framework for NYC response agencies and national partner agencies during a real-world event.

The case study research confirmed the potential for a conceptual model to specify the information attributes and flow paths of the event, according to an agency's needs. The research also confirmed the applicability of a model-based approach to include existing legacy systems and data structures to enable inter- and intra-agency information sharing during large events.

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LIST OF ACRONYMS AND ABBREVIATIONS

AAR	after action report
API	application program interface
ARC	American Red Cross
BIN	building identification number
CBRN	chemical, biological, radiological, and nuclear
CIMS	Citywide Incident Management System
CMS	Crisis Management System
DHS	Department of Homeland Security
DOD	Department of Defense
DOITT	Department of Information Technology and Telecommunications
DOT	Department of Transportation
DRTI	distributed real-time infrared
EMAC	Emergency Management Assistance Compact
EO	emergency operations
EOC	emergency operations center
EPA	Environmental Protection Agency
ESF	emergency support function
ESF-4	Emergency Support Function #4
FDNY	New York City Fire Department
FEMA	Federal Emergency Management Agency
GINA	Global Information Network Architecture
GIS	geographic information system
GPS	global positioning software
Haz-Mat	hazardous materials
HHS	Health and Human Services
HIFLD	Homeland Security Foundation Level Data
HPD	Housing Preservation and Development
HSPD	Homeland Security Presidential Directive
IAP	incident action plan
ICP	incident command post

ICS	Incident Command System
IMT	incident management team
IoT	Internet of Things
IST	incident support team
IT	information technology
JFO	Joint Field Office
MOA	memorandum of agreement
MODA	Mayor's Office of Data and Analytics
MOU	memorandum of understanding
MTA	Metropolitan Transportation Authority
NGO	non-governmental organization
NIMS	National Incident Management System
NYC	New York City
NYCDOB	NYC Department of Buildings
NYCEM	NYC Emergency Management
NY-TF1	New York Task Force 1
PREMA	Puerto Rico Emergency Management Agency
PRFD P	Puerto Rican Fire Department
RRCC	Regional Response Coordination Center
SAR	search and rescue
SOP	standard operating procedure
STS	socio-technical system
US&R	Urban Search and Rescue
USACE	United States Army Corps of Engineers
USFS	U.S. Forest Service

EXECUTIVE SUMMARY

Information sharing between response agencies during large-scale emergencies operations in New York City (NYC) remains a challenge in 2018. Since 9/11, one of the major goals of emergency management has been to develop interoperability between response agencies. This thesis examines the issue of interoperability from the perspective of information sharing. Rather than trying to reinvent or alter the response community, this thesis proposes a two-pronged approach to first identify the actual information sharing attributes through conceptual modeling, and then use a model-based architecture to allow for information sharing between agencies utilizing the new and existing legacy systems. This thesis proposes a means of understanding and sharing information within the existing frameworks of the response community rather than reinventing the systems of the participating agencies. The focus of this thesis is on the ability to share information between NYC agencies during large-scale emergencies. After 9/11, a presidential directive mandated a nationwide effort to organize and train response agencies to follow the incident command system (ICS) organizational structure. While the ICS has provided a universal approach to emergency approach in terms of organizational structure and terminology, it has not addressed information sharing between response agencies.

Through a case study of NYC agencies' responses to Puerto Rico for Hurricane Maria in Fall 2017, the current information environment during large-scale emergencies was assessed. As the third hurricane to strike the United States in 2017, the Hurricane Maria emergency response provided an opportunity to examine information sharing from experienced and knowledgeable responders. NYC agencies were deployed, as part of the overall national level roster of agencies, to assist in the response and recovery efforts. The NYC-based response assets used in the case study included the Urban Search and Rescue (US&R) New York Task Force 1 (NY-TF1), the New York City Fire Department (FDNY) Incident Management Team (IMT), and the NYC Department of Buildings (NYCDOB). This deployment provided the thesis the opportunity to examine the current state of information sharing of NYC agencies operating within a larger federal response during a large complex emergency response. The case study provided a current perspective on the

challenges facing the response community regarding information sharing dealing specifically with the continued existence of information silos, the redundancy of effort from a lack of mission awareness between agencies, and the flow of information outside the hierarchical organization of the ICS. By using the Hurricane Maria response in 2017 of NYC agencies to Puerto Rico, the case study provided a compelling justification for the need to propose methods for understanding and improving information flow during emergency operations.

The potential for a conceptual model approach was evaluated from the lessons learned through the case study of Hurricane Maria. A conceptual model represents the architecture of a system in discrete terms accurately depicting the entities, attributes, and relations that compose the operating environment. In broader terms:

A conceptual model-based approach identifies, at a high level, the essential elements, attributes and behaviors of a system. These ‘concepts’ have pan-tropic meaning across agencies and domains, and are not tightly coupled or programmed to data or specific solutions. This perspective allows the many different implementations to be rapidly mapped to the conceptual model at a linear cost in effort vice, the current approach that tends toward geometric cost due to complexity.¹

The conceptual model extends past the traditional response organizational charts and shows the basic system organization, common attributes of mission and information needs, and the flow of information during an emergency operation. The conceptual model in effect puts a meaningful description of the real world information environment on paper to allow an understanding of the unique attributes and relations that exist during an emergency operation.

Once an understanding of the information environment is achieved, through the conceptual model, a system must be developed to link the information systems together so that the needed information attributes and flow paths are established. This thesis proposed the use of open architecture framework and approach. An open architecture framework allows for the integration and interoperation of different systems and their data together while still maintaining their original system characteristics. As stated by Langford, open

¹ Thomas Anderson, personal communication, January 28, 2017.

architecture must be “network-centric, assemble-to-description architecture is scalable, extensible, and expandable with minimal effort.”² This architecture is significantly different from the enterprise systems common to most agencies, where adding or linking a new system requires either the existing system or new system to be reconfigured or modified to allow for the integration. This integration can be a costly and labor-intensive process for the agency using the scarce budget and staff resources of agency information technology (IT) staff. The importance of being able to maintain legacy systems while still allowing information sharing cannot be over emphasized due to the training and costs already invested in (one off) solutions. Describing the existing state of emergency response agency technology environment, one researcher has stated:

There are thousands of stove-piped technologies that are becoming increasingly complex as they are upgraded and extended. With each layer of code laid over existing foundations, these applications and technologies become self-limiting as their inherent complexity begins to overwhelm machine and human capabilities to define and implement interactions.³

Thus, although building interoperability and information sharing within the response community has been strived for, many of these efforts have created new challenges to the information flow.

The conceptual modeling approach of this thesis provides a solution to identify and quantify the formal and informal flow of information between participants during large-scale complex emergencies. The analysis of the model-based platform has furthered the conceptual model approach by proposing a platform that can share distinct information required by agencies while maintaining their legacy systems. The analysis of the model-based framework shows how this approach may allow the information needs identified through the conceptual model to be effectively shared among agencies. The model-based framework’s ability to retrieve select information from different databases with different

² Gary Langford, “GINA Network-Centric Assemble-to-Description Architecture National Maritime Intelligence-Integration Office (NIMO),” *NMIO Technical Bulletin* 6 (February 2014), <http://hdl.handle.net/10945/40315>.

³ Kenneth Stewart, “Researchers, Commanders Partner on Potential Networking Revolution,” Naval Postgraduate School, November 2, 2012, <https://web.nps.edu/About/News/Researchers-Commanders-Partner-on-Potential-Networking-Revolution.html>.

formats, all without the cost of altering existing systems, makes possible the information sharing detailed in the conceptual modeling approach.

During 2017, the United States experienced a range of large-scale emergencies from hurricanes along the eastern coast to record-sized wildfires in the west. These events all reinforced the need to gather and share information between agencies. To ensure its own preparedness, NYC must learn the lessons from these events. The case study of Hurricane Maria clearly described the impact of information gathering and sharing during large-scale emergencies. Information is the cornerstone of good decision making, and the use of the conceptual modeling and model-based platform has provided a potential framework for meeting the information needs of future emergency operations.

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I. INTRODUCTION

A. PROBLEM STATEMENT

The New York City Fire Department (FDNY) is a primary agency in the New York City (NYC) emergency response community whose mission entails executing time critical operations along with federal, state, and local government levels and private partner agencies to complex emergency events. The complexity of emergency operations events arises from the multiple mission spaces and ensuing necessary collaboration among the diverse group of response agencies. Each of these agency partners possesses numerous mission domain spaces, and each mission domain comes with its own information requirements, data stores, and culture. To meet the often lifesaving needs of people during operations, sharing information in a timely fashion both inter- and intra-agency is paramount to efficiency, safety, and mission success.

The Citywide Incident Management System (CIMS) specifies agency mission and primacy during multi-agency emergency responses in NYC. Under CIMS, multiple agencies may respond simultaneously to a large emergency event, according to their capabilities and missions. As a result, agencies can work at the same time and geographical locations and in related mission domains. The operational proximity of multi-agency missions, during extreme events, necessitates collaboration and information transfer throughout the response community. All agencies must have a comprehensive understanding of the joint response effort to ensure resources deployment is effective, mission objectives align, and redundancy of effort is minimized. When agencies work collaboratively, improvement to response effectiveness can be achieved.

Multi-agency cooperation is vital for mission success; however, the existing parochial cultures and differing levels of technological capability confound cooperation and information sharing between agencies during critical incidents. Thus, the efforts of agencies and time spent are wasted, especially during the initial response when resources are limited and expediency critical. To optimize the critical decision-making process of the FDNY during emergency operations (EO), effective joint agency information sharing must

occur. Achieving this information sharing requires cooperation among emergency responders and private industry sectors at the strategic, operational, and tactical levels, as well as a new approach and technology. To enhance operational cooperation, agencies typically propose technology-based solutions. Technology-based solutions, however, are highly varied, constantly changing, and implemented differently across agencies making effective integrated operations difficult if not impossible. To foster information sharing and successfully apply technology, a complete understanding of the information needs, capabilities, and relationships between agencies is required. Development of workable solutions can only occur by understanding the entire response system.

This thesis proposes a conceptual modeling approach to role-based sharing and consumption of information within a federated information environment during joint emergency operations that provides timely and actionable information.

B. RESEARCH QUESTION

Is a conceptual model-based approach to multi-agency information sharing during a large-scale emergency incident an effective solution to information flow for mission effectiveness?

- Secondary Questions:
 - Can mission specific tactical information be provided to improve emergency response effectiveness?
 - What are the fundamental concepts of an information model for an emergency response?
 - What are the relationships among the fundamental concepts of an emergency response?
 - Can a model-based application and framework approach provide customized information to prevent responder data overload during operations?
 - Does this solution address the complexities associated with evolving technology in a multi-agency context?

C. HYPOTHESIS

Information sharing between participants during responses to complex large-scale emergency events continues to challenge first responders. As discussed previously in Section A, sharing information in a timely fashion in both inter- and intra-agencies is paramount to achieving efficiency, safety, and mission success, and to meeting the potential lifesaving needs of people during emergency operations. A large body of work has documented the challenge of information sharing during large EO events in NYC from 9/11 and Super Storm Sandy in 2012.¹ These NYC events mirror the national response environment and the challenges faced by first responders in Katrina 2005 and Hurricanes Harvey, Irma, and Maria in 2017.² These events all demonstrated the impact of inadequate information sharing during large-scale emergencies and its effect on the homeland security enterprise. This lack of timely and accurate information limited both civilian populations' and first responders' ability to make strategic decisions during these events. Without accurate and current situational awareness, decisions on evacuations, resource allocation, and recovery needs cannot be accurately determined.³ These events highlight the need for agencies to share information to make effective timely decisions when operating in a complex multi-agency event. Research will show that by using a conceptual-based model approach to develop an understanding of the information needs and pathways, information sharing will improve during large-scale emergency operations.

A conceptual model represents the architecture of a system in discrete terms and accurately depicts the entities, attributes, and relations that compose the operating environment. In broader terms:

¹ New York City Mayor's Office, *Hurricane Sandy after Action Report and Recommendations to Mayor Michael R. Bloomberg May 2013* (New York: New York City Mayor's Office, 2013), 19, http://www.nyc.gov/html/recovery/downloads/pdf/sandy_aar_5.2.13.pdf.

² Frances Fragos Townsend, *The Federal Response to Hurricane Katrina Lessons Learned* (Washington, DC: White House, 2006), <http://library.stmarytx.edu/acadlib/edocs/katrinawh.pdf>; Chris Bousquet, "Data-Driven Emergency Response: Learning from Hurricanes Harvey and Irma," Data-Smart City Solutions, October 3, 2017, <http://www.govtech.com/data/Data-Driven-Emergency-Response-Learning-from-Hurricanes-Harvey-and-Irma.html>.

³ Townsend, *The Federal Response to Hurricane Katrina Lessons Learned*; Bousquet, "Data-Driven Emergency Response."

A conceptual model-based approach identifies, at a high level, the essential elements, attributes and behaviors of a system. These ‘concepts’ have pantropic meaning across agencies and domains, and are not tightly coupled or programmed to data or specific solutions. This allows the many different implementations to be rapidly mapped to the conceptual model at a linear cost in effort vice, the current approach that tends toward geometric cost due to complexity.⁴

The conceptual model extends past the traditional response organizational charts and shows the basic system organization, common attributes of mission and information needs, and the flow of information during an EO. To model a NYC emergency response, previous events were analyzed to determine the roles and responsibilities that agencies assumed and performed. Additionally, the NYC CIMS guide provided guidance on the defined roles and responsibilities for individual NYC agencies to assume during multi-agency responses.⁵ Combining the previous real world examples and the CIMS guidance document provided the basis for mapping out the participants, information sources, and relationships between responders. From this understanding, a model was then constructed to represent the response organization, information attributes (consumers and users), and the flow paths of information between participants. This model while NYC centric provides a template for the national homeland security enterprise communities to adapt to their specific organizational structure and information needs. This research documents the ability to use a conceptual model approach to define the identity of the participants, fundamental information relationships, and information flow between participating partners during a complex emergency response in NYC.

By using the conceptual model as a foundation, the understanding of information needs from the perspective of both the provider and user during a response to an emergency event will be possible. This comprehensive understanding of the information flow between agencies will allow for the development of a platform providing tactical level information to first responders in a timely and accurate means. Current technology related to information gathering, data storage, and display has significantly impacted the ability to

⁴ Thomas Anderson, personal communication, January 28, 2017.

⁵ “Citywide Incident Management System,” NYC Emergency Management, accessed June 12, 2017, <https://www1.nyc.gov/site/em/about/citywide-incident-management-system.page>.

share information between users.⁶ The cities of Miami and Houston during the 2017 hurricane season were able to use sources, such as social media and Internet of Things (IoT) sensors, to gather information, open cloud servers to store data, and electronic dashboards to provide data visualization through mobile apps for both civilians and first responders.⁷ Combining this expanded technological resource with the foundational understanding of information flow during an emergency event from the conceptual model will provide new opportunities for information sharing. Research seeks to demonstrate that the technology may provide tactical-level information in near real-time to emergency responders during large-scale complex events. Furthermore, the use of the conceptual model approach will likely provide a successful strategy for understanding similar organizational structures and attributes for communities across the homeland security enterprise.

The ability of the emergency responder to digest emergency response information is limited by both cognitive human capabilities and time dependence of decision making during emergency events as they develop.⁸ As technology has advanced, the amount of data and speed in which it can be provided to the emergency responder has grown beyond human comprehension. The tremendous amount of data and information available, the ability to make sense of the events and conditions, and organizing facts to support logical decision-making becomes extremely difficult when faced with an information deluge. Recent events have shown that this new deluge of available information results in “information overload” where decision makers cannot separate the relevant information from the extraneous when trying to make decisions under stress in a time-compressed complex emergency response.⁹ This research seeks to explore a model-based application

⁶ Minkyun Kim et al., “Assessing Roles of People, Technology and Structure in Emergency Management Systems: A Public Sector Perspective,” *Behaviour and Information Technology* 31, no. 12 (December 1, 2012): 1156, <http://search.proquest.com/docview/1671546099/>.

⁷ Bosquet, “Data-Driven Emergency Response.”

⁸ Mark Stanovich, *Network-Centric” Emergency Response: The Challenges of Training for a New Command and Control Paradigm* (Hanover, NH: Emergency Readiness and Response Research Center, Institute for Security Technology Studies, Dartmouth College, n.d.), 4, accessed February 2, 2018, <http://www.ists.dartmouth.edu/library/191.pdf>.

⁹ Stanovich, 4.

approach within an information platform to filter the information flow and provide the necessary facts and data to the decision maker involved in a large EO scenario.

D. METHODOLOGY

Forecasting the way forward for information sharing in the NYC emergency response community and the role of the FDNY requires a review of local initiatives, national trends, and recent real-world events related to current emergency information sharing advancements. Past after action reports (AARs) have documented the need for information sharing during recent large-scale events in NYC, as well as the consequences in terms of the loss of life and property when agencies do not share information.

The initial research step is to identify the current efforts underway in NYC to promote information sharing between agencies during large-scale complex emergencies. This review includes the Mayor's Office of Data and Analytics (MODA) project to develop a citywide intelligence hub.¹⁰ The MODA perspective will provide insight on the strategic level policy decisions being implemented to foster information sharing across NYC government agencies. The existing methods of data sharing and storage currently used by NYC agencies are reviewed to determine potential areas that the focus of this thesis may address. Additionally, the current identified challenges to information sharing at the strategic level are evaluated to determine potential solutions.

The next focus of the research is a case study to examine the lessons learned during the recent emergency response to Hurricane Maria in Puerto Rico during Fall 2017.¹¹ This event provides a representative scenario to examine the state of emergency response information sharing between agencies within a catastrophic natural event. Although differences exist between NYC and Puerto Rico in terms of response resources and capabilities, this event allows for the examination of the current status of information

¹⁰ "Citywide Intelligence Hub & February Data Drill—Data Sharing and Data Integration Discussion," NYC Analytics, February 17, 2017, <https://www1.nyc.gov/site/analytics/initiatives/citywide-data-sharing.page>.

¹¹ The NYC FDNY IMT, and DOB assets deployed to Puerto Rico in the aftermath of Hurricane Maria with separate missions working within the Federal Emergency Management Agency (FEMA) response led the response effort. Each agency was requested through different inter-agency agreements and reported to a separate chain of command.

gathering, storing, and sharing while operating in exceptional conditions. This recent real-world event provides a current perspective on the policies and technology in use by NYC agencies, as well as federal and local partner agencies during a large-scale emergency. Assets deployed from the NYC response community assisted in response and recovery operations across the island with various missions. Evaluation of the information sharing during the response to Maria can help identify the gaps that exist in coordination and collaboration between agencies at all levels during a response to a large complex emergency event.

As discussed in the hypothesis, the threat of “data overload” from the recent advancements in IT has affected a wide range of decision makers. The U.S. military faces similar challenges to first responders in trying to provide pertinent and accurate information during compressed decision-making periods.¹² Additionally, it also struggles with filtering the massive amount of data available from the multiple sensors and information sources in its operating environment that is described as the “widening gap between the volume of information that is generated and the subset of that information which can be successfully delivered to consumers.”¹³ To address this challenge the thesis will examine the suitability of using a conceptual model-based framework. This evaluation considers the potential for a conceptual model-based approach and open architecture system as a basis to develop an effective communication and information-sharing platform.¹⁴

Lastly, all the information gathered from the review of existing policies and procedures, recent event case studies is evaluated. This research seeks to determine if the conceptual modeling method can effectively improve the information-sharing capabilities within the emergency response community during a large-scale emergency response.

¹² Suri et al., “Exploring Value-of-Information-Based Approaches to Support Effective Communications in Tactical Networks,” *IEEE Communications Magazine* 53, no. 10 (October 2015): 39.

¹³ Suri et al., 40.

¹⁴ Anderson, “Dragon Pulse Information Management System (DPIMS).”

E. SIGNIFICANCE OF RESEARCH

The occurrence of large-scale emergencies and their impact on the homeland security enterprise has been highlighted again in 2017 by the landfall of three major hurricanes along the southeast coast of the United States. Each of these events required a large-scale response from the emergency response community at the local, state, and federal levels. In response to these hurricanes, the Department of Homeland Security (DHS) has requested, “surge staffing” of volunteers from all federal government agencies to assist the 38,000 federal employees already assisting with recovery efforts, through the 2006 Post-Katrina Emergency Management Reform Act.¹⁵ Furthermore, these responses required information sharing across multiple agencies, jurisdictions, and mission assignments. Additionally, these recent events have shown that the status of emerging technologies regarding information gathering, storing, and sharing has advanced and that new possibilities and opportunities are possible for response agencies.¹⁶

However, while these events occurred outside of NYC, many NYC emergency response agencies responded and assisted through mutual aid agreements. As part of the response, these participants have used the current NYC policies, procedures, and technology and put them into use. By applying the NYC centric policies during an event outside NYC, the ability to develop best practices for both the NYC agencies, as well as with national emergency response partners, is possible.

The use of conceptual modeling as a basis for developing an understanding of the information needs and flow during emergency operations may provide a model for emergency response communities to use within their own operational organization. This research also allows for the evaluation of U.S. military efforts regarding open architecture integration platforms to enhance information sharing for civilian first responders during complex emergencies

¹⁵ Eric Katz, “DHS Seeks Volunteers from Other Agencies to Join Hurricane Relief Surge Force,” *Government Executive*, September 15, 2017, <http://www.govexec.com/management/2017/09/dhs-solicits-feds-across-government-help-hurricane-response/141061/>.

¹⁶ Bosquet, “Data-Driven Emergency Response.”

F. THESIS ORGANIZATION

Chapter I introduces the problem of information sharing currently faced within the NYC response community and presents the research questions to explore solutions to the identified challenges. Hypotheses are presented, as is the methodology used, to answer the research questions. The significance of research and this organizational description of the document complete the first chapter.

Chapter II provides insight into information sharing within the NYC response community and describes the current state of the problem. This chapter provides context to the challenge and the importance of understanding the current capabilities and limitations of the numerous stakeholders necessary to understand the recommended solution. As part of this context, this research provides a discussion on the recent citywide initiatives on strategic information sharing to provide an understanding of the constraints and challenges to information sharing within NYC. Lastly, the research discusses the FDNY role and current efforts in developing information sharing during major emergencies in NYC.

Chapter III is a review of the existing literature regarding the adoption of new technology and learning both individually and organizationally during a crisis. The technology portion also reviews literature regarding the use of conceptual modeling as a means to understand systems' organization and operation.

Chapter IV details the roles and responsibilities of the FDNY and DOB during their deployment to the island of Puerto Rico post-Hurricane Maria. The interaction between the two agencies, as well as with FEMA assets in regards to information sharing, is provided. The chapter concludes with an analysis of the current state of information sharing and lessons learned during this deployment.

Chapter V discusses the integration of the conceptual modeling open architecture approach to understand how it applies to the challenge of information sharing in the NYC emergency response community. The chapter includes how to apply the use of a conceptual model approach as a means to understand and delineate the relationships that control information. The research analyzes the adaptability of the model-based applications to

meet the challenges identified in the conceptual model for sharing information between NYC response agencies.

Chapter VI describes how the leveraging of technology and lessons learned through this research can allow the development and implementation of near real-time information sharing in the NYC emergency response community. From the conceptual modeling approach, a clear articulation of the system and its attributes was achieved that led to a more comprehensive understanding of the system, which might be leveraged to develop efficient solutions to the challenge of information sharing in joint agency EO.

II. CURRENT SITUATION AND BACKGROUND

A. CURRENT STATE OF EMERGENCY RESPONSE INFORMATION SHARING IN NYC

To improve the current NYC information system, a comprehensive understanding of its existing components and processes is necessary. Effective change will result from developing an understanding of the existing information-sharing environment within the NYC EO community. Recognizing this fact, this section provides a description of the existing state of information sharing within NYC. An analysis of the organizational structure, current state of technology, agency policies, and operating culture provides an understanding of the existing status of the NYC information sharing system. This analysis identifies the current challenges and information sharing gaps from both the organizational and emergency response perspective. An analysis of the conceptual model approach examines the potential for this method to answer many of the identified challenges of information sharing in NYC.

The existing NYC emergency organizational response framework is the result of a number of different contributing factors including CIMS, the NYC charter and laws, and individual agency policies and procedures. Each of these factors affects the current ability and potential for future information sharing within NYC. These individual factors are also some of the reasons why NYC has such a robust and capable emergency response community.

The CIMS document provides direction to NYC agencies on their roles and responsibilities during multi-agency emergencies within NYC.¹⁷ The CIMS document is the adaptation of the National Incident Management System (NIMS) into the existing NYC emergency response community.¹⁸ NIMS is the national guidance document for implementing the incident command system (ICS) during emergency operations. The goal

¹⁷ NYC Emergency Management, “Citywide Incident Management System.”

¹⁸ George W. Bush, *Homeland Security Presidential Directive/HSPD-5: Management of Domestic Incidents* (Washington, DC: White House Office of the Press Secretary, 2003), <http://www.whitehouse.gov/news/releases/2003/02/20030228-9.html>NIMS document.

of both NIMS and CIMS is to use the ICS concept to standardize emergency responses by providing a common organizational structure, standardized language, and modular system to match the command system size with the needs of the event.

In the aftermath of 9/11 in NYC, as well as across the United States, it was apparent that a response framework was needed to coordinate and control the efforts of the various agencies involved with large-scale emergency responses. In response, the Homeland Security Presidential Directive 5 (HSPD-5) mandated the implementation of the ICS for all domestic emergency responses. NYC developed CIMS due to the mandate for the ICS to be used for all domestic emergency responses. CIMS adopted and modified ICS principles “to address New York City’s unique incident management requirements.”¹⁹ In addition to incorporating the standardized organizational structure and terms from the ICS, CIMS delineates the roles and responsibilities of NYC agencies at emergency events. CIMS also provides a framework for a means of integrating regional, state, and federal agencies into a NYC response. CIMS provides the template to apply the national ICS organizational structure to the existing parochial culture of the NYC emergency response community. Since the established NYC response community has overlapping missions and capabilities, CIMS provides guidance on how the division of responsibility may be broken down to reduce the redundancy of effort and maximize the effectiveness of response resources. Unfortunately, by trying to incorporate the competing agency interests, the CIMS system has provided a number of accommodations to mold the more traditional ICS concepts to the political realities of NYC. CIMS was created to solve the problems of joint agency coordination and collaboration that led to the tragic results on 9/11. By modifying the national framework of NIMS, CIMS provides accommodations that perpetuate some of the confusion on incident command experienced during 9/11. These accommodations include varying the organizational structure based on event type to allow multiple agencies to maintain unique radio codes and terms, and permit agencies to provide tactical direction to other agencies.²⁰ The CIMS document permits both single and unified command at the incident and operational levels depending on event type.

¹⁹ NYC Emergency Management, “Citywide Incident Management System.”

²⁰ NYC Emergency Management, “Citywide Incident Management System.”

A chemical, biological, radiological, and nuclear (CBRN) event can illustrate the challenges of implementing the CIMS doctrine during a real-world event. If the CBRN event is purely accidental, then the FDNY and NYPD will form a unified command. If terrorism or criminal intent is suspected or confirmed, the event then becomes a single command under the NYPD, with a unified operations section staffed with NYPD and FDNY resources. Technology adds to the confusion; both the FDNY and NYPD use separate radio frequencies, different radios codes, and have separate and distinct operating protocols for CBRN hazardous materials (Haz-Mat) events. CIMS also directs the agency with the core competency to provide tactical direction to other operating agencies. In a criminal or terrorism-based Haz-Mat scenario, the FDNY's core competency is life safety and mass decontamination, and the NYPD's is assessment and investigation. In this scenario, the FDNY would provide tactical direction to the NYPD; however, the NYPD would be the incident commander and in overall charge of the operation. The blurred lines of responsibility make delegating tasks and assigning responsibility very contentious. As stated in FDNY Battalion Chief John Esposito's thesis, which evaluated CIMS several years after implementation, "63% of the respondents said personnel from other agencies did not seek and did not follow the direction of the FDNY incident commander when that agency was performing a FDNY core competency."²¹ Additionally, his research of the FDNY chief officer's interaction with other agencies during emergency operations stated, "Only 16% answered that other agencies sought direction from the FDNY when performing FDNY core competencies at 90% or more of the incidents."²² Thus, agency members will only take tactical direction from commanders within their own organization.

Compounding the difficulty of setting up a comprehensive command structure is the delegation of life safety and criminal investigation. Under the CIMS document, life safety is a FDNY responsibility, which is the highest priority objective at all incidents and the FDNY shall continue to perform all tasks necessary to achieve its mission of life

²¹ John Esposito, "New York City Fire Department Chief Officer's Evaluation of the Citywide Incident Management System" (master's thesis, Naval Postgraduate School, 2011), 21.

²² Esposito, 21.

safety.²³ If terrorism or criminal intent is suspected, the event is automatically a single command event with the NYPD as incident commander. These two caveats provide leverage for each agency to justify its participation and command position regardless of the specific roles and responsibilities detailed within the CIMS document. Thus, in the struggle for preeminence, justification for grant funding and staffing levels, both agencies tend to insert themselves into an event and maintain involvement to maximize exposure and participation.

CIMS provides no direction on requiring information sharing between agencies at either the tactical or strategic level.²⁴ At the strategic level, NYC Emergency Management (NYCEM) is assigned the role of area command. As the area command element, NYCEMS' role is to coordinate decision-making and information sharing between participating agencies from the emergency operations center (EOC) located at NYCEM headquarters. In NYC, each of the agencies maintains command of its resources and the NYCEM acts in a coordinating role to assist in the completion of the mission. Since no defined requirements to provide information, specific reporting format, or method have been established, little to no information sharing occurs between agencies. Information reporting to the NYCEM EOC is from onsite NYCEM staff who gather information and provide briefings back to the NYCEM command. Both the FDNY and NYPD have established separate EOCs to coordinate their own agency operations. Additionally, unlike area command in other areas, the NYCEM does not have ultimate authority over the participating agencies.

At the tactical level, onsite coordination and collaboration is through face-to-face conversation when possible by the onsite command. As found by Esposito in his survey on command post operations, “only 22% of the fire chiefs believe that the incident commander and the command post were easily identifiable for incidents at which NYPD was the single

²³ Fire Department City of New York, *Citywide Information Management System (CIMS) Quick-Guide*, AUC 276 (New York: Fire Test Taking, 2007), <http://firetesttaking.com/pdfs/auc/276.pdf>.

²⁴ New York City Emergency Management, *Citywide Information Management System Charts* (New York: New York City Emergency Management, n.d.), accessed September, 2017, http://www.nyc.gov/html/oem/downloads/pdf/CIMS_charts.pdf.

agency command.”²⁵ If the incident commander is not readily identifiable to partnering agencies, the transformation of information does not occur. NYCEM Commissioner Bruno reinforced the importance of face-to-face communication, during a city council hearing on CIMS implementation when he characterized “face-to-face” communication as the “ultimate in interoperable communications over the course of the entire incident”.²⁶ The lack of tactical “face-to-face” communication between the two preeminent response agencies in NYC hampers the development of joint operations and efficient tactical operation.

The result is that in spite of the CIMS protocols, limited information sharing is currently occurring at either tactical or operational levels. While CIMS has provided guidance on how to conduct and manage operations, it has not addressed the need to share information. Without the efficient and timely sharing of information during emergency operations, NYC response agencies are at risk of repeating the tragedies that initiated CIMS.

The FDNY IMT has been used during recent extended duration large-scale events to act as an event management asset to develop coordinated responses through the production of an incident action plan (IAP). The IAP incorporates all the incident objectives and tactical operations for each agency operating at the event into one document.²⁷ While helping to coordinate response activities, the FDNY IMT deployment has not addressed the concept of information sharing between agencies.

CIMS only provides guidance for the overall organization structure and general areas of responsibility for joint operations at multi-agency events.²⁸ Individual agencies internally develop the tactics, procedures, and protocols for emergency responses. Thus, although an organizational structure for the response community has been defined, the

²⁵ Esposito, “New York City Fire Department Chief Officer’s Evaluation of the Citywide Incident Management System,” 35.

²⁶ Esposito, 37.

²⁷ Federal Emergency Management Agency, *FEMA Incident Action Planning Guide* (Washington, DC: Federal Emergency Management Agency, 2012), 7, https://www.fema.gov/media-library-data/20130726-1822-25045-1815/incident_action_planning_guide_1_26_2012.pdf.

²⁸ NYC Emergency Management, “Citywide Incident Management System.”

equipment used, tactics, and communications are created internally by each agency. This independent plan development results in agencies relying on agency specific internal resources to accomplish the mission. In regards to tactical level information sharing, since the operational plan is internally developed with agency specific assets, the need and ability to share information is rarely emphasized or addressed.

The status and use of technology varies widely between agencies. Due to individual agency needs, budget constraints and adoption rates technology varies widely between agencies. For the most part, each NYC agency determines technology needs independently. Unfortunately, delays, cost over runs, and a poorly working final product have at times plagued the development of new technologies.²⁹ The Department of Information Technology and Telecommunications (DOITT) does provide limited oversight on operating protocols and purchasing for city agencies.³⁰ This limited oversight has resulted in the development of a wide spectrum of technology in use across NYC. Additionally, due to the administrative layers for purchasing and scale of each agency, it is extremely difficult for agencies to maintain currency as technology evolves, which has led to a wide variety of adoption rates of technology for agencies. As agencies struggle with budget constraints, the focus is typically on maintaining and enhancing core mission capability rather than expanding capability or ability to share with other partner agencies. Cyber security has also curtailed the willingness and ability of agencies to share data sets. Recent cyber-attacks have reinforced cyber security concerns for agencies across the city.³¹ The threat from cyber-attack has resulted in the establishment of firewalls to protect individual agency data and the reluctance to open up data to other agencies and potential exposure to cyber-attacks. The reluctance to open databases has reduced the ability and willingness to share information between agencies.

²⁹ David M. Halbfinger, "City Sets Up Nonprofit Corporation to Oversee Technology Projects," *New York Times*, sec. N.Y./Region, 1, August 23, 2012, <https://www.nytimes.com/2012/08/24/nyregion/new-york-city-sets-up-nonprofit-corporation-to-oversee-tech-projects.html>.

³⁰ "Services for Agencies," NYC Information and Technologies, accessed February 2, 2018, <https://www1.nyc.gov/site/doitt/agencies/for-agencies.page>.

³¹ NYC Emergency Management, *New York City Hazard Mitigation Plan 2014, Draft for Public Review, Cyber Threats, Section III: Non-Natural Hazard Risk Assessment* (New York: NYC Emergency Management, 2014), http://www.nyc.gov/html/oem/downloads/pdf/hazard_mitigation/plan_update_2014/3.17_cyber_threats_public_review_draft.pdf.

The relative rarity of large-scale events requiring agencies to work together is another aspect that influences the current level of information sharing. The overwhelming majority of agency responses are single agency events, handled by agencies implementing their established internal policies and procedures. The FDNY responds to approximately 1.7 million incidents a year between the fire and EMS branches.³² Out of these responses, the FDNY handles almost all the responses as a single agency.³³ The large complex events that require multi-agency coordination are the exception rather than the rule. Since the normal response procedures work for such an overwhelming number of responses, it is extremely difficult for agencies to pivot and adopt a new strategy of information sharing and collaboration under the intense pressure and compressed decision-making window of a large complex event. Rather, commanders rely on the proven agency specific tactics and techniques they used previously and try to apply them to the situation at hand. As detailed previously, these existing tactics and strategies do not include agency information sharing.

Large complex events are typically unique events that present responders with unforeseen challenges. Recent examples in NYC include 9/11 and Super Storm Sandy. In each instance, response agencies faced incidents on which existing policies and procedures provided little or no guidance.³⁴ Additionally, these emergencies exposed how changes in the response environment, such as fire protection, building codes, and population shifts, have led to conditions for which existing policies and procedures were not prepared. Due to the relatively rarity of the large complex event, changes in the response environment can occur over time and not be exposed until a catastrophic event occurs and the existing tactics are then found to no longer be applicable.

The traditional perception of separate and distinct missions between response, recovery, and support agencies also discourages information sharing. The focus of response

³² Bill de Blasio, Daniel A. Nigro, and James E. Leonard, *FDNY Strategic Plan 2015–2017* (New York: Fire Department City of New York, n.d.), accessed February 2, 2018, http://www.nyc.gov/html/fdny/pdf/ofc/FDNY_strategic_plan_2015_2017.pdf.

³³ New York City Independent Budget Office, *Chart Book, Analysis of Fire Department Response Data, 2013* (New York: Independent Budget Office Chart Book, 2016), <http://www.ibo.nyc.ny.us/ibo/reports/analysis-of-fire-department-response-data-2013-february-2016.pdf>.

³⁴ New York City Mayor's Office, *Hurricane Sandy after Action Report*, 19.

agencies, such as the FDNY, is on immediate life safety and controlling emergencies.³⁵ Other agencies handle recovery efforts, which typically start upon completion of FDNY operations. Although the extent of recovery operations is dependent on the conditions that the FDNY leaves the scene in, the transfer of command and control between agencies is usually informal. Information is rarely gathered and preserved in a manner additional agencies can use.

The concept of information sharing, while a great altruistic goal, must provide a tangible result if agencies are going to invest time and resources. All agencies have a limited amount of funding and staffing to accomplish their specified missions. Information sharing provides limited benefit in the near term; rather, the benefit of information sharing is typically realized downstream through the reduction of redundant missions and an inefficient use of resources due to a lack of information.³⁶ This lack of reward or incentive is observed at the individual, agency, and community levels of the response community.³⁷ Correspondingly, the commitment of resources for relatively rare events with limited benefit to any level of the agency has received limited attention from administrations. Only by taking a more holistic view of the event from a citywide view can the potential and benefit of increased information sharing be clearly quantified. Examining the entire system exposes the inefficiencies of multiple agencies collecting the same data and the resulting waste of resources through redundant efforts. In contrast, research shows that information sharing will not occur unless the individual receives incentives during emergency operations.³⁸ Although information sharing is generally regarded favorably and can be shown to improve operations quantitatively, adoption and implementation has been slow due to the complexity of the constantly evolving problem and a lack of perceived cost-benefit by field and agency level staff.

³⁵ de Blasio, Nigro, and Leonard, *FDNY Strategic Plan 2015–2017*.

³⁶ Nitesh Bharosa, JinKyu Lee, and Marijn Janssen, “Challenges and Obstacles in Sharing and Coordinating Information during Multi-Agency Disaster Response: Propositions from Field Exercises,” *Information Systems Frontiers* 12, no. 1 (March 1, 2010): 49–65, <https://doi.org/10.1007/s10796-009-9174-z>.

³⁷ Bharosa, Lee, and Janssen, 49–65.

³⁸ Bharosa, Lee, and Janssen, 49–65.

Since each agency operates within its own domain space the corresponding solutions for information sharing tends to be agency specific. The uniqueness of each agencies solution for information sharing further complicates the potential for developing a citywide comprehensive information-sharing platform. As every agency looks through its own lens of mission domain and information needs, the ability to integrate between different technology formats and needs becomes ever more difficult. Additionally, it is extremely difficult to predict the information needs of multiple agencies during complex emergencies. By their nature, complex emergencies introduce new complexities and previously unknown interrelations for emergency managers. Specifying ahead of time the information commanders will need during complex emergencies is extremely difficult. The tendency is to provide all available information, overwhelming the Incident Commander with data saturation. The goal is to provide baseline relevant information with the ability to access additional information as unique information needs occur. Specifying the type and need of information to provide commanders with the information they need and not overload by presenting all data becomes extremely difficult.³⁹

The existing NYC response community is characterized as a parochial structure of independent agencies acting parallel to each other during emergency responses. Each agency has developed independently from the other in creating their response policies, procedures, and protocols. Each agency culture reinforces the concept of self-reliance and places little or no value on interagency collaboration.⁴⁰

All the aforementioned conditions of the NYC emergency response community have led to the current environment where information sharing is limited at best and non-existent in most cases. Unfortunately, NYC represents just one more example within the emergency response community at large that struggles with information sharing at the tactical level. These same organizational and cultural challenges are documented in emergency responders across the United States and Europe.⁴¹ Although these problems

³⁹ Vimala Nunavath, Andreas Prinz, and Tina Comes, "Identifying First Responders Information Needs: Supporting Search and Rescue Operations for Fire Emergency Response," *International Journal of Information Systems for Crisis Response and Management* 8, no. 1 (January–March 2016): 25–46.

⁴⁰ Thomas J. Currao, "A New Role for Emergency Management: Fostering Trust to Enhance Collaboration in Complex Adaptive Emergency Response Systems" (master's thesis, Naval Postgraduate School, 2009), 110.

⁴¹ Bharosa, Lee, and Janssen, "Challenges and Obstacles in Sharing," 49–65.

have been widely documented, the need and benefit for information sharing during emergency operations has also been widely documented.⁴²

The question then becomes how to overcome the documented challenges to meet the recorded need for agencies to share information during complex emergency events. To overcome these challenges, this thesis proposes a conceptual modeling approach to provide a potential method to overcome them. The entire response system can be analyzed by using a conceptual model approach. The federation of information allows for a comprehensive view of the system. The federation of the information allows agencies to maintain their separate and distinct databases and still share with partner agencies. This federated information at the conceptual level allows individual agencies to access and interpret information as needed. All these agencies are then operating on the common data set, which will lead to the development of a common operating picture for event agencies. Lastly, information transfer from agency to agency as the event proceeds from inception to recovery is possible. This “super convergence” of information provides the ability to align multiple missions’ information needs.

The advancement of technology in regards to the ability to collect, store, and combine large quantities of data have made the federation of data possible through a conceptual modeling framework, where users and components are linked in a multi-dimensional system.⁴³ Additionally, the use of a geographic information system (GIS) has made the possibility of tying databases to specific locations possible. By having a universal tag for location, GIS has provided the unifying force to link various data sets together and allow multiple domains to be linked and merged.⁴⁴ This technological innovation has also provided significant reductions in the cost of information-sharing technology. As technology has developed, the overall cost for users has been reduced through the ability to process and store more data.

⁴² Bharosa, Lee, and Janssen, 49–65.

⁴³ Gary Langford, “GINA Network-Centric Assemble-to-Description Architecture National Maritime Intelligence-Integration Office (NIMO),” *NMIO Technical Bulletin* 6 (February 2014), <http://hdl.handle.net/10945/40315>.

⁴⁴ “Public Safety & Disaster Relief,” GPS, accessed February 2, 2018, <https://www.gps.gov/applications/safety/>.

B. RECENT INFORMATION SHARING INITIATIVES

Policy level staff have recognized the need and benefits of data and information sharing between NYC agencies. Executive Order 306 in 2013 established the NYC MODA.⁴⁵ MODA has been tasked with “allowing the City to aggregate and analyze data from across City agencies, to more effectively address crime, public safety, and quality of life issues”⁴⁶ To accomplish this mission, MODA has developed a citywide data sharing platform “DataBridge” with “automated data feeds from over 50 source systems belonging to roughly 20 agencies and external organizations.”⁴⁷ All this data is uniformly GIS tagged when stored to allow agencies to correlate information and perform cross-agency analysis. In February 2017, MODA conducted data sharing and integration exercise involving 22 city agencies over two days.⁴⁸ The main takeaways from the exercise included “challenges with permissions, performance, communication, usability, and organization of files,” as well as the importance of the “single version of the truth” and “real-time data processing.”⁴⁹ The parochial nature of NYC agencies combined with need for cyber security protocols have combined to limit both the ability and willingness to share information across agencies. Policy level staff have made progress, but significant issues remain to create the environment where effective multi-agency information sharing is realistic.

C. INFORMATION SHARING AND THE FDNY

The introduction of information sharing represents a new mission for the FDNY. As a primary response agency, the FDNY’s role will be both a collector of information, as well as that of a consumer. As stated earlier, only by providing incentives will agencies

⁴⁵ NYC Mayor’s Office, *Executive Order No. 306 Mayor’s Office Of Data Analytics April 17, 2013* (New York: NYC Mayor’s Office, 2013), http://www.nyc.gov/html/om/pdf/eo/eo_306.pdf.

⁴⁶ “About the Office of Data Analytics,” NYC Analytics, accessed February 2, 2018, <https://www1.nyc.gov/site/analytics/about/about-office-data-analytics.page>.

⁴⁷ NYC Analytics.

⁴⁸ NYC Analytics, “Citywide Intelligence Hub & February Data Drill.”

⁴⁹ NYC Analytics, 8.

embrace information sharing at any level.⁵⁰ As fire suppression activity continues, a decrease in the additional role of information collection could justify additional budget lines and staffing for the FDNY.⁵¹ The position of information source for multiple agencies could provide an additional and expanded role in emergency events that the FDNY have not historically been involved in, such as the cooling tower survey in 2014.⁵² The collection and management of response data by the FDNY can quantify the work done by the agency. Emergency services are extremely difficult to quantify value in terms of performance and this data collection role may afford the opportunity to provide a solution.

Just creating a model or platform for information will not be enough to ensure implementation. To ensure that information gathering is institutionalized, the system must be codified into policy and procedure. The development of an established policy for information sharing will have to be coordinated across the entire NYC emergency response community. The concept of sharing requires the establishment of some level of collection, format, and storing of information to facilitate the rapid integration of diverse information streams into one unified data set. The use of the conceptual model method will minimize the impact of different formats and storage methods by individual agencies. By providing clear policy guidelines, the collected event information can efficiently be shared between agencies across the entire emergency response community.

D. CONCLUSION

As with any major endeavor, the proposed information sharing will require a commitment of agency resources. Additionally, the introduction of a new paradigm of information sharing will contrast with the existing parochial culture of response agencies in NYC. The question that needs to be asked is whether it is worth it for individual agencies or NYC as a whole to invest resources into this project. To answer this question, a review

⁵⁰ Bharosa, Lee, and Janssen, “Challenges and Obstacles in Sharing,” 9–65.

⁵¹ Fire Department City of New York, *Statistics Citywide Performance Indicators 01/01/16—12/31/16* (New York: Fire Department City of New York, 2016), <http://www1.nyc.gov/assets/fdny/downloads/pdf/about/citywide-stat-2016-annual-report.pdf>.

⁵² Allison T. Chamberlain, Jonathan D. Lehnert, and Ruth L. Berkelman, “The 2015 New York City Legionnaires’ Disease Outbreak: A Case Study on a History-Making Outbreak,” *Journal of Public Health Management and Practice* 23, no. 4 (2017): 410–416, <http://doi.org/10.1097/PHH.0000000000000558>.

of past multi-agency complex emergencies was looked at to develop a sense of the impact of the current limited information-sharing system in NYC. The examination of 9/11, Super Storm Sandy, and “Snowmageddon” (2010 blizzard) showed that in each instance, the cost associated with the lack of information sharing was substantial. In the aftermath of 9/11, the impact from the lack of information sharing acted as a springboard for action across the country.⁵³ Super Storm Sandy in 2012 confirmed that NYC still was still challenged during large complex events to coordinate and collaborate between agencies.⁵⁴ During the Blizzard of 2010, the lack of coordination between snowplows, the transportation system, and emergency medical services resulted in the stranding of hundreds of Metropolitan Transportation Authority (MTA) buses and FDNY ambulances throughout the city.⁵⁵ This lack of coordination led to serious delays in responding to medical emergencies and transporting patients to medical facilities across the city. Streets blocked by buses and ambulances severely delayed fire trucks’ responses to a number of calls. These stuck vehicles prevented streets from being plowed, which significantly increased the time and effort to get the streets plowed. Neither the FDNY nor the MTA had the ability to determine which streets were plowed by the sanitation department. Furthermore, agencies did not know the priorities of the sanitation department in plowing the streets.⁵⁶ Additionally, the sanitation department lacked the ability to communicate effectively with their deployed resources and redirect them to critical areas or needs.

These events highlight the steep cost in both human suffering and financial toll on NYC from a failure to coordinate resources during large-scale emergencies. As the cityscape becomes even more densely populated, and the complexity of the events

⁵³ Federal Emergency Management Agency, *Summary of Post 9/11 Reports, Lessons Learned* (Washington, DC: Federal Emergency Management Agency, 2002), <http://www.hsd.org/?view&did=448479>.

⁵⁴ New York City Mayor’s Office, *Hurricane Sandy after Action Report*, 19.

⁵⁵ Elizabeth Weinstein and Skip Funk, *Preliminary Review of the City’s Response to the December 2010 Blizzard Report and Recommendations to Mayor Michael R. Bloomberg* (New York: Mayor’s Office of Operations, and Mayor’s Office of Citywide Emergency Communications, 2011), 4, http://www.nyc.gov/html/om/pdf/2011/review_of_2010_blizzard_response_01-10-11.pdf.

⁵⁶ Weinstein and Funk, 5.

increases due to merged missions and overlapping responsibilities, the lack of information sharing will magnify the cost to NYC.

III. LITERATURE REVIEW

The literature review assesses theories, frameworks, and previous emergencies pertaining to the difficulty of information sharing among different agencies and organizations during a crisis. This review includes published material from journal articles, peer reviewed research, AARs from local, state, and federal sources, and commissioned consultant reports.

The ultimate goal of information sharing is to foster learning in the response community and expedite the efficiency of operations. The literature pertaining to organizational learning and change, technology implementation, and crisis response is vast. As Stern states, “learning is a concept which cuts across virtually all of the major theoretical and meta-theoretical cleavages in the social sciences.”⁵⁷ This literature review is organized into four major areas:

- Interaction between technology and users
- Organizational challenges
- Crisis learning
- Technology

A. INTERACTION BETWEEN TECHNOLOGY AND USERS

Socio-technical system (STS) theory is a basic framework that describes the relationship between technology and the user. STS holds that “the interaction of social and technical factors creates the conditions for successful (or unsuccessful) system performance,” and consequently, addresses both aspects to optimize performance.⁵⁸ Additionally, researchers have proposed that to achieve effective system performance,

⁵⁷ Eric Stern, “Crisis and Learning: A Conceptual Balance Sheet,” *Journal of Contingencies and Crisis Management* 5, no. 2 (June 1997): 287.

⁵⁸ Guy Walker et al., “A Review of Sociotechnical Systems Theory: A Classic Concept for New Command and Control Paradigms,” *Theoretical Issues in Ergonomics Science* 9, no. 6 (2008): 481.

tasks should first be planned to align with the organization's objectives using the least amount of organizational architecture.⁵⁹ The structure of this architecture should be based on the situational, technical, and social needs of the organization.⁶⁰ The ever-changing dynamic between humans and technology due to innovation and technical evolution make application of this theory difficult. Oosthuizen and Pretorius point out that the unintended or unpredicted consequence of introducing technology often leads to new options that may change user requirements.⁶¹ One current example is "the IoT" that links the physical and electronic worlds through automated smart sensors, which are currently redefining both our expectations and relationships with technology.⁶²

The effective implementation of technology is dependent on the joint ability to manage human and technological aspects. According to McMaster and Baber, interoperability failures of organizations are rooted in their inability "to take account of the interactions between 'social' and 'technical' issues, generally preferring to address these separately."⁶³ This assumption is supported by Appelbaum's work with developmental frameworks for autonomous work groups within organizations that perform interconnected technological tasks.⁶⁴ Building on previous STS works, Appelbaum asserts, "Humanism and effectiveness must be linked together in the design of work and work systems."⁶⁵ STS

⁵⁹ Walker et al., 482.

⁶⁰ Steven H. Appelbaum, "Socio-Technical Systems Theory: An Intervention Strategy for Organizational Development," *Management Decision* 35, no. 6 (August 1997): 452.

⁶¹ Rudolph Oosthuizen and Leon Pretorius, "Assessing the Impact of New Technology on Complex Sociotechnical Systems," *The South African Journal of Industrial Engineering* 27, no. 2 (August 2016): 15.

⁶² James Manyika et al., "The Internet of Things: Mapping the Value beyond the Hype," McKinsey & Company, last modified June 2015, <http://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/the-internet-of-things-the-value-of-digitizing-the-physical-world>.

⁶³ Richard McMaster and Chris Baber, "Socio-Technical Interoperability in Multi-Agency Operations" (paper presented at 15th International Command and Control Research and Technology Symposium, Santa Monica, CA, June 2010), 1, http://www.dodccrp.org/events/15th_iccrts_2010/papers/021.pdf.

⁶⁴ Appelbaum, "Socio-Technical Systems Theory," 452.

⁶⁵ Appelbaum, "452.

theory differs from the more standard socially or technologically deterministic views that look for a singular or dominant cause of change.⁶⁶

The foundational material for STS theory is well documented and evolved with technological advancements. Social scientists, such as Cherns, have been able to extend the underlying principles of STS theory into related intellectual communities. Cherns was particularly successful in extending the use of the theory's individually focused design, ergonomics, and overarching systems design and implementation. The design of computer-based information systems has, in large part, been based on the framework derived from these sociotechnical design theories.⁶⁷ Due to this extensive foundation, some consider STS theory "the most extensive body of conceptual and empirical work underlying employee involvement and work design applications today."⁶⁸ The proposed information-sharing platform will require a combination of end user acceptance and new technology. STS theory provides a framework for addressing the technical and human aspects to meet the mission objectives of an information-sharing platform.

This review of STS literature has examined a well-founded body of research on the factors affecting technology development and implementation in organizations. As innovation continues, a number of technological and social adaptations may alter the understanding of STS. The sophistication of artificial intelligence, Web 2.0 technology, and social media trends, may transform the currently understood methods and means of decision processes. Current research is investigating the impact of this new data reality. As stated by Giudice and Evangelista, "liquidity of data, information and knowledge" will influence the social and economic relationships and potentially create new socio-technical configurations.⁶⁹ The interaction between the user and technology will be altered as the

⁶⁶ Steve Sawyer and Mohammad Hossein Jarrahi, "Sociotechnical Approaches to the Study of Information Systems," in *Computing Handbook, Information Systems and Information Technology*, ed. Heikki Topi and Alan Tucker, 3rd ed. (Boca Raton, FL, London, and New York: Chapman and Hall/CRC, 2014), 5-2.

⁶⁷ Sawyer and Jarrahi, 5-2.

⁶⁸ Appelbaum, "Socio-Technical Systems Theory," 452.

⁶⁹ Caputo M. Del Giudice and Federica Evangelista, "How Are Decision Systems Changing? The Contribution of Social Media to the Management of Decisional Liquefaction," *Journal of Decision Systems* 25, no. 3 (June 2016): 214.

capabilities of technology increase. The evolution of video games from simple graphics and user controls to the highly interactive and visual realism of today's systems is one example of this drastic change.

B. ORGANIZATIONAL CHALLENGE

This section of the literature review examines the internal organizational issues that may affect information sharing and interoperability. During complex events, the response community faces unprecedented challenges that result in organizational changes and the development of new relationships.⁷⁰ For example, the 2003 HSPD-5 mandates the implementation of the ICS for all domestic emergency responses.⁷¹ This organizational mandate requires individuals to operate as part of an organizational structure different than they are accustomed to in their daily jobs.⁷² For this federation of individuals and agencies to work together effectively, personnel relationships and the development of trust is paramount. As Currao states in his summary of interviews of the NYC emergency response community, "The accomplishment of strategic objectives is heavily reliant on inter-organizational trusted relationships."⁷³ Harrington reinforces the importance of trust from the perspective of law enforcement with his discussion of overcoming the "deep rooted histories" of rivalry between agencies.⁷⁴

Waugh details law enforcement's difficulty in adhering to the organizational structure of the ICS mandated as the emergency response management framework after 9/11. Waugh asserts that the ICS organizational structure is inconsistent with the independence usually permitted to law enforcement responders.⁷⁵ The ICS details very

⁷⁰ Louise K. Comfort, "Managing Intergovernmental Responses to Terrorism and Other Extreme Events," *Publius* 32, no. 4 (Fall 2002): 29.

⁷¹ Bush, *Homeland Security Presidential Directive/HSPD-5*.

⁷² Jessica Jensen and William L. Waugh Jr., "The United States' Experience with the Incident Command System: What We Think We Know and What We Need to Know More About," *Journal of Contingencies and Crisis Management* 22, no. 1 (March 2014): 9.

⁷³ Currao, "A New Role for Emergency Management," 110.

⁷⁴ Michael J. Harrington, "New York City First Responders: Enhancing Collaboration between NYPD and FDNY" (master's thesis, Naval Postgraduate School, 2014), 82.

⁷⁵ Jensen and Waugh, "The United States' Experience with the Incident Command System," 9.

specific roles and responsibilities within a structured organizational chart. This structure differs from law enforcement agencies that expect individual officers to take on various roles depending on the response scenario. This inconsistency lowers performance because of the unfamiliar roles and responsibilities for the individual law enforcement officer and organization as a whole. Waugh goes further in his review of ICS performance during a catastrophic event when he states it may not work when it involves multiple agencies and jurisdictions to respond.⁷⁶

Buck documented this lack of effectiveness outside the fire service in 2006 in his review of the ICS as an organizing tool for coordinating the response of disaster relief agencies. In this review, Buck stated, “ICS has been most successful among firefighting organizations and less successful with law enforcement, public health, and public work organizations.”⁷⁷

The implementation and impact of ICS has received only limited peer reviewed research. In 2014, Jensen examined the development of the ICS in the real world and the available research on its overall performance. This research located only 14 scholarly articles in peer-reviewed journals detailing empirical research on the ICS in the United States.⁷⁸ In her review, Jensen found, “There is little evidence that the system is consistently used as designed or a salve to common response problems.”⁷⁹ The response community assumes since the ICS is the national framework for domestic response, it is a successful and effective organizational structure, but no empirical research can document this fact conclusively. In regards to information sharing, some consensus seems to exist that for the ICS system to operate effectively, participants must develop a uniform situational awareness of the event.⁸⁰ The proposed information-sharing platform by

⁷⁶ Jensen and Waugh, 10.

⁷⁷ Dick A. Buck, Joseph E. Trainor, and Benigno E. Aguirre, “A Critical Evaluation of the Incident Command System and NIMS,” *Journal of Homeland Security and Emergency Management* 3, no. 3 (August 2006): 4.

⁷⁸ Jensen and Waugh, “The United States’ Experience with the Incident Command System,” 9.

⁷⁹ Jensen and Waugh, 9.

⁸⁰ Jensen and Waugh, 11.

supplying an enhanced situational awareness may provide an opportunity to evaluate the performance and effectiveness of the ICS.

C. CRISIS LEARNING

The concept of information sharing has been a focus in the emergency response community since the documented failures during 9/11 and has been noted in the analyses and AARs following almost every crisis thereafter. The consensus of these reports is that the gathering, sharing, and use of timely information will improve the overall effectiveness of the response effort. Although information sharing has received much attention, actual progress on improvement has been limited. This struggle for improvement hinges on the infrequency of these events, required organizational culture change, and the monetary and resource cost for developing new information-sharing norms.⁸¹ One of the major reasons cited by practitioners for this continued struggle is the tendency of the emergency response community to use a crisis as the mechanism for change. Researchers have looked at whether decision makers are making good long-term strategic decisions under the operational pressure and scrutiny of the public during a complex emergency. Additionally, making decisions based on an event that is unique, unplanned, and in most cases, characterized by newly formed complex interrelationships, has been researched. Sterns' work considers if a crisis is a good environment from which the government can learn. He examines the plausibility of a crisis to act as a catalyst for learning, and what aspects encourage or inhibit that learning. Stern describes, "The road from individual insight via coalition-building and ratification to implementation and maintenance of change is often a long and difficult one."⁸² Although the emergency response community recognizes a need to develop an effective solution, implementing one is a more daunting task. Etheredge lists three reasons why governments fail to learn: the use of a historical solution for a current problem, the presence of self-blocking behavior, and the repetition of errors.⁸³ Etheredge uses the executive branch as a model for government learning in general. His work details

⁸¹ Federal Emergency Management Agency, *Summary of Post 9/11 Reports*.

⁸² Stern, "Crisis and Learning: A Conceptual Balance Sheet," 304.

⁸³ Lloyd S. Etheredge, *Can Governments Learn?: American Foreign Policy and Central American Revolutions* (New York: Pergamon Press, 1985), 160–174.

how leaders tend to rely on past successful solutions, even though the current environment may be much different. Additionally, he details how leaders tend to surround themselves with like-minded people who reinforce the leader's beliefs. Lastly, he documents how practitioners fail to learn from predecessors' mistakes.

An additional theory proposed by Elliot is that the developments of policies independent from practitioners contribute to a failure of the agency to learn and change procedures.⁸⁴ Elliot supports this theory by looking at two very similar cases seven years apart, where the comparable breakdowns between developing care protocols and actually employing them at the same agency resulted in the death of two children. Harm to both of these children had been documented but they received little or no response from the overseeing authorities. These children lived three blocks apart and the same agencies and individual staff administered them in both incidents. Although the need for change was identified and policies altered, the lack of staff participation in the process resulted in no change to actual agency practices. An example after 9/11, within the response community, is HSPD-5, which mandates all emergency response organizations use the ICS. Similar to Elliot's example, this policy was applied without widespread discussion and buy-in from the practitioners, particularly urban agencies. FDNY Battalion Chief Esposito reinforces that just because the policy appears on paper does not mean a sudden transformation of the response community.⁸⁵ The difficulty in implementing policy separate from practitioners resulted in a NYC-specific hybrid system to attempt to resolve differences between existing organizational and mandated ICS structures.⁸⁶

Stern discusses the different implementation hurdles of crisis learning. He emphasizes the importance of understanding the context of the situation for lessons learned and the importance of the context for decision making.⁸⁷ Additionally, the pressure to act provides an impetus for change; however, the short time for analysis tends to lead to poor

⁸⁴ Dominic Elliott, "The Failure of Organizational Learning from Crisis—A Matter of Life and Death?," *Journal of Contingencies and Crisis Management* 17, no. 3 (September 2009): 157.

⁸⁵ Esposito, "New York City Fire Department Chief Officer's Evaluation of the Citywide Incident Management System," 47.

⁸⁶ NYC Emergency Management, "Citywide Incident Management System."

⁸⁷ Stern, "Crisis and Learning: A Conceptual Balance Sheet," 298.

long-term strategic policies.⁸⁸ The implementation of the ICS, which adopted a wildland fire organizational structure as a national model after 9/11, illustrates this point. Due to the well-publicized response breakdowns among agencies, the pressure on the government to act was intense. Although debate still occurred both within the fire service and among other agencies on the merits of this system, it was nationally mandated.⁸⁹ Following the implementation, in 2006, the National Research Council found “essentially no support for the command-and-control model either as a heuristic device for conceptualizing the disaster management process or as a strategy employed in actual disasters.”⁹⁰ The ICS mandate provided a rapid answer to the pressing need of a response organization framework, but it might not solve the strategic challenge of effective information sharing during complex emergencies.

To be successful in identifying the lessons learned and educating the whole organization, then the next step is to understand how the organization can ensure this information takes hold in a lasting manner. First, based on the low frequency of complex events and the attrition of staff between events, maintaining information and lessons learned is difficult.⁹¹ Second, the ability to gauge the positive or negative effect of a change is often not possible until the next crisis emerges.⁹² How to remedy these two conditions remain unanswered in the literature at this time. Although a number of studies and research papers have examined these issues from different perspectives, as Elliot states, “We have identified the paucity of attention dedicated to examining the processes of knowledge transfer.”⁹³ Regarding at what level learning occurs, Stern asks, “Is it individual, small group, or organizational levels where the information gets processed?”⁹⁴ Stern characterizes this point as a, “hot-bed of divergence that encompasses almost all of the major theoretical

⁸⁸ Stern, 308.

⁸⁹ Jensen and Waugh, “The United States’ Experience with the Incident Command System,” 7.

⁹⁰ National Research Council, *Facing Hazards and Disasters: Understanding Human Dimensions* (Washington, DC: The National Academies Press, 2007), 142.

⁹¹ Stern, “Crisis and Learning: A Conceptual Balance Sheet,” 288.

⁹² Stern, 305.

⁹³ Elliott, “The Failure of Organizational Learning from Crisis,” 162.

⁹⁴ Stern, “Crisis and Learning: A Conceptual Balance Sheet,” 286.

and meta-theoretical cleavages in the social sciences.”⁹⁵ Although the research on crisis learning is incomplete, analysis shows that a change of policy must include input from practitioners from all levels of the organization. Additionally, generational information sharing in agencies can be influenced by the infrequency of events and staff attrition. Lastly, due to the time between events and evolution of technology and organizations, some of the previously learned lessons may now be ineffective.

D. TECHNOLOGY

A review of several case studies detailed the current level of electronic information sharing in the emergency response community. The three cases selected for review included the 2014 Boles Fire in Weed, California, Ohio State University, and a real time disease map.⁹⁶ These case studies provide a snapshot of existing commercially available hardware and software resources, as well as available information outputs. From these examples, the Boles Fire represents the most robust use of information collection and sharing. At this incident, first responders using commercially available products were able to capture real-time information and overlay limited existing metadata to provide a more complete picture of the degree of impact on the town. What is not clear in this example and in the others is the economic cost to implement and maintain both the technology and staff proficiency. The training of users is not discussed in any of the articles and it is not clear if these systems require previously trained staff or if just in time training can be used to develop competent staff. Additionally, the available information does not address how organizations handled large-scale disasters with long-term multiagency efforts.

These case studies reinforce the implications of Moore’s law, the *doubling* of transistors on a circuit and the resulting continued expansion of a computer’s technology

⁹⁵ Stern, 287.

⁹⁶ “Rapid Damage Assessment Using Real-Time ArcGIS Online: Boles Fire, Weed CA,” Fire What?, accessed January 15, 2017, <http://wildlandfire.maps.arcgis.com>; “Ohio State Goes Live with Real-Time GIS Maps Website,” College Planning & Management, June 20, 2015, <https://webcpm.com/articles/2015/06/10/ohio-state-real-time-gis-maps.aspx>; “Real Time Disease Map: HealthMap,” GIS Geography, last updated February 15, 2018, <http://gisgeography.com/real-time-disease-map-healthmap/>.

capability every 18 months.⁹⁷ This doubling of capacity translates into the rapid evolution of technology that has brought computing from room-sized mainframes to hand-held smart phones and radical improvements in functionality over the last 50 years. This rapid evolution of technology is supported through Roberts' law of computer performance, which predicts performance doubles every 21 months.⁹⁸ This rapid technological advancement has made the potential for information sharing possible but poses both practical and policy implications for agencies. The rapid evolution tends to lead to a heterogeneous technology environment due to the rate of individual agency adoption and implementation. This diverse technology makes developing and implementing information sharing an ongoing challenge. New policy questions and requirements for inter-agency agreements will be shaped by the amount and type of information that now can be shared.

The recent advance in IT makes information sharing both more feasible and beneficial between agencies. This sharing of information through technology pathways however has to build initially on the trust and cooperation of the participants. Once agreements, such memoranda of understanding (MOUs) and memoranda of agreement (MOAs), to share technology are established, the automated machine-to-machine methods will reduce the need to reestablish the human relationship dynamic between agencies. During crisis events, the information pathways will already exist to enable critical information to move between agencies during the critical early stages of the event.

Incorporating Department of Defense (DOD) technology into the homeland community is another avenue for information-sharing development. The GINA system is a technology that the DOD used for information sharing in the civilian emergency response community.⁹⁹ The technology difference is that the GINA framework allows conceptual models to be built in a federated virtual space using domain language that are executed as

⁹⁷ Cara McGoogan, "Moore's Law Is Not Dead, Says Intel Boss," *The Telegraph*, January 5, 2017, <http://www.telegraph.co.uk/technology/2017/01/05/ces-2017-moores-law-not-dead-says-intel-boss/>.

⁹⁸ Lawrence G. Roberts, "Internet Growth Trends," *Lawrence Roberts* (blog), January 2000, <http://www.packet.cc/files/InternetTrends.htm>.

⁹⁹ U.S. Army Corps of Engineers, *GINA Information Management System Relevance to GEOINT Exploitation of Manmade Environments Nations to Insurgents, GEMENI* (Washington, DC: U.S. Army Corps of Engineers, 2010).

applications in a secure network available environment. Since the models are at the conceptual level, a top down design approach may be implemented that is not restricted by data standards or rigid ontological models.¹⁰⁰ A case study involving the United States Forest Service (USFS) and the GINA program using distributed real-time infrared (DRTI) to support wild fire suppression activity in the western United States allowed the evaluation of the program's potential.¹⁰¹ This example is particularly useful because it demonstrated the potential for non-commercial technology to accomplish the goal of multi-agency real time information sharing using a public sector resource.

At the heart of the conceptual model approach is the language, which forms a framework for understanding and defining the concepts and interrelations between them. Jens Allwood has researched the concept of domain language and the ability of language to model the structuring of the real world conceptually. As Allwood states, language “provides support for a fundamental classification of real phenomena”¹⁰² Thus, through linguistic means, concepts are constructed so that the individual concepts can become compatible elements within a larger system.¹⁰³ This body of work is extremely important when trying to unite the different cultures and lexicons found across the emergency response community through a conceptual model. Although, attempts have been made through NIMS and the ICS structure to provide uniformity of terminology individual agencies language, differences remain within agencies. Additionally, due to factors, such as the introduction of new technology, variation of technology adoption rates, and the internal development of policies, the concept of the universal language is extremely difficult, if not impossible to achieve. Rather, as Allwood proposes, the conceptual approach will “allow information to be flexibly structured in a regular and predictable way

¹⁰⁰ Thomas S. Anderson, “Dragon Pulse Information Management System (DPIMS): A Unique Model-Based Approach to Implementing Domain Agnostic System of Systems and Behaviors,” in Proceedings SPIE 9831, Ground/Air Multisensor Interoperability, Integration, and Networking for Persistent ISR VII, 98310N (2016), <https://doi.org/10.1117/12.2226035>.

¹⁰¹ Shawn Scott, *Distributed Real-Time Infrared (DRTI) 2016 after Action Report* (Gowen Field, ID: Air National Guard, 2016).

¹⁰² Jens Allwood, *Semantics as Meaning Determination with Semantic—Epistemic Operation* (Göteborg, Sweden: Göteborg University, Department of Linguistics, 1999), 4.

¹⁰³ Allwood, 11.

to meet requirements of context such as those given by the currently relevant linguistic and extra-linguistic activity and purpose.”¹⁰⁴ This research supports the thesis that a flexible and adaptable model can be constructed using an understanding of the language of the response community.

The conceptual model framework approach to addressing the challenges of information sharing within the emergency response community is a relatively new approach. As Allen, Karanasio, and Norman have stated, “while several large-scale events and enquiries have emphasized the need for addressing information integration among emergency responders, until very recently, there have been few empirical studies and significant insights.”¹⁰⁵ These authors stated the need for operational and behavioral changes at the policy and agency level, as well a paradigm shift for system design.¹⁰⁶ A review of existing literature using the conceptual model approach has found limited work with research specifically focused on the emergency response community. Research by Nunavath, Prinz, and Comes in 2016 has provided a summary of much of the research supporting a conceptual model approach to emergency response information needs.¹⁰⁷ As they stated in their conclusion, information models have been a successful strategy in software development to provide an accurate representation of information attributes and flow. However, the application of information models has not been applied to examine emergency operations information structure.¹⁰⁸ The authors recognized the current difficulties previously discussed in this literature review, such as “semantic inconsistencies, management and sharing of emergency information with other responders.”¹⁰⁹ In furthering their work, the authors stated, “information models can be helpful in developing, making explicit and communicating clear and detailed descriptions

¹⁰⁴ Allwood, 16.

¹⁰⁵ David K. Allen, Stan Karanasios, and Alistair Norman, “Information Sharing and Interoperability: The Case of Major Incident Management, *European Journal of Information Systems* 23, no. 4 (2017): 418–432, doi: 10.1057/ejis.2013.8.

¹⁰⁶ Allen, Karanasios, and Norman, 431.

¹⁰⁷ Nunavath, Prinz, and Comes, “Identifying First Responders Information Needs,” 25–46.

¹⁰⁸ Nunavath, Prinz, and Comes, 41.

¹⁰⁹ Nunavath, Prinz, and Comes, 41.

of information that is available.”¹¹⁰ This thesis proposes to continue this work by developing a conceptual model for a specific scenario that federates the existing information systems to provide access to the relevant information required by the response community. This scenario provides a template to apply and expand the conceptual modeling approach to other emergency operations.

The review of this literature is limited because real-time information gathering and displaying is a rather new capability in the emergency response community. The majority of the available literature is information from the private sector as product narratives and third-party evaluations and is extremely limited. The body of peer-reviewed research, while limited, supports this thesis research question on the potential for using the conceptual modeling approach to emergency response operations.

¹¹⁰ Nunavath, Prinz, and Comes, 42.

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IV. CASE STUDY—HURRICANE MARIA: PUERTO RICO DEPLOYMENT; ANALYSIS OF THE INFORMATION SHARING BY THE NYC EMERGENCY RESPONSE COMMUNITY

This chapter provides a case study of the response to Hurricane Maria in Puerto Rico during Fall 2017 to evaluate the current capabilities of NYC EO agencies to gather and share information, within the larger framework of a FEMA-led response. As such a recent largescale event, Hurricane Maria provides this thesis with significant research value to study information sharing and gathering. The case study also provides the opportunity to evaluate the potential for new strategies proposed by this thesis and to address the documented challenges of information sharing during the event.

The impact of Hurricane Maria on Puerto Rico was catastrophic. The combination of high winds and heavy rains destroyed most of the island's infrastructure and required a massive response of emergency agencies to address the needs of the population. Additionally, the location of Puerto Rico as a separate island from the continental United States provided logistical challenges to the recovery effort not typically experienced by response agencies within NYC or the continental United States.

As extreme as the impact of Hurricane Maria was to the island of Puerto Rico, the response effort and roster of agencies involved closely mirror what would be expected for a response to a major emergency event in NYC. As part of the response to Hurricane Maria, NYC sent a cross section of agencies to assist in search and rescue and recovery efforts. The primary NYC agencies included the Urban Search and Rescue (US&R) New York Task Force 1 (NY-TF1), the NYC Department of Buildings (NYCDOB), and the FDNY incident management team (IMT). On the national level, FEMA responded and acted as the overall coordinating agency to manage the multi-agency response efforts. This roster

of both NYC and national assets closely parallel the response effort to Super Storm Sandy in 2012 and what will be expected during a future large-scale event in NYC.¹¹¹

A. BACKGROUND

During the early morning hours of September 20, 2017, Hurricane Maria made landfall in southeast Puerto Rico as a Category 4 hurricane with maximum sustained winds of 155 mph, the strongest storm to strike the island since 1928.¹¹² During the next several hours, Hurricane Maria traversed the island from east to west delivering hurricane force winds and catastrophic flooding to the majority of the island.¹¹³ Due to the size and strength of Hurricane Maria, tropical force winds battered the island until well into the evening. During Hurricane Maria's approach and traverse across Puerto Rico, it is estimated that large parts of the island received in excess of 20 inches of rain.¹¹⁴ This hurricane was the second to strike Puerto Rico in 2017. On September 6, 2017, the center of Hurricane Irma passed just north of the island but still caused widespread wind damage, flooding, and coastline storm surge across large portions of the island.¹¹⁵

Figure 1 shows the results of this one-two punch; widespread damage throughout the country to the infrastructure that supports a modern economy and its 3.7 million inhabitants.¹¹⁶ Damage occurred to approximately 80% of 30,000 miles of distribution lines, 2,400 miles of transmission lines, and 300 substations that make up the electrical

¹¹¹ Federal Emergency Management Agency, *Testimony of W. Craig Fugate Administrator Federal Emergency Management Agency before Senate Appropriations Committee Subcommittee on Homeland Security December 5, 2012* (Washington, DC: Department of Homeland Security, 2012), https://www.fema.gov/media-library-data/1411484284114-e8fb5fa4daa75683bc75adc9fb01fd9d/12_5_12_hurricane_sandy_response_and_recovery.pdf.

¹¹² "Major Hurricane Maria," National Weather Service, September 20, 2017, <http://www.weather.gov/sju/maria2017>.

¹¹³ National Weather Service.

¹¹⁴ "Hurricane Maria's Torrential Rainfall Measured by IMERG," National Aeronautics and Space Administration, September 21, 2017, <https://pmm.nasa.gov/extreme-weather/hurricane-marias-torrential-rainfall-measured-imerg>.

¹¹⁵ "Impacts from Irma—September 2017," National Weather Service, September 2017, http://www.weather.gov/bmx/event_irma2017.

¹¹⁶ "Puerto Rico Population 2017," World Population Review, December 20, 2017, <http://worldpopulationreview.com/countries/puerto-rico-population/>.

service grid.¹¹⁷ The telecommunication system for the entire island was also almost completely destroyed. With 90% of cell towers damaged across the island, and almost complete destruction of cable and wireline service, inter- and intra-communication in Puerto Rico was almost nonexistent.¹¹⁸ Access to fresh water was also significantly damaged with more than half the population's water supply unavailable due to flooding or supporting utility damage.¹¹⁹ Additionally, the road network across Puerto Rico was almost completely demolished with large sections of roads and bridges completely destroyed across the island.¹²⁰

¹¹⁷ "Puerto Rico and Federal Partners Unite to Address Power Restoration Needs," Federal Emergency Management Agency, October 17, 2017, <https://www.fema.gov/news-release/2017/10/17/4339/puerto-rico-and-federal-partners-unite-address-power-restoration-needs>.

¹¹⁸ Federal Communications Commission, *Communications Status Report for Areas Impacted by Hurricane Maria* (Washington, DC: Federal Communications Commission, 2017), http://transition.fcc.gov/Daily_Releases/Daily_Business/2017/db0927/DOC-346943A1.pdf.

¹¹⁹ "Statistics Progress in Puerto Rico Hurricane Maria Update," Federal Emergency Management Agency, last updated November 6, 2017, <https://www.fema.gov/de/media-library/assets/images/151463>.

¹²⁰ "Puerto Rico Road Status," Federal Emergency Management Agency, last updated September 28, 2017, <https://www.fema.gov/media-library/assets/images/143781>.

Statistics Progress in Puerto Rico

Hurricane Maria Update

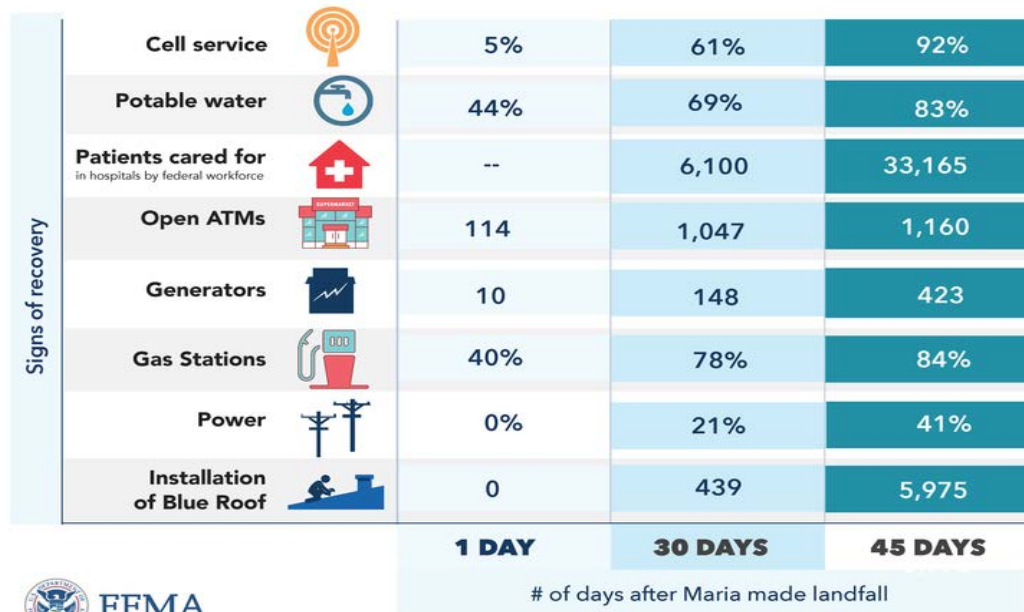


Figure 1. FEMA Response Snapshot Showing Services Impacted by Hurricane Maria.¹²¹

The level of damage and immediate needs of the Puerto Rican population far exceeded the capacity of the local response community. As the hurricane approached the island and the potential for widespread damage was forecasted, multiple resources under the guidance of FEMA were prepositioned in Puerto Rico for immediate deployment.¹²² In addition, multiple resources, both personnel and relief supplies, which had been originally deployed to Florida for Hurricane Irma, were still in Florida. Many of these resources were available for reassignment since the impact from Hurricane Irma on Florida was less than anticipated. Additionally, the State of Florida activated its own extensive

¹²¹ Source: Federal Emergency Management Agency, "Statistics Progress in Puerto Rico Hurricane Maria Update."

¹²² FEMA Public Affairs, "Overview of Federal Efforts to Prepare for and Respond to Hurricane Maria," *Federal Emergency Management Agency* (blog), last updated October 31, 2017, <https://www.fema.gov/blog/2017-09-29/overview-federal-efforts-prepare-and-respond-hurricane-maria>.

logistical support network in conjunction with FEMA to provide relief supplies and equipment to Puerto Rico.¹²³

As part of this national response to Hurricane Maria, resources from NYC were deployed to assist in the response and recovery efforts. With a population of over 700,000 Puerto Rican immigrants in the NYC area and the historical ties between the regions, having resources from NYC involved with the response effort was particularly important. Mayor de Blasio made the NYC commitment to the response clear on September 27, 2017 when he stated, “New York City is ready to do whatever it takes to assist in the aftermath of this devastating hurricane.”¹²⁴ Additionally, since 2012 when Super Storm Sandy devastated parts of NYC, a concentrated effort has been made to deploy NYC resources to assist other municipalities during emergency events. The deployment of NYC resources provides both a goodwill gesture by NYC, as well as providing an opportunity to prepare both equipment and personnel for emergency responses.

B. NEW YORK CITY RESPONSE

This case study examines three different NYC resources deployed to Puerto Rico: US&R NY-TF 1, NYCDOB, and the FDNY IMT. These resources do not represent the entire response community of NYC, but do provide an adequate sample to evaluate the current information-sharing status of NYC agencies.

1. US&R NY-TF 1 Response

NY TF-1 is one of the 28 advanced search and rescue task forces coordinated and overseen by FEMA. They are strategically located throughout the country and respond to large-scale catastrophic events to perform rescue and recovery operations.¹²⁵ The US&R

¹²³ “Scott Issues Updates on State Action to Assist Puerto Rico,” Rick Scott, November 17, 2017, <https://www.flgov.com/2017/11/17/gov-scott-issues-updates-on-state-action-to-assist-puerto-rico-10/>.

¹²⁴ “Mayor de Blasio Announces Additional Staff Deployments to Assist with Hurricane Recovery,” NYC Emergency Management, September 27, 2017, <http://www1.nyc.gov/office-of-the-mayor/news/619-17/mayor-de-blasio-additional-staff-deployments-assist-hurricane-recovery>.

¹²⁵ “What is US&R?” New York Task Force 1, accessed January 16, 2018, <https://www.nytf1.org/78-front-page/8-beginners>.

teams operate under emergency support function (ESF) 9, search and rescue (SAR) mission to provide lifesaving assistance to affected communities as a FEMA asset designated by Homeland Security Act of 2002 (Stafford Act).¹²⁶ To support the efforts and coordinate activities of the different US&R teams, an incident support team (IST) is deployed. The IST's mission is "to maximize the speed with which task forces are mobilized and utilized."¹²⁷

US&R task forces typically consists of two 31-person teams, four canines, and a comprehensive equipment cache.¹²⁸ To accomplish rapid life safety tasks, US&R task force members are highly trained in 4 areas: "search, to find victims trapped after a disaster; rescue, which includes safely digging victims out of tons of collapsed concrete and metal; technical, made up of structural specialists who make rescues safe for the rescuers; and medical, which cares for the victims before and after a rescue."¹²⁹ US&R members are highly trained first responders specializing in operations in a variety of hazardous situations requiring special skills, equipment, and techniques.¹³⁰ NY TF-1 was deployed along with other five other US&R teams to assist in the rescue and recovery effort immediately after Hurricane Maria made landfall in Puerto Rico.¹³¹ The mission for NY TF-1 was the search and rescue of targeted areas for civilians trapped in collapsed buildings. By September 28, eight days after Hurricane Maria made landfall, the six US&R teams had surveyed approximately 90% of the island.¹³² During this sweep of the island, FEMA reported, "US&R task forces saved or assisted 843 individuals and five pets, while searching over

¹²⁶ Federal Emergency Management Agency, *Emergency Support Function #9—Search and Rescue Annex* (Washington, DC: Department of Homeland Security, 2016), 4, https://www.fema.gov/media-library-data/1470149567157-f1dc17ef606b8b82629bacf1c358dd55/ESF_9_Search_and_Rescue_Annex_20160705_508.pdf.

¹²⁷ Federal Emergency Management Agency, *Urban Search and Rescue (US&R) Incident Support Team (IST)*, in *Federal Disaster Operations, Operations Manual*, 9356.2-PR (Washington, DC: Department of Homeland Security, 2000), https://www.fema.gov/pdf/emergency/usr/ist_ops_manual.pdf.

¹²⁸ New York Task Force 1, "What is US&R?"

¹²⁹ New York Task Force 1.

¹³⁰ New York Task Force 1.

¹³¹ NYC Emergency Management, "Mayor de Blasio Announces."

¹³² "USAR in Puerto Rico," Federal Emergency Management Agency, last updated September 29, 2017, <https://www.fema.gov/media-library/assets/images/143904>.

2,600 structures.”¹³³ The results of these missions and status of the structures was recorded using the “Iron Sights” global positioning software (GPS) software system. The results of these surveys and other information regarding road closures and utility damage were captured by US&R staff and were transferred to the FEMA EOC.

2. NYC Department of Buildings

As part of the Emergency Management Assistance Compact (EMAC) agreement between Puerto Rico and New York State, the NYCDOB provided staff to “evaluate the conditions of structures and infrastructure throughout the City of San Juan.”¹³⁴ On September 24, the initial two-person team was deployed, and a second 12-person team followed on October 6. In addition, 10 staff members from the NYC Housing Preservation and Development (HPD) agency were deployed to work in conjunction with the NYCDOB staff.¹³⁵ The mission objectives for the NYCDOB team evolved over the duration of the mission in response to changing priorities of the local agencies and recognition of the capabilities of the NYCDOB teams.¹³⁶ The three main objectives were the following:

- San Juan barrios and sub-barrios: Rapid damage assessment along with damaged roofs (blue tarp program) and abandoned buildings
- Structural detailed damage assessment of the 205 police precincts throughout Puerto Rico
- Windshield inspections to confirm damage from FEMA satellite imagery of San Juan (approximately 1,876 locations)

These missions required a number of preliminary steps that had to be accomplished to develop an electronic base map to orientate the inspection teams and record inspection

¹³³ “FEMA Provides Update on Federal Response in Puerto Rico and U.S. Virgin Islands,” Federal Emergency Management Agency, last updated January 3, 2018, <https://www.fema.gov/news-release/2017/09/28/fema-provides-update-federal-response-puerto-rico-and-us-virgin-islands>.

¹³⁴ NYC Department of Buildings, *After Action Report NYC Department of Buildings Emergency Response to Hurricane Maria* (New York: NYC Department of Buildings, 2018), 1.

¹³⁵ NYC Department of Buildings.

¹³⁶ NYC Department of Buildings, 5.

results. Unlike the continental United States, Puerto Rico uses a distinct quadrangle and coordinate system along with administrative boundaries called sub barrios that are unique to the island.¹³⁷ Additionally, due to the storm damage, all of San Juan's GIS capabilities were unavailable. Even when power was restored and contact made with local GIS staff, they lacked the technical knowledge and proficiency to assist in developing GIS information for the response. Adding to the operational challenge for field staff, many landmarks and roads were damaged, which further compounded the ability for DOB inspectors to orientate themselves during inspection missions. Without access to maps depicting general information, such as building footprints, tax parcels, or address location, NYCDOB inspectors were challenged to map the location of inspection results accurately.¹³⁸ To overcome the lack of information from resources within Puerto Rico, NYCDOB staff created a base map using information from DHS' Homeland Security Foundation Level Data (HIFLD).¹³⁹ Different sources of information layers were added to this base map to enhance the accuracy and relevance of the information shown for both field staff and EOC representatives. The additional information layers included FEMA aerial data, U.S. census data, and NOAA satellite and area imagery.¹⁴⁰

Once the base map was established, the next step was to develop a recording protocol to capture, organize, and display the inspection results from the field inspectors. Using a commercially available data collection device, NYCDOB GIS staff were able to provide an electronic copy of the ATC-45 Rapid Evaluation Assessment Form for inspectors to record information. Based on the information recorded on the form, a color code was assigned to the structure to provide visual representation of its status on an electronic mapping platform.

This use of an electronic form was a major advancement from Super Storm Sandy in 2012 when NYCDOB staff recorded all results on paper forms. During Super Storm

¹³⁷ NYC Department of Buildings, 16.

¹³⁸ NYC Department of Buildings, 10.

¹³⁹ "Homeland Infrastructure Foundation-Level Data (HIFLD)," Department of Homeland Security, accessed January 16, 2018, <https://hifld-dhs-gii.opendata.arcgis.com/>.

¹⁴⁰ NYC Department of Buildings, *After Action Report NYC Department of Buildings Emergency Response to Hurricane Maria*, 10.

Sandy, the hard copy field inspection forms were driven daily to DOB headquarters where additional staff compiled the information into a database over the course of a few days. This process resulted in a delay of days before information gathered in the field could be electronically displayed or analyzed. During the Hurricane Maria Puerto Rico deployment, using the electronic collection method, the NYCDOB was able to provide inspection results in near real-time. Additionally, DOB inspectors were able to capture photos and other location-related documents and have them geo-tagged to specific locations. Having the ability to view photos from locations substantially improved the ability to convey building status between agencies that used different evaluation metrics and symbols. NYCDOB field inspectors captured approximately 6,000 photos geo-tagged to specific locations, which were linked to completed inspection forms and made available to platform viewers.¹⁴¹ Having the ability to associate a picture to a specific location through GIS tagging is crucial for identifying locations in Puerto Rico.

As the DOB provided information to the EOC and partner agencies, the potential to gather additional information and record different data was recognized. During the deployment, a number of requests were received to collect additional data due to the flexibility of the collector and NYCDOB staff experience in creating additional data fields. The NYCDOB was able to add additional collection fields as the deployment mission evolved to accommodate requests from local agencies.

As shown on Figure 2, a visual representation of the results is provided, as well as site-specific results for each location.

¹⁴¹ NYC Department of Buildings, 11.

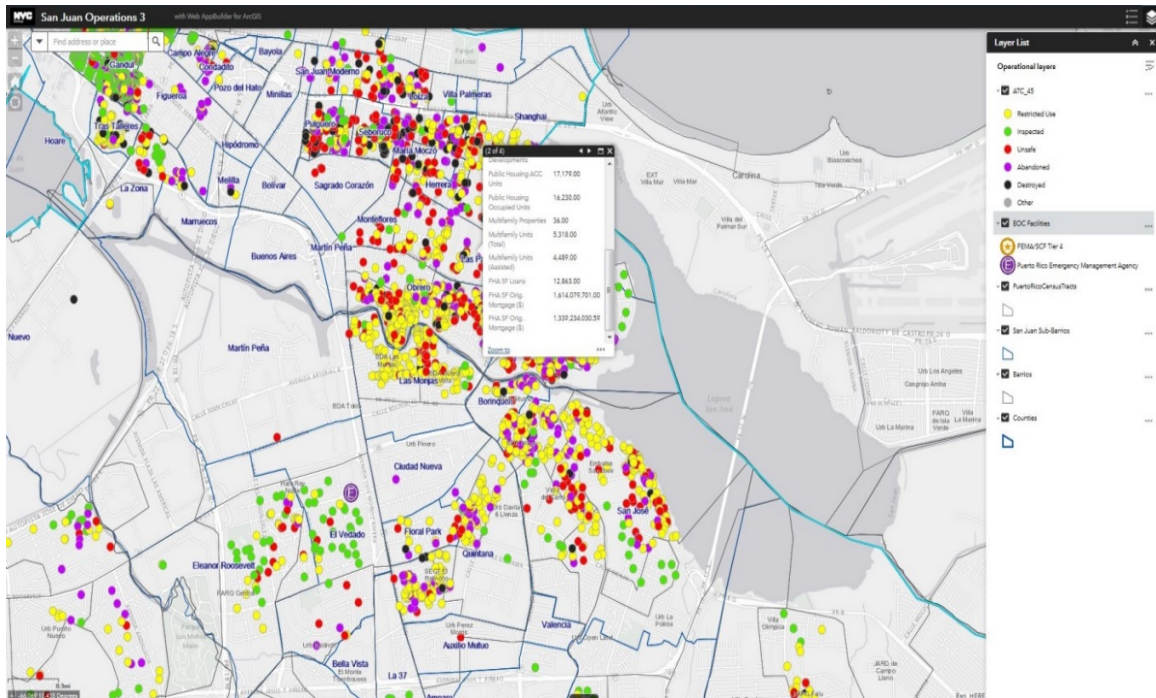


Figure 2. NYCD0B Inspection Results.¹⁴²

This electronic map format developed by NYCD0B allowed decision makers to understand the general damage trends and access specific address information.

To assist emergency managers to evaluate progress, the NYCD0B developed inspection result dashboards. The dashboard shown in Figure 3 illustrates the aggregated information from different neighborhoods in the San Juan area. As shown, viewers could see individual structure inspections, overall mission completion percentage, and category totals. These dashboards were provided to 11 separate agencies located in NYC, Washington, DC, and Puerto Rico.

¹⁴² Source: Aidan Mallomo, email message to author, January 10, 2018.

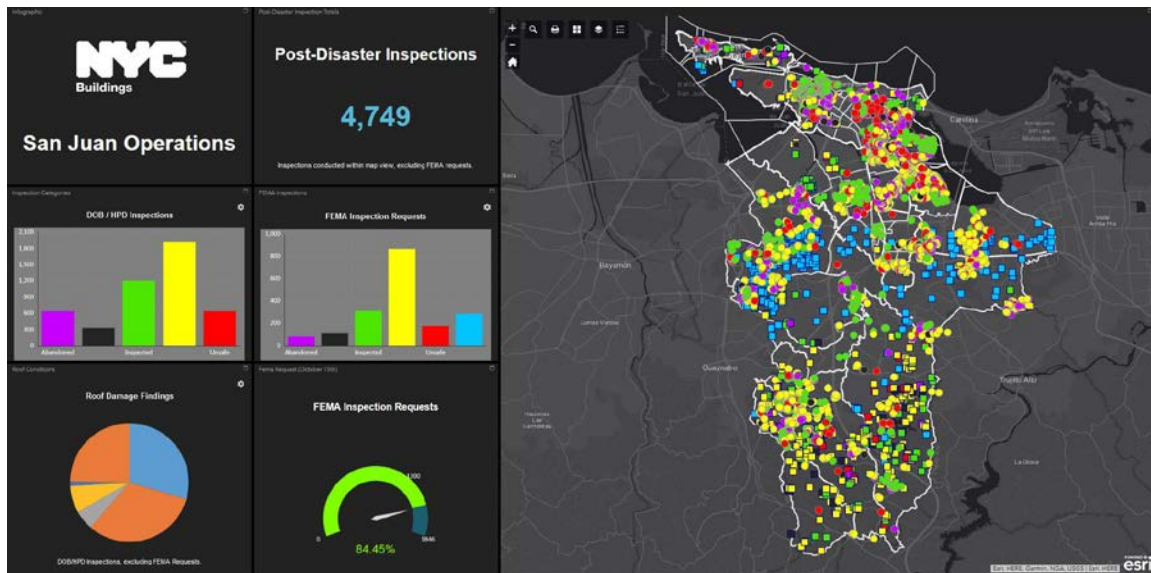


Figure 3. NYCDOB Dashboard.¹⁴³

Access to the information was controlled through a secure GIS portal. Through this portal, the NYCDOB could provide access to 50 users simultaneously and provide information in near real-time from inspectors in the field.¹⁴⁴ As stated in the AAR from Puerto Rico, “cloud based collaboration between agencies allowed for a common operating picture among agencies, which improved efficiency and effectiveness of NYCDOB in completing its mission.”¹⁴⁵ During the operational period, the NYCDOB provided access to GIS users from FEMA, the Puerto Rico Emergency Management Agency (PREMA), the City of San Juan, and multiple NYC agencies working in Puerto Rico.

By using portable electronic information gathering devices, approximately 85% of buildings identified as potentially damaged through aerial imagery were inspected within five days. This information was made available to response agencies in near real-time. Based upon the difficulty of travel in Puerto Rico, and a lack of familiarity with the area by NYC DOB inspectors, this accomplishment was extraordinary.

¹⁴³ Source: Aidan Mallomo, email message to author, January 10, 2018.

¹⁴⁴ NYC Department of Buildings, *After Action Report NYC Department of Buildings Emergency Response to Hurricane Maria*, 13.

¹⁴⁵ NYC Department of Buildings, 14.

3. FDNY IMT

The FDNY IMT was deployed to Puerto Rico as part of an Emergency Support Function #4 (ESF-4) agreement between the Department of Agriculture USFS and FEMA. The ESF-4 agreement “provides Federal support for the detection and suppression of wildland, rural, and urban fires resulting from, or occurring coincidentally with, an incident requiring a coordinated Federal response for assistance”¹⁴⁶ The ESF-4 framework is the primary mechanism for deploying wildland fire resources across the United States and consists of a well-established coordinating and logistical support network. As an ESF-4 asset, the FDNY IMT reported to a USFS ESF-4 coordinator who maintains coordination with regional FEMA officials through either the Regional Response Coordination Center (RRCC) or Joint Field Office (JFO).¹⁴⁷ This deployment arrangement added an additional layer between the FDNY IMT and other resources working directly for FEMA in Puerto Rico.

The FDNY IMT arrived in Puerto Rico on September 25, 2017 and was tasked with assisting the Puerto Rican Fire Department (PRFD) in performing an assessment of the impact of Hurricane Maria on the department.¹⁴⁸ The PRFD is a statewide fire department with 94 firehouses spread across the island and is made up of approximately 1,650 firefighters. Specifically, the FDNY IMT mission was to focus on the following:

- Damage assessment of fire stations and equipment
- Assessment of fire department staff needs
- Assessment of emergency operations capabilities
- Restore PRFD communications

¹⁴⁶ Federal Emergency Management Agency, *Emergency Support Function #4—Firefighting Annex* (Washington, DC: Department of Homeland Security, 2008), <https://www.fema.gov/pdf/emergency/nrf/nrf-esf-04.pdf>.

¹⁴⁷ Federal Emergency Management Agency, 2.

¹⁴⁸ “Eight Incident Management Teams Mobilized to Puerto Rico and Virgin Islands,” *Wildfire Today*, September 28, 2017, <http://wildfiretoday.com/2017/09/28/eight-incident-management-teams-mobilized-to-puerto-rico-and-virgin-islands/>.

The FDNY IMT deployment consisted of 64 members trained and equipped to support a local agency response to a major- or long-duration emergency. The FDNY IMT utilizes the ICS to support and assist local jurisdictions during a major emergency event. The initial location of the team incident command post (ICP) was 35 miles away from the FEMA EOC, where the majority of response agencies operated.¹⁴⁹ Based on the condition of the road network and lack of connectivity, this remoteness severely impacted the ability of the FDNY IMT to gather and share information with other response agencies.

After four days, the FDNY IMT was able to relocate its ICP to an area adjacent to the FEMA EOC. This ICP relocation allowed the FDNY IMT staff to access partner agencies easily and develop working relationships and information-sharing procedures. Once relocated, the FDNY IMT was able to initiate contact with the IST supporting the various US&R teams operating in Puerto Rico. The IST in Puerto Rico had been operating prior to the arrival of the FDNY IMT and was able to provide GIS data from previous and ongoing US&R rescue operations, situational awareness from both an operational and political perspective, and printing and plotting equipment.

To complete the damage assessment mission in the PRFD stations located across the island, the FDNY IMT formed inspection taskforces. The FDY IMT staffed six of these task forces and assigned them to canvass four to five PRFD facilities during each operational period.¹⁵⁰ These missions were conducted on a regular schedule to update information and provide continued support to isolated firehouses during the deployment.

To record information, the FDNY IMT used a commercially available data collector customized by FDNY GIS staff with a dropdown menu to ensure uniformity of information collection and that the requisite information was collected. The FDNY IMT struggled with many of the same GIS challenges as the NYCDOB inspectors previously described in this chapter. The lack of connectivity and geographical isolation for the FDNY IMT during the first four days of the deployment significantly slowed its ability to generate

¹⁴⁹ FDNY Incident Management Team, *After Action Review Puerto Rico Fire Department Support 09/25/2017 thru 10/12/2017* (New York: Fire Department City of New York, 2018).

¹⁵⁰ FDNY Incident Management Team, 13.

an operational plan and format to gather and organize information. Once the FDNY IMT ICP was adjacent to the FEMA EOC, the ability to collaborate and leverage existing GIS work and equipment in a connected environment resulted in rapid performance improvement. Additionally, similar to the NYCDOB, the FDNY IMT experienced mission creep and a change to the corresponding information requirements requiring the dropdown menus to be updated and altered to capture new data.

The planning and operation sections of the FDNY IMT did not initially develop a unified approach to data collection. As stated in the AAR, “had Planning and Operations jointly developed a plan for collecting and analyzing information the headaches of redesigning an effective survey three days into the incident would have been prevented.”¹⁵¹ Similar to the NYCDOB, the FDNY IMT was challenged with operating in an unfamiliar location without the GIS support framework of base maps, tax parcels, or other standard identifying information sources. The deployment to Hurricane Maria represented a change in focus from previous FDNY IMT missions. As stated in the AAR, “the incident objectives included a great deal of survey work and data management,” which shifted the focus and task load of some positions, particularly within the planning section.¹⁵²

Once the FDNY IMT was relocated and began to interact with the other operating agencies, the collection and sharing of information began to accelerate. In conjunction with NYCDOB, the FDNY IMT was able to develop a base map that allowed users to view different information streams simultaneously. As shown in Figure 4, a number of different information layers could be turned on to allow users to tailor the view of the map to represent information specific to their needs.

¹⁵¹ FDNY Incident Management Team, 11.

¹⁵² FDNY Incident Management Team, 12.



Figure 4. FDNY Base Map.¹⁵³

Using this base map, the FDNY task forces canvassed the island on a regular schedule to assess the PRFD locations and provide status updates. As shown in Figure 4, each location was represented by an icon that could be opened to view the collected data. Figure 5 shows the dropdown menu used by the FDNY IMT taskforce at each PRFD facility.

¹⁵³ Source: Tim Mahon, email message to author, October 12, 2018.

PRFD_Survey_Merge_Added: Bayamón II	
Qty_	11.00
Station__Town	Bayamón II
Supervisor	Sergeant Eulando Piñero
Address	Carr. #167, Km. 14.6 Urb. Bethl
Telephone	787-279-3033
Latitude	18.34
Longitude	-66.20
Contacted_Member	FF Bravo
Contact_Number_FH	
FH_Structure	Functional
All_App_in_Service	Yes
App_Make_Model	
App_Fuel_Adequate	Yes
App_OOS_Storm	No
Manpower_Sufficient	Yes
Language_Difficulties	No
FH_Water_Service	Yes
FH_Potable_Water	No
FH_Electricity	Generator
FH_Generator_Fuel	Diesel
FH_Generator_Cond	Functional
FH_Sewer	Functional
FH_Toilets	Functional
FH_Storm_Damage	None
District_Water_Source	Tanker
Water_Source_Working	Yes
Zoom to	

Figure 5. FDNY IMT Drop Down Menu.¹⁵⁴

Additionally, photos, such as those seen in Figure 6, could be geo-tagged to provide clarity on the conditions of the facility.

¹⁵⁴ Source: Tim Mahon, email message to author, October 12, 2018.



Figure 6. FDNY IMT PRFD Image.¹⁵⁵

Similar to the NYCDOB, the importance of GIS-based information gathering was not part of the initial mission focus but became more critical as the value of this information was recognized. The value of this information also added to the mission creep, as agency administrators asked for additional information to be collected. Although the FDNY IMT was able to collect and display information using a commercial product, as stated in the AAR, “its use was complex and the pre-work involved in developing a good survey that was simple to use was extensive.”¹⁵⁶ Furthermore, regarding the use of the app, it “requires a skilled GIS support staff that must be dedicated entirely to its use.”¹⁵⁷ The FDNY IMT reported that this “mission was so heavy in data collection and reporting” that it required the development of different operating strategies and assignment of staff dedicated to this

¹⁵⁵ Source: Tim Mahon, email message to author, October 12, 2018.

¹⁵⁶ FDNY Incident Management Team, *After Action Review Puerto Rico Fire Department Support 09/25/2017 thru 10/12/2017*, 12.

¹⁵⁷ FDNY Incident Management Team, 11.

function.¹⁵⁸ Looking forward to future missions assignments, it is forecasted that the expectations and reliance on information gathering will continue to expand.

C. FEDERAL AGENCIES

Although the focus of this research is on information sharing between NYC agencies, it is important to understand the context of the response environment during a large-scale emergency. The following section provides a brief overview of the level of effort and information challenges faced at the federal agency level. The level of FEMA involvement to Hurricane Maria in Puerto Rico is considered representative of a response to future large-scale events in NYC. Additionally, as the lead agency for emergency responses at the federal level, understanding FEMA's challenges can potentially help understand challenges faced by NYC agencies.

Due to the forecasted impact of Hurricane Maria on Puerto Rico, a presidential emergency declaration was issued on September 18, 2017.¹⁵⁹ This declaration authorized FEMA to coordinate all disaster relief efforts and specifically to “identify, mobilize, and provide, at its discretion, equipment and resources necessary to alleviate the impacts of the emergency.”¹⁶⁰ This broad mandate clearly placed FEMA as the lead agency to control and coordinate the immediate search and rescue, as well as the long-term recovery effort in Puerto Rico.

Due to the widespread damage to Puerto Rico, the local agencies were completely overwhelmed. Starting even before the storm made landfall, FEMA began prepositioning staff and supplies. Immediately after the hurricane, massive amounts of resources began to flow to the island. As shown in Figure 7, by September 29, large amount of resources were involved with the response effort.¹⁶¹

¹⁵⁸ FDNY Incident Management Team, 11.

¹⁵⁹ “President Donald J. Trump Approves Puerto Rico Emergency Declaration,” White House, September 18, 2017, <https://www.whitehouse.gov/briefings-statements/president-donald-j-trump-approves-puerto-rico-emergency-declaration-2/>.

¹⁶⁰ White House.

¹⁶¹ “Logistics Snapshot for Hurricane Maria—9/29/2017 at 12 PM,” Federal Emergency Management Agency, last updated September 30, 2017, <https://www.fema.gov/media-library/assets/images/143995>.



Figure 7. FEMA Resources Deployed.¹⁶²

FEMA’s response included over 13,000 federal staff on the ground by October 4, 2017. This workforce grew to over 17,500 federal civilian and military service members involved with response and recovery operations by October 16, 2017.¹⁶³ This workforce included staff from 36 federal departments and agencies.¹⁶⁴ All these agencies required and generated large amounts of data to ensure resources and information were being supplied to the affected civilian population.

¹⁶² Source: Federal Emergency Management Agency, “Logistics Snapshot for Hurricane Maria—9/29/2017 at 12 PM.”

¹⁶³ “Snapshot for Hurricane Maria (Puerto Rico)—10/16/2017,” Federal Emergency Management Agency, last updated October 16, 2017, <https://www.fema.gov/media-library/assets/images/148104>.

¹⁶⁴ “Coordinated Federal Support Continues for U.S. Virgin Islands and Puerto Rico Following Hurricanes Irma and Maria,” Federal Emergency Management Agency, last updated January 3, 2018, <https://www.fema.gov/news-release/2017/10/11/coordinated-federal-support-continues-us-virgin-islands-and-puerto-rico>.

Multiple agencies conducted simultaneous missions to identify and mitigate impacts due to the total devastation of the island's infrastructure. As shown in the following bullets, multiple agencies were conducting various missions through the DHS' ESF framework, which generated tremendous amounts of data.¹⁶⁵

- ESF-1—Department of Transportation (DOT)/state road closure data
- ESF-2—Communications/cell tower status
- ESF-3—United States Army Corps of Engineers (USACE) generator and temporary roofing missions
- ESF-4—Fire station data**
- ESF-6—Shelter information from the American Red Cross (ARC) and local reports
- ESF-7—Commodity distribution data from FEMA
- ESF-8—Hospital, pharmacy, medical facility information from Health and Human Services (HHS)
- ESF-10—Hazmat response status**, water status information from the Environmental Protection Agency (EPA)
- ESF-12—Electrical outage information against power restoration mission from the Department of Energy (DOE), USACE, PREPA
- ESF-13—Federal police presence against reported crimes

These resources are in addition to the agencies and departments working directly with the Puerto Rican government through the EMAC process.

The coordination of these agencies concerning information collection, storing, and sharing was challenging. FEMA GIS staff identified three main challenges:

¹⁶⁵ John D. Boesch, email message to author, February 1, 2018.

- Data acquisition methods did not match leadership intent
- Data housing techniques are outdated and lack uniformity
- Data coordination within the FEMA ICS structure has no clear owner

Early on in the deployment, agency leadership provided an intent for the need to use data for decision making. As this intent travelled through the layers of the organizational command structure, the message became watered down and lacked clarity.¹⁶⁶ The eventual outcome is that the field staff did not have a clear picture of the actual data collection needs and methods on how to accomplish the information-gathering mission, which resulted in a gap between the information collected in the field and the information the analysts needed.

Despite the ongoing push through NIMS and the ICS structure for interoperability during emergency responses, the collection and storage of data during emergencies is neither uniform nor comprehensive. FEMA has advocated a Crisis Management System (CMS) with a web EOC platform with limited success. Without an organizational mandate, individual agencies choose the format for data storage and collection. This agency individualization of data formatting makes integrating different data sources costly in both staff resources and time. During Hurricane Maria, the lack of uniformity doubled or even tripled the analysis time for FEMA staff.¹⁶⁷

The ICS system defines many functions for an emergency response organizational framework but has no clear direction for data coordination. During Hurricane Maria, both the operational and planning branches within the FEMA framework asserted data management responsibility.¹⁶⁸ With no clear line of authority, it was extremely difficult to develop information standards and protocols during the response, which compounded the difficulty of communicating the information needs and formatting protocol to the field information collectors.

¹⁶⁶ John D. Boesch, email message to author, February 1, 2018.

¹⁶⁷ John D. Boesch, email message to author, February 1, 2018.

¹⁶⁸ John D. Boesch, email message to author, February 1, 2018.

The FEMA Hurricane Maria response demonstrated both the complex nature of large-scale EO and the challenges still remaining regarding information collection and sharing. The ICS organizational framework provides a method to align missions and tasks during EO but does not provide guidance on EO information collection and sharing. The response also demonstrated how agencies tend to use individual agency practices and policies regarding information gathering and storing. Without a flexible and adoptable information system, which can incorporate these individual agency processes, the challenges identified in this case study will be repeated.

D. ANALYSIS: DEPLOYMENT INFORMATION SHARING

The Hurricane Maria response to Puerto Rico provides the ability to research the current level of information sharing between NYC agencies during a large-scale emergency. The last large-scale emergency that could match the size and impact of Hurricane Maria would be Super Storm Sandy in November 2012. As discussed in the literature review, the rate of technology advancement, described by Moore's Law and Robert's Law, has transformed the information-sharing environment since 2012 and limited the comparison value. Although the event occurred in Puerto Rico, the presence of multiple NYC agencies and focus on electronic information sharing means the actual geographical location has little impact on its value as a case study. Instead, the lack of available baseline information typically found within NYC presented additional challenges to the response agencies that magnified some of the information-sharing issues.

Although the emergency response organization is standardized under the mandate of NIMS and organized through ICS, information-collection and sharing procedures vary across agencies. As both the FDNY IMT and NYCDOB found, currently no established procedure exists to integrate information collection and sharing during a large-scale emergency. The collection of information is dependent on established individual agency procedures and mission. During the Hurricane Maria response, the FDNY IMT and NYCDOB were able to coordinate information platforms due to the ongoing joint training they have conducted over the last three years. In contrast, the US&R NY-TF 1 team has not been part of this training and used different policies and procedures to gather and collect

information. As a result, none of the agencies had any familiarity with each other's staff or policies and procedures. This lack of familiarity slowed the process of data integration and sharing. Instead of building on existing past practices, staff had to develop basic sharing protocols while also completing their assigned mission tasks. Additionally, as part of the NYC assistance effort, staffing from NYCEM and HPD were deployed. These staff members had little or no awareness of the information-gathering and sharing skills of the FDNY IMT and NYCDOB. Without pre-training and familiarity with the collector device, HPD staff struggled to gain proficiency in electronically gathering information. Additionally, without having witnessed the downstream benefits of collecting data electronically in terms of timeliness and ability to manipulate data, the tendency was to rely on traditional paper forms for data recording. The use of paper forms reintroduced the lag time for data review and analysis present during Super Storm Sandy in 2012.

The review of the EO response to Hurricane Maria has shown that the current emergency response community's ability to share information across different mission types both between local agencies and with the larger federal response community is possible but limited in practice. This case research also pointed out the impact of different technology adoption rates within and between different agencies. In the case of the FDNY IMT, the operations section initially relied on paper forms to record information and continued to maintain a paper copy of all site surveys throughout the deployment. Even though the planning section began using an electronic collection device almost from the start, unfamiliarity with the device and reliance on previous policy and procedure prevented full adoption of the easier and more efficient collector.

Information sharing between agencies was also a struggle due to the variation in technology adoption and use. The HPD staff working with the NYCDOB had little or no familiarity or training with the use of a collector app. Just in time training was provided prior to deployment to prepare the HPD staff. Although training was provided, the HPD staff struggled to use the collector effectively and record information. From the FDNY IMT and NYCDOB experience since Super Storm Sandy of introducing a new technology, trying to operate it under harsh conditions is extremely difficult. Preferably, staff should be trained at regular intervals and use the device on a frequent basis to maintain skills.

The response to Hurricane Maria also highlighted the scope of agencies that respond to a large-scale emergency. Having 17,500 people from 36 different federal agencies and departments all generating and consuming information produces an enormous amount of data. Moreover, many of these agencies possess their own existing policies and procedures in regard to gathering and sharing information. Agencies as varied as the DOD, DOE, Department of the Interior, and EPA had a significant footprint on the response, but operated with much different information-gathering and sharing procedures and protocols. Although these agencies missions are different, much of the data collected is useful across agency lines and is not mission specific in value.

The wide scope of agencies involved in Hurricane Maria also demonstrates the variation in language and terms used by individual agencies and localities. In performing damage assessments, the NY-TF 1, FDNY IMT and NYCDOB used color coding and terms on the maps. As shown in Table 1, although similar, some important differences exist between the response agencies.

Table 1. Hurricane Maria Map Color Coding.

Map Color	FDNY IMT PRFD Facility	NYC DOB Building Assessment	US&R NY-TF1
Black	Destroyed	Destroyed	
Red	Inoperable	Unsafe	Structure Destroyed
Yellow	Damaged but Operable	Restricted Use	Structure Damaged
Green	Functional	Inspected	Structure Intact
Purple		Abandoned	
Blue	All other conditions		
Orange			Structure Failed

In the case of the color “red,” the building status can be very different depending on which agency conducted the inspection. The FDNY IMT considers it inoperable but it can be used as a location to stage or distribute supplies for other agencies. The NYCDOB

and US&R teams have labeled the building either unsafe or destroyed.¹⁶⁹ These two terms can represent very different degrees of damage to the building. Similarly, for the color “green,” the NYC DOB has noted the building as inspected but does it mean that staff can use it? Additionally, the difference between the FDNY IMT “functional” and US&R “structure intact” requires an interpretation to determine the actual building condition. This discussion is not to compare which color scheme is more effective, but rather it is to illustrate a wide variety of terms and symbol convention remains within the established response community.

Hurricane Maria also exposed the lack of information sharing across mission types. The IST to support US&R NY-TF 1 teams was pre-staged in Puerto Rico prior to landfall. The IST gathered intelligence prior to the storm and then gathered and organized the inspection results from the operating US&R teams. This cache of data provided a wealth of information on building, roads, and other infrastructure. For other agencies that responded in later waves of response, this information was not easily accessible, but would have been extremely useful to create base maps and act as foundational data to build on during their own missions. The NYCDOB was not familiar with the IST members and was not able to access this data source until the FDNY IMT arrived on scene. The FDNY IMT was able to leverage the IST information and equipment because some of the IST were FDNY members and had worked with IMT members in NYC. The NYCDOB and FDNY IMT GIS staff were familiar with each other through joint training held over the last three years. In addition, the senior staff for both organizations were familiar with each other, ensured that all levels were introduced, and information sharing resulted throughout the deployment. Once introductions between the three organizations were completed, the level and quality of information sharing dramatically improved for both the tactical operators and strategic decision makers. Without formal information-sharing procedures, the development of information sharing between agencies during Hurricane Maria was based on previous personnel relationships and proximity of agency resources.

¹⁶⁹ Steve Spall, text message to author, January 15, 2018.

The information reporting formats varied among agencies. While the FDNY IMT and NYC DOB used the same commercial collector, the NY-TF 1 used a different collector. These collectors used different data management software, and as referenced previously, different symbols and color coding. In addition, since the some of the missions for the FDNY IMT and NYCDOB were unique, new symbols and terminology were created on scene to organize information.

For the NYCDOB, the “blue tarp” program, for which inspectors were tasked with identifying buildings that needed roof covering, was a new mission with specific information gathering data that had to be added rapidly to ensure that people got the help they needed. The decision of what information to gather, terms to use, and map symbols were made by the NYCDOB over the course of a day with little or no input from other operating agencies. Likewise, for the PRFD facility survey by the FDNY IMT, no existing map symbols or terminology existed to characterize the information they were gathering. The need to develop terms and symbols during large-scale events is common due to the infrequency of these events and the novel impact they have on the infrastructure, which prevents the use of standard nomenclature.

As demonstrated during the Hurricane Maria response, the current response framework does not specify any information-gathering or sharing protocols. This individualization of information systems results in silos of information and the resulting redundancy of effort by agencies capturing the same information attribute. Information sharing seems to be an outgrowth of establishing and staffing an EOC to develop information sharing based on the proximity of staff. Unfortunately, as demonstrated by the initial ICP location of the FDNY IMT, not all agencies establish their operations within the EOC. Furthermore, frequently, the EOC is staffed by agency liaisons who may not be familiar with agency capabilities or needs. For Hurricane Maria, the familiarity of FDNY and DOB staff led to early collaboration and leveraging of relationships to broaden the information network to the wider FEMA response network. Relying on the development of informal relations between agencies with little or no previous history of working together may not always lead to effective information sharing. Furthermore, without a comprehensive overview of the information environment, agencies are not even aware of

the existing information of partner agencies that may impact their own mission space. Unlike the ICS' organizational structure that provides direction and opportunity for functional roles to integrate, no information-sharing mechanism has been developed.

The review of the case study of the emergency response to Hurricane Maria in Puerto Rico shows that the emergency response information system has greatly improved since Super Storm Sandy in 2012. The cursory review leads to the belief that technology and training has advanced to the point where tactical information can be gathered and shared within the response community in near real-time. Additionally, the analysis has shown that information collecting and sharing during EO is a fluid process. As mission needs change, technology improves, and agency collaboration is required, the means and methods of information management must evolve to meet the needs of both the responders and those affected. The case study also confirms that information sharing still needs additional research to ensure that the various information streams are understood, merged, and shared within the entire response community. The difficulty is that the large-scale emergency brings together a disparate group of agencies and departments with distinct operating language and information-recording procedures that have to be united into one information system. This system has to be all encompassing, as well as flexible to allow for adaptation to unforeseen future information needs. Information gathering and sharing is not a fixed task, but rather, it is a constantly evolving process driven by incident needs and technological capability.

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V. TECHNOLOGY ASSESSMENT OF MODEL-BASED ARCHITECTURE

A. INTRODUCTION

The focus of this chapter is to examine the suitability of using a conceptual model-based framework and innovative approach “to share information, intelligence and information feeds from a host of disparate technologies and agencies” for a large-scale emergency event in NYC.¹⁷⁰ The goal of this analysis is to assess the applicability of a model-based approach to improve information sharing during a multiagency response comprised of a complex network of disparate response agencies. This evaluation considers the potential for a conceptual model-based approach and open architecture system as a basis to develop an effective communication and information-sharing platform.¹⁷¹

The recent series of natural disasters in 2017 including the hurricanes along the American gulf coast, as well as the wildfires that have raged in Southern California, highlighted the need for large coordinated multi-agency response efforts. As discussed in the case study of the Hurricane Maria response to Puerto Rico, response agencies have existing procedures and technologies that inhibit the ability to integrate and share information. The case study further demonstrated the value of information-sharing platforms to both tactical operators and strategic decision makers. However, to achieve truly effective information sharing, the hurdle of operating with individual agencies legacy systems needs a solution. A viable solution must also accommodate the constant evolution of technology and be adaptable to the dynamic joint mission space of large-scale emergency responses.

B. NEW YORK CITY RESPONSE ENVIRONMENT COMPLEXITY

The emergency response community of NYC is composed of numerous agencies and departments with separate and often overlapping mission assignments. As described

¹⁷⁰ Stewart, “Researchers, Commanders Partner.”

¹⁷¹ Anderson, “Dragon Pulse Information Management System (DPIMS).”

by Kapacu and Garayev, the typical strategy of governments responding to large-scale emergencies is to take “an all-hazard approach as the primary strategy used to deal with disasters, organizations responsible for emergency management find themselves, quite often, involved in the midst of networked governance that envisions shared goals and responsibilities as well as coordinated and unified action to produce a commonly owned result.”¹⁷²

Thus, agencies have realized that large-scale emergencies are beyond the scope of their own capabilities or even multi-agency resources within a jurisdiction. As detailed in the case study in the previous chapter, the Hurricane Maria response in Puerto Rico had 36 different federal agencies and departments staffed by over 17,000 federal government employees in addition to the state, local, and non-governmental organizations (NGOs) operating.¹⁷³ All these individuals and agencies are operating simultaneously at the event, and producing and using information according to their missions. Furthermore, many of the agencies have overlapping missions, which adds to the complexity of the roles and responsibilities of the response community. While each of these agencies becomes part of the larger response community, most maintain the policies, procedures, and technologies that are native to their agencies.

To overcome the challenges of limited individual capability, agencies must form efficient collaborative partnerships. To achieve this multi-agency coordination and a more effective response, response information must be shared in a timely manner. For an information platform to provide timely information, it must be able to access information from the participating agencies. During a large-scale emergency, an information platform must be able to embrace the agencies’ legacy systems to gather and provide relevant information. As stated by Hu and Kapacu, “in sum, to improve emergency management performance, organizations do not work alone but communicate and coordinate with other

¹⁷² Naim Kapucu and Vener Garayev, “Designing, Managing, and Sustaining Functionally Collaborative Emergency Management Networks,” *The American Review of Public Administration* 43, no. 3 (May 2013): 312–330.

¹⁷³ Federal Emergency Management Agency, “Snapshot for Hurricane Maria (Puerto Rico)—10/16/2017.”

organizations in an emergency management network.”¹⁷⁴ Failure to address this problem will leave the NYC emergency response community as a collection of individual actors operating independently from each other. During previous major emergencies in NYC, this lack of sharing has resulted in a duplication of services and inefficient targeting of response and recovery resources particularly early on in recovery efforts when needs are most critical.¹⁷⁵ As one researcher has stated, “Network actors that are isolated and disconnected from the whole might be ineffective, insufficiently prepared, unhelpful, and even detrimental to the whole network, especially during the response stage.”¹⁷⁶ The ability of NYC to develop an understanding of the how technology can fill the role as a bridge between individual emergency response agencies to facilitate effective information sharing, will in large part, determine the success of future large-scale emergency responses.

C. THE ARCHITECTURE DILEMMA AND INFORMATION

Collaboration as defined by researchers Kanensnsk, Burlin, and Abramson is the method in which “people from different organizations produce something together through joint effort, resources, and decision making, and share ownership of the final product or service.”¹⁷⁷ Technology, while holding the promise for solving the challenges of information sharing, is also a source of difficulty for agency information sharing during emergency response. Due to the independent nature of the agencies within NYC, a host of distinct legacy systems exists across the response community. These individual legacy systems make developing a collaborative effort difficult, if not impossible. The agency disconnect caused by legacy systems is particularly impactful because it affects information sharing by time delays or reduced information sharing at every stage of the response effort. Currently, the NYC government is composed of approximately 130

¹⁷⁴ Qian Hu and Naim Kapucu, “Information Communication Technology Utilization for Effective Emergency Management Networks,” *Public Management Review* 18, no. 3 (2016): 323–348.

¹⁷⁵ New York City Mayor’s Office, *Hurricane Sandy after Action Report*, 7.

¹⁷⁶ Kapucu and Garayev, “Designing, Managing, and Sustaining,” 325.

¹⁷⁷ John M. Kamensky, Thomas J. Burlin, and Mark A. Abramson, “Networks and Partnerships: Collaborating to Achieve Results No One Can Achieve Alone,” in *Collaboration Using Networks and Partnerships*, ed. John M. Kamensky and Thomas J. Burlin (Lanham, MD: Rowman & Littlefield, 2004), 8.

separate agencies resulting in over 50 separate and distinct source systems for data.¹⁷⁸ During the initial stage, this disparity prevents the development of a comprehensive strategy since access to potentially key information is limited. During ongoing operations, overlapping missions and information silos reduce effectiveness and introduce a redundancy of effort. Lastly, at the conclusion of the event, the ability to transfer or share the joint final information product or service is difficult, which minimizes the ability to leverage lessons learned throughout the response community.

Unfortunately, as one researcher stated, “Legacy systems are quite often critical organization assets that reflect the accumulated knowledge of an organization” and further stressed, “Integrating, modernizing, or even replacing a legacy system can be fraught with risk.”¹⁷⁹ Typically, legacy systems do not integrate well with other existing systems or new technology. Legacy systems usually have a proprietary application program interface (API) or rigid ontologies that are not easily integrated with other systems. Legacy systems are also usually designed for current technology standards, and as successive waves of technological advancement occur, data standards change and integration becomes exceedingly difficult. Furthermore, legacy systems are usually the result of evolving mission and business practices, which have a “cumulative effect on legacy system complexity” that makes replacement or integration increasingly challenging.¹⁸⁰

Legacy systems, while a major challenge to information collaboration, are just one of a host of challenges relating to the existing architecture of individual agencies. Individual agency platforms, security firewalls, and technology adoption rates all affect the potential for information sharing. Since large-scale emergency events are relatively rare, the need for agency collaboration is often not a design parameter when an agency is considering new technology. Rather, most agencies focus on their internal processes and

¹⁷⁸ NYC Analytics, “Citywide Intelligence Hub & February Data Drill.”

¹⁷⁹ Maria Wahid Chowdhury and Muhammad Zafar Iqbal, “Integration of Legacy Systems in Software Architecture,” in Specification and Verification of Component-Based System SAVCBS 2004 Workshop Proceedings: SIGSOFT 2004/FSE-12, 12th ACM SIGSOFT Symposium on the Foundations of Software Engineering (Newport Beach, CA: 2004 SAVCBS Workshop, 2004), 110.

¹⁸⁰ Azad M. Madni and Michael Sievers, “Systems Integration: Key Perspectives, Experiences, and Challenges,” *Systems Engineering* 17, no. 1 (March 2014): 37–51, doi: 10.1002/sys.21249.

core missions. With limited resources in terms of IT staff and budgets, and the difficulty involved in overhauling existing legacy systems, spending tends to focus on the immediate internal needs of an agency. In the case of NYC, a director and six team members staff the Mayor's Office of Data and Analytics, the agency charged with the integration and sharing of data.¹⁸¹ This small agency is responsible for a city that employs over 360,000 people working in 130 different agencies.¹⁸² Furthermore, with the increased threat of cyber security, the ability or even willingness of agencies to allow information portals to transfer information is extremely limited. Lastly, the variance of information adoption rates between agencies also tends to lead to a heterogeneous technology environment that makes agency collaboration that much harder.

Figure 8 represents a conceptual view of the data flow during an emergency event. Operators from the right feed information into a central data hub, which allows access by senior staff and other coordinating agencies to develop and maintain a common operating picture. As shown, NYC agencies, along with federal, state, and NGO agencies, gather and consume information during the event. Based on the Hurricane Maria case study in the preceding chapter, approximately 45 agencies will operate during a similar sized event in NYC. All these agencies will both provide and consume information while networked together to mitigate the impacts of the emergency. As Kapucu and Garayev have stated, for emergency response network systems to be effective, they “would bring more flexibility and horizontality, in terms of intra-organizational and inter-organizational relationships, as well as a strong emphasis on coordination, collaboration, and communication.”¹⁸³ Since timely information sharing during modern emergency responses is dependent on electronic information systems, it follows that the network architecture that underpins the information-sharing platform must also be flexible and horizontally open to allow the ease of information transfer between legacy and new technology network architecture.

¹⁸¹ “Meet the Team,” NYC Analytics, accessed March 3, 2018, <https://www1.nyc.gov/site/analytics/about/meet-team.page>.

¹⁸² Department of Citywide Administrative Services, *Fiscal Year 2015 New York City Government Workforce Profile Report* (New York: Department of Citywide Administrative Services, 2015), 5, http://www.nyc.gov/html/dcas/downloads/pdf/misc/workforce_profile_report_fy_2015.pdf.

¹⁸³ Kapucu and Garayev, “Designing, Managing, and Sustaining,” 313.

Citywide Intelligence Hub

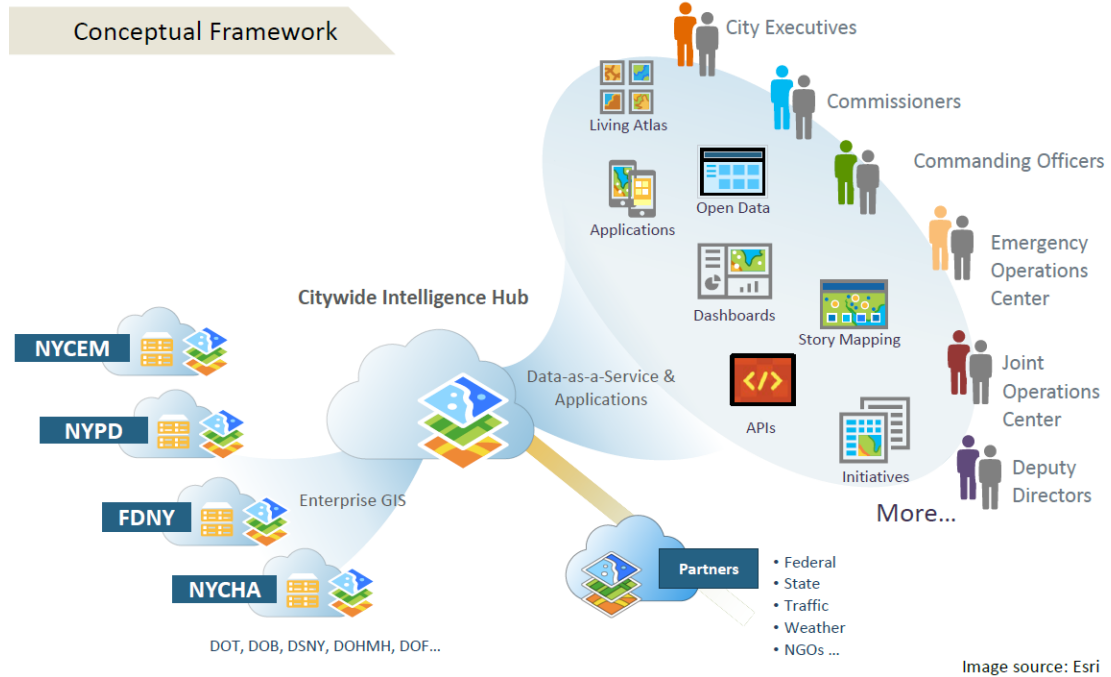


Figure 8. MODA Conceptual Information Network.¹⁸⁴

Figure 8 shows the MODA conceptual information network, which contrasts with the information model in Figure 9 that depicts the actual information sharing between NYC agencies during Hurricane Maria. As expected during a large-scale event, multiple agencies were operating in separate mission spaces gathering and consuming information. As shown in Figure 9, and discussed in the case study in Chapter IV, although all the agencies were NYC assets, they were operating under different agency administrators with different mission focus and priorities. However, these separate missions had the need to merge information from the various sources to provide comprehensive intelligence of current conditions on the ground, which is critical for good strategic decision making.

¹⁸⁴ Source: Mayor's Office of Data and Analytics Citywide Intelligence Hub and February Data Drill Data sharing and data integration, in discussion with the author, February 17, 2017.

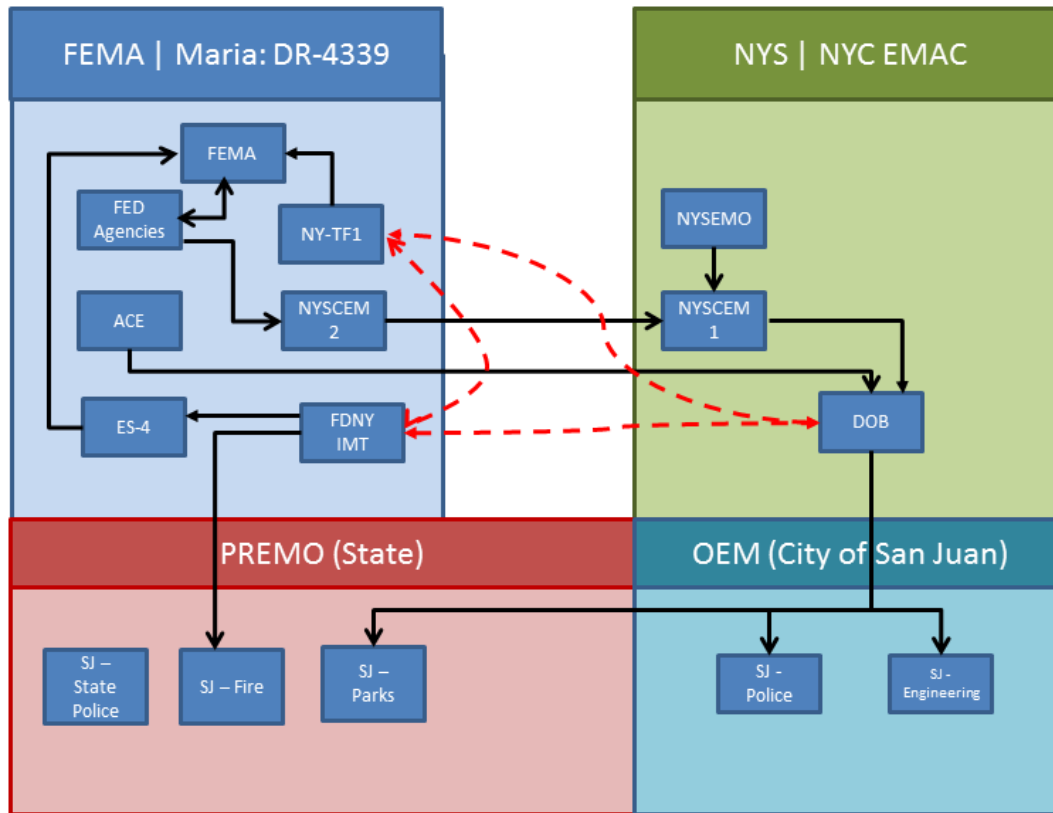


Figure 9. Information Sharing among NYC Agencies.¹⁸⁵

As seen in Figure 9, information streams included aerial overflight images from the USACE, ATC-45 Field Building Assessment Form from the NYCDob, the search and evacuation status from the US&R NY-TF 1, and firehouse condition, road, and utility assessment data collected by the FDNY IMT. The solid black lines in Figure 9 represent the established policies, procedures, and protocols to gather and share information between agencies. As discussed in Chapter IV, informal lines of communication and information sharing were also established. Represented by the red dashed lines in Figure 9, these conduits transcended the geographical and mission domains of the formal organizational structure. These informal lines represent the reality of emergency operations and the ad hoc nature of information gathering and sharing typical during large-scale emergencies. Even though a uniform organizational structure is mandated, the underlying informational

¹⁸⁵ Source: Courtesy of Aiden Mallamo, email message to author, March 6, 2018.

flow paths vary dependent on the mechanism of disruption causing the event. Using the example of a flood versus a terrorism-based event, the organizational structure and roster of agencies will be similar due to the all hazards approach but the information needs, relationships, and flow between agencies will greatly vary. Based on the rarity and uniqueness of large-scale emergencies, pivoting to establish new more universal information collection and sharing capabilities, in place of existing systems and procedures, is not a realistic goal for agencies.

As discussed in Chapter IV, and in the preceding paragraphs of this chapter, large-scale emergencies require a large pool of response agencies generating and consuming information. Before any viable system can be developed, a clear understanding of the attributes and relations both internally and externally of agencies must be understood. As shown in Figure 9, agencies are operating within the same geographical area but they are also operating in separate information domain spaces. Additionally, by understanding the mission of each agency, mission specific information sharing can improve individual agency awareness and the resulting decision-making process. Using the conceptual approach, the successful use of the informal lines of communication and data sharing, by the FDNY and DOB staff, is understood and formalized, which enhances overall event information sharing. Additionally, by visualizing the entire process, the awareness and enhancement of information sharing between seemingly disparate operation, such as the US&R TF-1 and NYCDOB, is possible. Furthermore, by delineating the information attributes of each agency, through a conceptual modeling approach, information parallels can be identified to enhance further agency effectiveness by reducing redundant efforts. As discussed in Chapter IV, many of the mission information needs coincided between agencies. Many of these information overlaps will not be apparent to individual agencies geographically located separately with little contact during day-to-day operations.

As an example, the FDNY IMT PR firehouse assessment concentrated on the functional ability of the PRFD's facilities in regards to equipment, staff, and station status. The FDNY IMT operating within its specific mission, used information limited to firehouse centric data to decide on the allocation of resources. In reality, these firehouses are part of the wider community, and external conditions, such as neighborhood and infrastructure

damage, influence their ability to meet their mission. If two fire stations had the same relative damage as recorded by the FDNY IMT, but the NYCDOB assessment information showed a relatively intact neighborhood versus a neighborhood with widespread damage, the firehouse in the most damaged neighborhood would have higher resource delivery priority. By federating all the information into a conceptual space, and then examining the available information against agency needs, the potential for enhancing the situational awareness of agencies and improving strategic decision making is possible.

From the case study in Chapter IV, the initial step is to link the various information streams through a unifying concept, or point of reference. Typically, this linkage is achieved using the location concept, a GIS reference point, such as latitude/longitude, street address, or tax map information. In Puerto Rico, due to the lack of consistent street addresses and a lack of available tax information, the latitude/longitude format was the most feasible. Using this unifying information article, all the data streams can then be associated in a federated set of incident data. In the case of Hurricane Maria, this association enabled the integration of the aerial photography with the on-the-ground field surveys conducted by the NYCDOB. Additionally, the information collected by the US&R TF-1, using a separate information collector product, could integrate with the FDNY IMT and NYC DOB field reports. This information integration with a common GIS marker allowed all the NYC agencies as shown in Figure 9 to integrate their data into once comprehensive database. Thus, all the information gathered through the different missions could be centrally located and allow interoperable sharing between response agencies.

After achieving information federation between agencies, the next challenge is to extract the information needs for each agency. Using the conceptual model approach, where the key concepts are articulated, e.g., agency, mission, event, the mission information requirements of each agency can be determined and the requisite information fields identified that provide the needed data. As discussed in Chapter IV, a significant amount of data overlap existed between agencies and missions. During the Hurricane Maria response, the NYCDOB used the ATC-45 form shown in Figure 10. This form provides a basis for completing a rapid assessment of a building in the earliest stages of the response effort. Users record general building information conditions on the form to provide a

baseline for further agency review and response. The ATC-45, while an evaluation form, represents the concept of “building” where the meta-data for the concept describes the key building attributes and evaluation parameters. An agency may have a system or process that may access the building and related metadata in part or completely. Each agency conducts its operation as per its own internal policies but provides information to the wider pool of response agencies. Additionally, as within the conceptual model and comprehensive data set, agencies are able to select both the information they gather and extract according to the needs of their mission. Furthermore, the conceptual model approach allows for the flexibility of changing of both the information collected and requested during an operation. As detailed in the case study, multiple agencies took on new missions or had mission objectives evolve as the recovery progressed due to changing humanitarian and political needs. From the discussion in Chapter IV, agencies, such as the NYCDOB and US&R TF-1, performed similar inspections in the same geographical area. By aggregating the data into one data set and linking the information through GIS, agencies could then gain a significantly better situational awareness of conditions and potential challenges to their mission.

ATC-45 Rapid Evaluation Safety Assessment Form																																												
Inspection Inspector ID: _____ Inspection date: _____ Affiliation: _____ Inspection time: _____ ☐ AM ☐ PM Areas inspected: ☐ Exterior only ☐ Exterior and interior																																												
Building Description Building name: _____ Address: _____ Building contact/phone: _____ Number of stories: _____ "Footprint area" (square feet): _____ Number of residential units: _____ Type of Building ☐ Mid-rise or high-rise ☐ Pre-fabricated ☐ Low-rise multi-family ☐ One- or two-family dwelling ☐ Low-rise commercial Primary Occupancy ☐ Dwelling ☐ Commercial ☐ Government ☐ Other residential ☐ Offices ☐ Historic ☐ Public assembly ☐ Industrial ☐ School ☐ Emergency services ☐ Other: _____																																												
Evaluation Investigate the building for the conditions below and check the appropriate column. <table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="text-align: left; width: 40%;">Observed Conditions:</th> <th style="text-align: center; width: 10%;">Minor/None</th> <th style="text-align: center; width: 10%;">Moderate</th> <th style="text-align: center; width: 10%;">Severe</th> <th style="text-align: center; width: 30%;">Estimated Building Damage (excluding contents)</th> </tr> </thead> <tbody> <tr> <td>Collapse, partial collapse, or building off foundation</td> <td style="text-align: center;">☐</td> <td style="text-align: center;">☐</td> <td style="text-align: center;">☐</td> <td>☐ None</td> </tr> <tr> <td>Building significantly out of plumb or in danger</td> <td style="text-align: center;">☐</td> <td style="text-align: center;">☐</td> <td style="text-align: center;">☐</td> <td>☐ > 0 to < 1%</td> </tr> <tr> <td>Damage to primary structural members, racking of walls</td> <td style="text-align: center;">☐</td> <td style="text-align: center;">☐</td> <td style="text-align: center;">☐</td> <td>☐ 1 to < 10%</td> </tr> <tr> <td>Falling hazard due to nonstructural damage</td> <td style="text-align: center;">☐</td> <td style="text-align: center;">☐</td> <td style="text-align: center;">☐</td> <td>☐ 10 to < 30%</td> </tr> <tr> <td>Geotechnical hazard, scour, erosion, slope failure, etc.</td> <td style="text-align: center;">☐</td> <td style="text-align: center;">☐</td> <td style="text-align: center;">☐</td> <td>☐ 30 to < 70%</td> </tr> <tr> <td>Electrical lines / fixtures submerged / leaning trees</td> <td style="text-align: center;">☐</td> <td style="text-align: center;">☐</td> <td style="text-align: center;">☐</td> <td>☐ 70 to < 100%</td> </tr> <tr> <td>Other (specify) _____</td> <td style="text-align: center;">☐</td> <td style="text-align: center;">☐</td> <td style="text-align: center;">☐</td> <td>☐ 100%</td> </tr> </tbody> </table> ☐ See back of form for further comments.					Observed Conditions:	Minor/None	Moderate	Severe	Estimated Building Damage (excluding contents)	Collapse, partial collapse, or building off foundation	☐	☐	☐	☐ None	Building significantly out of plumb or in danger	☐	☐	☐	☐ > 0 to < 1%	Damage to primary structural members, racking of walls	☐	☐	☐	☐ 1 to < 10%	Falling hazard due to nonstructural damage	☐	☐	☐	☐ 10 to < 30%	Geotechnical hazard, scour, erosion, slope failure, etc.	☐	☐	☐	☐ 30 to < 70%	Electrical lines / fixtures submerged / leaning trees	☐	☐	☐	☐ 70 to < 100%	Other (specify) _____	☐	☐	☐	☐ 100%
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Figure 10. ATC-45 Rapid Evaluation Safety Assessment Form.¹⁸⁶

D. INFORMATION MODELING APPROACH IN A MODEL-BASED FRAMEWORK

Since 9/11, the goal of emergency management has been to unite all responders in a collaborative interoperable network where information is gathered and shared in near real-time between all participants. The complexity of meeting the interoperability goal has increased as the emergency response community has embraced different technology. The reliance on GPS tagged data, remote sensing, visualization of data, along with the traditional radio interoperability, has complicated the concept of interoperability in the emergency response network. Describing this condition, Stewart commented:

There are thousands of stove-piped technologies that are becoming increasingly complex as they are upgraded and extended. With each layer of code laid over existing foundations, these applications and technologies become self-limiting as their inherent complexity begins to overwhelm machine and human capabilities to define and implement interactions.¹⁸⁷

The conceptual model approach of this thesis recognizes the existing technology infrastructure and institutionalized procedures and policies of agencies and proposes a means to allow for information sharing in this reality. The following section discusses the potential for an open architecture model-based platform to offer enhanced information-sharing capabilities.

1. Extensibility

An open architecture framework allows for the integration of different systems and their data together while still maintaining their original system characteristics. As stated by Langford, “network-centric, assemble-to-description architecture is scalable, extensible, and expandable with minimal effort.”¹⁸⁸ This approach is significantly different from the enterprise systems common to most agencies, where adding or linking a new system requires either the existing system or new system to be reconfigured or modified to allow

¹⁸⁶ Source: Applied Technology Council, *ATC-45 Rapid Evaluation Safety Assessment Form* (Redwood City, CA: Applied Technology Council, 2004), <https://www.atcouncil.org/pdfs/ATC45Rapid.pdf>.

¹⁸⁷ Stewart, “Researchers, Commanders Partner.”

¹⁸⁸ Langford, “GINA Network-Centric.”

for the integration. This integration can be a costly and labor-intensive process for the agency using the scarce budget and staff resources of agency IT staff.

In real world plain speak, this integration means that the model-based solution does not require changes to the in-place protocols at any level, local agency to federal department, to transfer information between systems. Furthermore, the object relation approach allows the targeting of specific data within a separate database for retrieval, which allows the data and the system itself to remain unchanged. As stated by Paula Carlson from NCYEM, “most large-scale incidents will have not only an evolving element, but also evolving agencies that could be involved at varying degrees for different times along the timeline of the incident.”¹⁸⁹ Furthermore, a model-based solution has the ability to evolve with the incident without requiring any of the agencies involved to perform resource intensive reconfigurations of their internal IT systems. Thus, a conceptual model-based solution provides a system with limitless extensibility, which is a critical element for an information system used for large-scale complex emergency response operations.

2. Modeling

Modeling is the initial step in translating the real world into discrete components to allow for the understanding of underlying concepts and relationships that define the environment. As part of this research, a “conceptual modeling” approach is used. A conceptual modeling approach can provide the “ideal mental model of the function” of the application.¹⁹⁰ A conceptual model definition is “describing the objectives, inputs, outputs, content, assumptions and simplifications” used to describe the real world.¹⁹¹ By using the conceptual modeling approach, the adoption of emergency response information into the common framework is possible. The information from the conceptual model is used to develop “a decision making model to enable leaders to evaluate trend data and/or combine

¹⁸⁹ Paula M Carlson, email message to author, January 18, 2018.

¹⁹⁰ Jeff Johnson and Austin Henderson, *Conceptual Models Core to Good Design*, ed. John M. Carroll (Williston, VT: Morgan and Claypool Publishers, 2012) 10, doi: 10.2200/S00391ED1V01Y201111HCI012.

¹⁹¹ Stewart Robinson et al., “Conceptual Modeling: Definition, Purpose and Benefits,” in *Proceedings of the 2015 Winter Simulation Conference* (2015): 2812–2826, <https://www.informs-sim.org/wsc15papers/277.pdf>.

data to evaluate the outcome of information/action combinations.”¹⁹² In the case of emergency response, it means, “rescuers are able to share information, intelligence and information feeds from a host of disparate technologies and agencies”¹⁹³ The conceptual model approach provides the framework for understanding an event while also having the ability to adapt to changes in the response environment regarding information needed or changes to agency participation.

As shown in Figure 11, the model has the ability to represent the real world and all the incident specific attributes associated with a response. Unlike the traditional organizational structure, the model can depict both the formal and informal lines of communication and information sharing. The organizational constraints of established response mandates and existing legacy procedures and systems do not limit the conceptual model. Rather, as shown in Figure 11, the mission is divided into the individual necessary operations that are further distilled into specific tasks. Additionally, the model can represent both information needs and data generated by agencies. This approach allows the identification of the information needs and capabilities that exist outside of the traditional organizational structures, as well as unique and incident specific relationships.

¹⁹² Magram, “On the Fence,” 78.

¹⁹³ Stewart, “Researchers, Commanders Partner.”

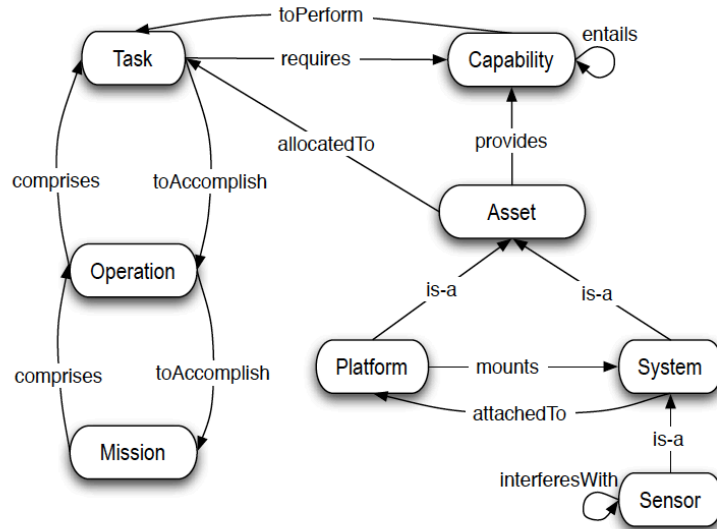


Figure 11. The Conceptual Modeling Approach.¹⁹⁴

A scenario of a damaged building event within NYC will illustrate the applicability of the concept. Individual agencies will respond to building locations to perform specific missions (life safety, building assessment etc.) as shown in Figure 12.

¹⁹⁴ Source: The main concepts in the Military Missions and Means Framework. Mario Gomez et al., “An Ontology-Centric Approach to Sensor-Mission Assignment,” in *EKAU '08: Proceedings of the 16th International Conference on Knowledge Engineering: Practices and Patterns*, ed. Aldo Gangemi and Jérôme Euzenat (Berlin, Heidelberg, Germany: Springer-Verlag, 2008), 347.

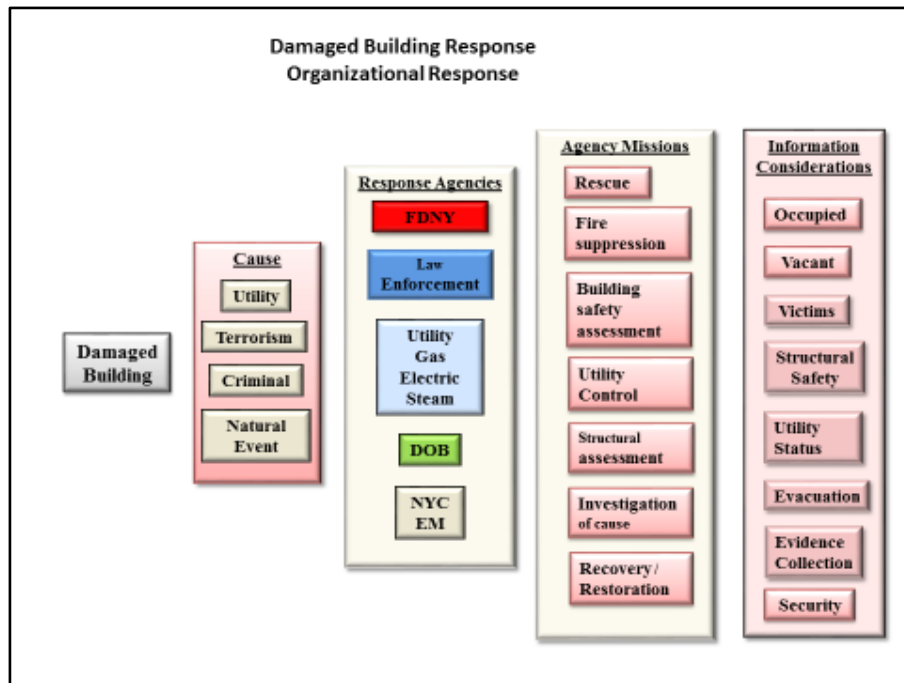


Figure 12. NYC Damaged Building Response.

Similar to Figure 11, the conceptual model of a response to a damaged building, Figure 12 is broken down into the discrete elements that define the response. This simplified illustration provides the responding agencies, missions, and information attributes. The benefit of this conceptual model approach is that the information is better understood because the perspective is from a more comprehensive and realistic view of the response community. Further, any number of agency specific perspectives is easily made through new model specifications. Thus, the damaged building is the unifying factor that ties all agency efforts together in NYC, which is the building identification number (BIN) that specifies an exact location. The cause of the event specifies agency response and its corresponding mission. The complexity of emergency response can be illustrated by looking at the mission list. Using the example of the building safety assessment mission, the first question is which agencies are responsible for this task. In NYC, fire, police, DOB, or utilities can all complete this task depending on the mechanism causing the building damage. In the case of terrorism, law enforcement would need to check for building safety while after a utility explosion, it may require a combination of fire, utility, and DOB

representatives to examine the structure simultaneously. Each of these building surveys will need to consider the information attributes shown in the last column of Figure 12. Without the conceptual model, the interrelationships and commonality of information attributes are hard to comprehend. From the conceptual model using the building address as the unifying attribute, any number of combinations of mission and information attribute is possible to meet specific agency needs. From the generic set of response information attributes, agencies can choose the appropriate sources and use for their agency specific missions. The benefit is that although agencies are using different sets of data, the individual components are identical across the response community, which provides a uniform situational awareness for all participants.

In addition to understanding organizational information needs, the flow of information during an event is critical to making timely decisions. As shown in Figure 13, the flow of information between agencies often takes paths outside the traditional organizational hierarchy. As mandated by CIMS, a unified command post is established at large-scale incidents to coordinate agency activities. As shown in Figure 12, all information will flow to this command post and then be forwarded to NYCEM for a briefing to city hall. The benefit of the conceptual model is that it illustrates these formal lines of communication and also the informal information flow. In Figure 13, the dashed lines represent the informal lines of communication that have been developed between the FDNY and DOB to streamline information gathering and sharing. These informal information lines have been developed out of recognition of the similarity of information needs shown in Figure 12.

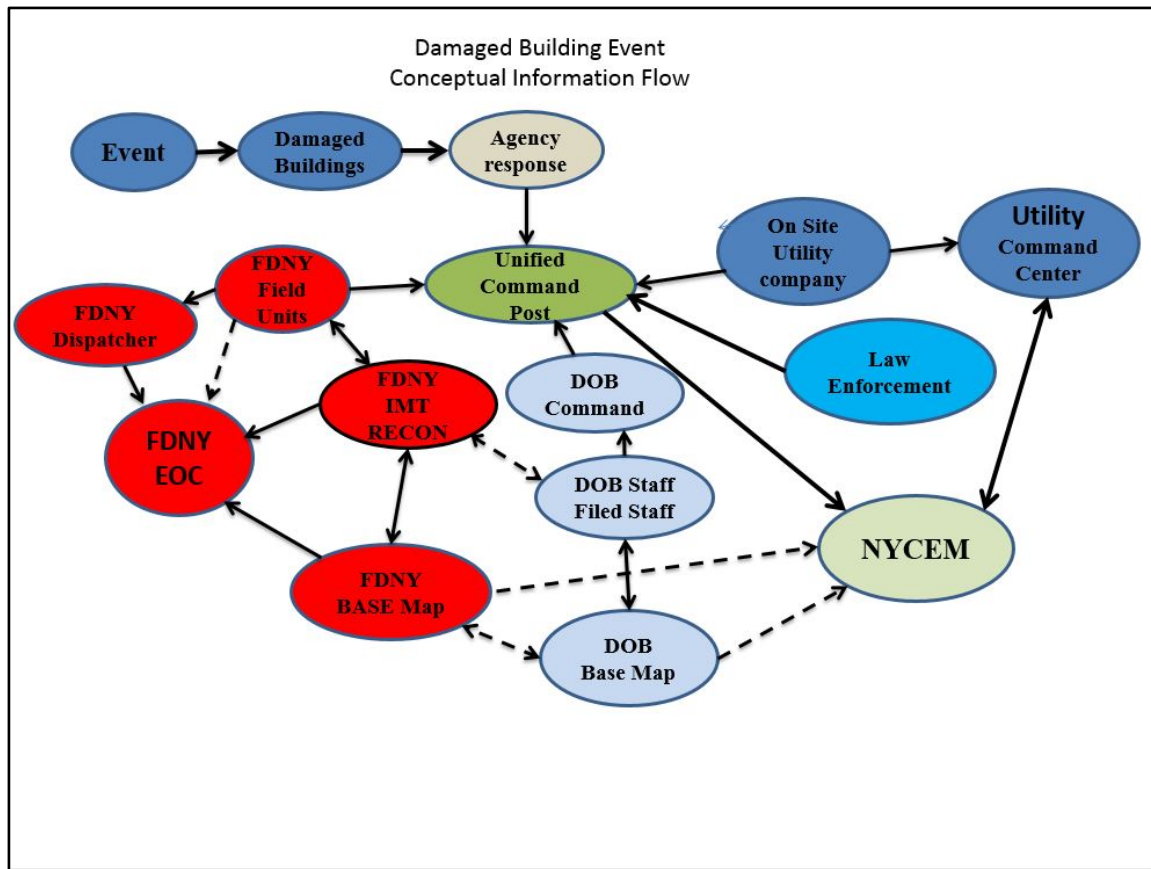


Figure 13. Information Path during Damaged Building Response.

During a building collapse, the need for knowing the status of building occupancy, utility conditions, and structural stability are universal information needs for response agencies. As shown in Figure 13, the FDNY and DOB have developed methods to share this information at lower levels of the response organization by placing the information in the hands of the on-site staff without having to travel through the entire response chain of each agency. Without the use of the conceptual model, neither the commonality of information attributes nor the informal flow paths will be apparent.

3. Adaptability

Since the conceptual model-based approach does not require the reconfiguration of legacy systems or databases to receive and share information, the system is highly adaptable. Through the configuration available via a web service, system extensions to new

concepts and new relationships for a system are specified by naming. Simply put, there is a list of concepts and relationships available. The system is extended with new concepts merely by adding the name of a new concept to the list of concepts, and as such, no compiling is necessary. This ease of alteration allows the program to adjust to information requirement changes requests from either consumers or providers during an event. In the case study example of Chapter IV, the US&R and FDNY IMT used different hand-held devices to collect information. These different information streams can be integrated as concepts within the framework quickly and with relative ease. Similarly, as in the case study of Chapter IV, when senior leaders requested the inclusion of the “blue tarp” program for NYCDOB, the model-based framework can again be readily adapted to allow the system to accommodate a new request.

This adaptability is critical when considering the variation in emergency events and their corresponding information needs. Large-scale emergency events are complex and evolving situations. The information needs between events may or may not match and the means to gather and share information will probably have changed. As technology continually moves forward, and the IoT becomes a reality, the ability to add remote sensing data and other linked information sources will be vital to emergency responders.

4. Model-based Framework in the DOD

The challenge of interoperability is not unique to the emergency response community. The U.S. military has been developing interoperable solutions at a number of different levels. At the network integration and interoperability level, the USACE has developed model-based solutions in GINA, an open standards system. GINA is a base architecture system, which means that “The GINA environment is ‘agnostic’ ... It takes components, programs and technologies and represents them within itself in a manner that is universal within the GINA environment, allowing for previously unseen levels of interoperability.”¹⁹⁵ Unlike traditional systems that create new code or links to integrate different operating systems, this framework has an object relationship with all items that forgoes the need to provide new links or coding. This type of framework is particularly

¹⁹⁵ Stewart, “Researchers, Commanders Partner.”

important when trying to prepare for future integration as new system and information sources are made available. The GINA system's base architecture approach allows the ability to accomplish new system integrations rapidly and with minimal investment of IT resources and impact on existing system frameworks. In describing this architecture, Langford asserts it is "scalable, extensible, and expandable with minimal effort."¹⁹⁶ The GINA framework is a system that "brings together unrelated programs, components and data streams in a single architecture allowing for unprecedented levels of interconnectivity and cooperation."¹⁹⁷ The framework provides the means to connect the individual agency platforms, legacy systems, and new technology in one federated environment. As explained by network engineer Ryan Hale, "GINA does not require the end systems to be modified to talk to them, GINA is built to understand all of the various data inputs or 'languages' and then creates links and relationships."¹⁹⁸ This structure is important because it allows the system solution the ability to grow and evolve as the participants and their information needs change during the incident. This federated environment allows users the flexibility and adaptableness to evolve with changes in the operating environment and information needs of the response community. Thus, the framework extends the concepts and attributes of the conceptual model to allow information to be stored and shared between multiple agencies.

The current capabilities to store and manage "big data" were not even an option for NYC agencies during Super Storm Sandy in 2012. With the present ability to gather and store large amounts of data, the need for a system to integrate the individual systems to federate data for use during emergency operations is needed. Similar to NYC, the DOD has faced this problem and developed the GINA platform. The GINA framework is flexible, unlike the brittle architecture of most legacy systems that have rigid conventions for integration and updating. By applying a configurable model-based approach that allows for the adaptation of new technology, the DOD has provided a template for addressing emergency operation information sharing.

¹⁹⁶ Langford, "GINA Network-Centric."

¹⁹⁷ Langford, 2.

¹⁹⁸ Stewart, "Researchers, Commanders Partner."

E. RESULTS AND RECOMMENDATIONS

The need to share information between multiple agencies using a variety of databases and legacy systems during emergency events is a common theme throughout this thesis. The case study demonstrated the current difficulties experienced by agencies during the recent Hurricane Maria response in Puerto Rico in sharing information. This chapter has provided a discussion of the potential benefit of the conceptual modeling approach to understanding the information environment during a large-scale response to an emergency operation. The conceptual modeling approach provides the ability to visualize the entire information flow, including the wants and needs, of individual agencies. Additionally, by identifying the overlapping information components within individual agency missions, emergency operations streamlining is possible. Using the conceptual model approach in a model-based framework (e.g., GINA) can provide a clear understanding of the actual information flow, which is typically significantly different from the hierarchal organizational structure of the ICS system used in the United States. The applicability of a model-based approach to mimic the conceptual model and ability to provide a “non-brittle” software architecture that federates the information and provide access to a comprehensive pool of response data has been demonstrated. Furthermore, the model-based approach has the ability to integrate legacy systems and reduce the need to alter or scrap existing standard operating procedures (SOPs) during extreme events. Additionally, the ability of the approach to adapt to the changing needs of mission objectives and information needs as the progresses has been discussed. Lastly, the approach of the DOD with the GINA platform was examined to show the ability to provide a model-based approach to address issues similar in nature during emergency operations within the civilian mission space. This chapter has shown how the open architecture approach is suited for integrating the various information streams found and expected during large-scale emergency operations.

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VI. FINDINGS AND RECOMMENDATIONS

This thesis has discussed how effective information gathering and sharing during large-scale emergency events continues to challenge responders at both the strategic and tactical levels of the response. The response to the recent series of hurricanes along the southeast coast and other natural disasters across the country has once again reignited the discussion on the effectiveness of the emergency response community to share information. This research reviewed the status of information sharing during a large-scale event through a case study of the response of specific NYC agencies to Puerto Rico in the aftermath of Hurricane Maria in 2017. This case study provided the research the ability to evaluate the current level of methods and technology in use by NYC agencies operating in conjunction with a larger federal effort. The research has demonstrated that the challenges of information sharing experienced during previous large complex events still exists. Although technology provides a potential solution for information sharing, the research has also documented how existing technological legacy systems impede the establishment of information sharing between agencies. Additionally, through the case study of Chapter IV, the “normal” procedures and protocols of individual agencies also make integrating efforts extremely difficult. Lastly, the thesis has detailed how the flow of information does not follow the organizational framework of the standardized emergency response mandated by the ICS. Information has been shown through the case study analysis to flow both horizontally and vertically across the response organizational chart. Furthermore, within a large-scale event, such as Hurricane Maria, information relationships between agencies operating under different commands and conducting separate missions have been identified. The case study of Chapter IV has shown that although a national framework for coordinating agency response has been developed, the flow of incident information does not conform to this rigid structure and the need to cross pollinate data between agencies is required.

This research applies the use of a conceptual model approach and open architecture technology to address the challenge of emergency response information sharing. By using the conceptual model approach, a comprehensive understanding of the true flow of

information can be attained. Using the conceptual model approach makes it possible to understand the information attributed to agencies. These agency information attributes include information consumed and provided, information flow between agencies, and data formats. From this model and visualization of the event information system, the development of a more efficient and effective information sharing process is possible. The conceptual model is not bound by the ICS' hierarchal structure, but rather it represents the actual established formal and informal channels of communication needed to share information efficiently among agencies. Additionally, the conceptual model provides an understanding of all the information being gathered, stored, and shared during this event. The delineation of the entire information set during an event allows agencies to filter data sources to what they need to make strategic decisions for their mission. This awareness of the information data across the whole event environment also allows agencies the ability to incorporate and change information sources as their missions evolve over the course of the event. Furthermore, by having a federated set of information, all event participants are basing decisions on the same set of data. Even though agencies are completing separate missions in different locations, both geographically and organizationally, the underlying data is consistent across all mission domains.

The analysis of the model-based application approach to developing extensible information solutions in Chapter V demonstrates how the application can be the mechanism for translating the conceptual model into a database to store and share information. The discussion of Chapter V details the ability of this approach to provide a non-brittle platform that can adapt to the needs of the event while maintaining the individual agency legacy systems. The model-based framework has the ability to federate (share) information attributes while keeping individual legacy databases intact to allow for the cross pollination of information outside the traditional hierarchal organizational structures. This ability to share information while also maintaining individual legacy systems and structures is necessary to achieve the true interoperability of information during a large complex emergency response that involves multiple agencies and missions.

The initial three chapters of the thesis provide the background and existing conditions regarding the gathering and sharing of information during large-scale

emergency events. The case study of Chapter IV examines these challenges in a current context through the deployment of three NYC response agencies to Puerto Rico in the aftermath of Hurricane Maria in 2017. Chapters V and VI discuss the potential solution to the identified challenges of information sharing by applying a conceptual model to understand the information attributes of an event. Secondly, the model-based application approach was assessed as a platform to allow the sharing of information, as described by the conceptual model, with agencies' existing legacy systems. All this research has led to the development of the final findings and recommendations.

A. COMPARISON WITH ORIGINAL HYPOTHESIS

The original hypothesis of this research focused on the continuing challenge of information sharing between NYC agencies during a large-scale emergency event. The case study of Chapter IV, examining the response to Hurricane Maria in Puerto Rico, supports the gap in information sharing among agencies in a large-scale response, which is still a challenge. The analysis of the recent event shows the continuing challenges of information sharing of three NYC agencies operating within the larger context of a massive federal level response. The research shows that improvement in emergency response has occurred through changes in technology and organizational structure, but challenges remain in the ability and tendency to share information between agencies.

The central thesis proposed was a conceptual modeling approach to tackle the challenge of information sharing. This approach would provide a means to describe the roles and responsibilities of the participants and flow of information during the event to provide a thorough understanding of event information attributes. The conceptual model approach would also provide a flexible and adaptable framework to adjust as participants' roles and information needs change both during and between emergencies. The conceptual model also has to be able to incorporate different technology frameworks. As discussed in Chapters III and IV, the rate of technology adoption varies between agencies creating a wide spectrum of old legacy and new innovative technology that must successfully interface for information sharing to occur.

The analysis of the model-based framework in Chapter V in conjunction with the conceptual modeling approach provides a potential solution to the current identified information-sharing challenges. Working off the conceptual model, a model-based framework would make a federated information environment capable of integrating different agency information streams available. The framework allows the interface with new and existing technologies without the intensive effort to reprogram existing legacy systems.

B. CAN A CONCEPTUAL MODEL BE DEVELOPED FOR AN INFORMATION PLATFORM TO ALLOW MULTI-AGENCY INFORMATION SHARING DURING AN EMERGENCY INCIDENT?

This thesis supports the premise that a conceptual model can represent multi-agency information sharing during an emergency response. In fact, a conceptual model may be the only way to represent the fluid and dynamic nature of the emergency response. As demonstrated through the case study, no two emergencies are exactly alike and each event inherently possesses different information needs and participants. The use of a conceptual model may be the most effective way to depict the formal and informal lines of information sharing accurately during a large event. The conceptual model approach also provides a global understanding of event information in regards to information providers and consumers, information flow between agencies, and information formats used. Furthermore, the conceptual model provides a mechanism to adapt as technology innovation continues to evolve the means and methods of information sharing for successive emergencies.

C. CAN SPECIFIC TACTICAL INFORMATION BE PROVIDED TO IMPROVE EMERGENCY RESPONSE EFFECTIVENESS?

The case study of Chapter IV showed how specific tactical information could be gathered and shared among agency participants. The availability of technology and training of the NYCDOB and FDNY IMT also showed how mission information gathering could be adapted to meet the evolving needs of the incident. Furthermore, the information gathered is typically multi-mission valuable; specific data collected from one task was beneficial to other agencies operating in a nearby geographical location but distinct mission

space. The case study showed how agencies have adopted different forms of technology to gather, store, and share tactical information in near real-time. This tactical information was available to command and control levels to form the basis of strategic decision making. The information was also able to be filtered to provide the appropriate information to the decision makers. The case study also highlighted the ongoing difficulty of sharing information across separate mission spaces during the event. These difficulties arise from the isolation of individual information gathering efforts, variance in the technology being used, and established policies both internally and within the ICS system. Through the familiarity of NYC agency personnel, many of these obstacles were overcome and informal lines of information sharing and communication were established to allow for enhanced information sharing.

The analysis of the Hurricane Maria response in the Chapter IV case study confirms that tactical information can be provided in near real-time to operating forces during a large-scale emergency response.

D. WHAT ARE THE FUNDAMENTAL CONCEPTS OF AN INFORMATION MODEL FOR AN EMERGENCY RESPONSE?

The conceptual model approach is focused on presenting the basic level of a system operation. In the case of emergency management response, these basic response concepts include response participants, mission, information attributes, and organizational structure. Each of these concepts drives both the actions of agencies and interaction between participating agencies during an emergency response. By using a conceptual model, these fundamental concepts can be visualized to enhance the understanding of how the response system functions.

The roster of participants who respond to any large-scale emergency is fairly consistent. The roster of agencies between Super Storm Sandy and Hurricane Maria is composed of almost identical agencies. Due to the robust nature of emergency management in the United States and the organizational mandate since 9/11, the response to a large complex emergency is fairly well defined regarding agencies.

The roles and responsibilities of each agency will be defined by the event and is the second fundamental concept that defines an emergency response. The mission of an agency will vary based on the mechanism that has caused the emergency. Emergencies driven by natural disasters, such as hurricanes or floods, will require a different set of roles and responsibilities than a terrorism related event, such as 9/11. While a substantial consistency of agency roles and responsibilities between events is based on the core mission of an agency, such as a fire department or law enforcement agency, each event most likely will require specific agency requirements unique to the event mechanism. As an example, a terrorism event may require a significant Haz-Mat role for a fire department that would not be required for flood or hurricane events.

The next fundamental concept for developing the conceptual model is the information attributes of the participating agencies. These information attributes define the agency in terms of information collection and storage, information provider or user status, and information needs. Decisions must be made for agencies to develop strategy and execute tactics during an event. Thus, each agency requires a level of information awareness to form the decision-making process. The conceptual model displays these needs for all the involved agencies and allows for an assessment of information attributes for the whole response system. Additionally, the conceptual model identifies common information attributes across the response community to reduce redundant information efforts. Furthermore, by providing a more comprehensive view of event information, the conceptual model provides awareness of data availability while maintaining data unanimity among all agencies.

The last fundamental concept is the organizational structure of agencies responding to the emergency event. After 9/11, the organizational response to large-scale emergencies has been defined through the DHS and FEMA. As detailed in the case study of Chapter IV, the structure of large-scale emergency response is managed through FEMA and defined through the emergency support functions. This formal organizational response structure is critical to understanding the flow of information. Additionally, as shown in the case study, the informal lines of communication that arise during large-scale emergency events need to be understood and supported. As discussed in Chapter V, cross pollination of

information between different commands, missions, and agencies can lead to enhanced response effectiveness. The conceptual model is able to illustrate these ad hoc lines of information sharing that are typically unique to the event and evolve as information needs change during an emergency event timeline.

E. WHAT ARE THE RELATIONSHIPS AMONG THE FUNDAMENTAL CONCEPTS OF AN EMERGENCY RESPONSE?

The fundamental concepts of the conceptual model are related through mission task and geo-location. Due to the overlapping missions and responsibilities, the fundamental concepts are first related through task orientation. As demonstrated in the case study of Chapter IV, multiple agencies were tasked with performing assessments of buildings from either a structural, life safety, or utility standpoint. Thus, multiple participants had mission overlap and produced related information data points. The unifying factor between these data points is the geo-location of information. Although separate agencies operated under different commands and were performing separate missions, all the information gathered was tied to a discrete geo-location. The use of a discrete location allows the disparate information streams generated by the separate missions and organizational structures to be coherently merged. The geo-location also allows the data sets to be organized and visualized through electronic mapping.

F. CAN THIS MODEL-BASED APPROACH PROVIDE CUSTOMIZED INFORMATION TO PREVENT RESPONDER DATA OVERLOAD DURING OPERATIONS?

The analysis of the conceptual model approach shows that by understanding the roles and responsibilities of the emergency responders, as well as their path of information flow, a clear understanding of the needs of agencies can be inferred. Just as importantly, the conceptual model approach has the flexibility to adjust those characteristics in response to either an emergency or mission evolution. As demonstrated in the case study, predicting the information needs of an emergency before the event is difficult. The reality is that information needs will evolve as a function of time as mission focus changes from lifesaving to recovery operations. The conceptual model approach can then adjust “on the fly” to account for the evolution of mission and subsequent new information wants and

needs of the operating forces. This combined ability to conceptualize the information and adapt to evolving conditions provides the capacity of the conceptual model approach to tailor the information to the decision makers. By understanding the fundamental concept of the roles and responsibilities of the participants, along with the information attributes, information presented to agencies can be focused and relevant. The comprehensive nature of the conceptual model offers the opportunity to understand both the information attributes throughout the response community and the information flow path needed between agencies.

G. CONCLUSION

This thesis has shown through the case study that the need for information sharing is still a major challenge for the emergency response community. Since the watershed moment of 9/11, and Hurricane Katrina, great strides in progress have been achieved in regards to overall emergency management organization. This organizational progress however has not resulted in improving the tendency or effectiveness of information sharing between agencies. Unlike the rigid organizational structure developed as part of NIMS, this thesis has shown how information needs do not follow a hierarchal structure. Rather, information sharing during a large complex emergency requires information to be shared up and down organizational structures, across agencies, and between mission spaces.

Technology has provided an increased ability to gather store and share data among the emergency response community. New challenges have also been introduced in the form of integration between different platforms, different levels of technology adoption, and acceptance of new technology within the community. Therefore, while technology has provided new possibilities, it has come with a price in regards to integration. This challenge will continue into the future as the IoT and the prevalence of “big data” becomes more and more prevalent in both regular everyday lives, as well as during emergency responses.

The conceptual modeling approach of this thesis provides a solution to identify and quantify the formal and informal flow of information between participants at large-scale complex emergencies. The analysis of the model-based platform has furthered the conceptual model approach by proposing a platform that can share distinct information

required by agencies while maintaining the agencies' legacy systems. The analysis of the model-based framework shows how this approach may allow the information needs identified through the conceptual model to be shared effectively among agencies. The model-based framework's ability to retrieve select information from different databases with different formats without the cost of altering existing systems makes possible the information sharing detailed in the conceptual modeling approach.

As stated by physicist William Pollard, "Information is a source of learning. But unless it is organized, processed, and available to the right people in a format for decision making, it is a burden, not a benefit." This thesis has substantiated the potential for the conceptual modeling approach to describe the information flow and attributes of the emergency response community. Furthermore, the thesis has analyzed the potential of a model-based framework to merge databases to share the need information along the lines of communication described through the conceptual model, as well as to improve information sharing during large-scale emergency events.

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